COST action FP0703 – ECHOES

Country report

Estonia

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Summary

Introduction

Estonia is a small country (total area 45 227 km²) located in the Northern Europe. The climate and weather are mainly determined by the Golf stream and the air masses from Atlantic ocean (west) and continental air from Russia (Figure 1). Depending on the prevailing air mass the weather can by mild and wet or dry with rather high summer or low winter temperatures. The rate of annual precipitation is higher than the evaporation and 20-25% of the land suffers on swamping (Vallner, 1998; Valk, 2005).

Relief is rather flat, the maximum height reaches to 318m over mean sea level. However, the forest growth conditions have wide range depending on the soil type and local relief and water regime. The forest site types range from dry alvars, poor dry or wet sandy or gley soils to the fertile typical brown soils and fertile brown lessive soils. Phytoproductivity (dry mass per hectare in year) of the forest ecosystems reaches up to 15 Mg $ha^{-1}y^{-1}$ (Kõlli and Lemetti, 1999). Main forest forming species in Estonia are Scots pine (*Pinus sylvestris*), Norway spruce (*Picea abies*), Silver birch (*Betula pendula*), grey alder (*Alnus incana*), black alder (*Alnus glutinosa*) and aspen (*Populus tremula*).

According to the National Forest Inventory (NFI) data more than half (51,5%) of the Estonian land is a forest land (Pärt, et al., 2008). However, the estimate of fraction of forest land for the beginning of the last century in Estonia is 18.3% (Etverk, 2003). The increase of forest area is caused mainly by melioration, forest silviculture and management and conversion of agricultural land into forest.

Figure 1: Estonian location in the Europe. (ESRI world basemap)

Since 1958 the forest area in Estonia is almost doubled (from 12 711 km² to 21 133 km²) and growing stock volume is more than tripled (from 131 * 10^6 m^3 from 453 *10^6 m^3) (Pärt *et al.* 2008). The causes of this increase are conversion of abandoned agricultural lands into forest after World War II during the soviet system introduced collective farming, increased final felling ages of the stands (Etverk, 2003). The tendency of increase in forest area still continues since after the Soviet Union collapse about 300 000 hectares of agricultural lands are abandoned.

Average age of the stands is skewed towards final felling age (Pärt *et al.,* 2008) and this indicates that Estonian forest are in the next decades at the reaching the limit of their maximum carbon storage capacity will not efficiently be functioning as carbon sink process (Nilson, 1998). At present the regime of regeneration cuttings and regulation of other silvicultural forest management activities in Estonia do rather support the idea of forest as a carbon storage not the forest as a carbon sink process. A definite problematic aspect with aging of forests is their increasing sensitivity to biotic and abiotic environmental impacts.

1. Impacts

1.1. Observed impacts

1.1.1. Observed climatic evolution

The (essential) climate variables that the have direct impact to the forest ecosystems on are availability of photosynthetically active radiation, air and soil temperature, precipitation, evaporation, nutrient supply and composition of ambient air. Most of the energy driving the climate processes and for photosynthesis is coming from the Sun and the changes in the long term components of the radiation (short- and long-wave) budget are the main indicators of global or local warming or cooling. However, extrapolation of the current trends to predict the future climate is generally not justified and these trends are fitted on very fluctuating observation.

Time series at the Tõravere meteorological station located in South-East Estonia (58° 15' 55'' N; 26° 27' 58''E) covering the period from 1962 - 2002 show that there was a significant increasing trend in the annual totals of net radiation (*B*) (Russak, 2003). The causes can be explained by analysing separately the short-wave and long-wave radiation budgets. Russak (2003) shows that during 1955-1992 there is a significant decrease about 6.4 % in the annual totals of global radiation (*Q*) and since 1992 there is an observable increase in *Q.* The trends are explained with the changes in the cloudiness and in the atmosphere transparency. Cloudiness is related to the incoming air masses from the Atlantic (North Atlantic Oscillation index) and atmosphere transparency is related to the global influences like industry and volcanic activities. For example the eruptions of the El Chichoni (1982) and Mt. Pinatubo (1991) are clearly detectable from atmosphere transparency data. At present the atmosphere transparency in Tõravere has at the level of the mid 1930-s of Tartu (Russak, 2003). There is a significant decreasing trend of the yearly average surface albedo for the period 1955-2002 which is related to the shortening of the snow cover period about 33.5 days. Increase of the long-wave radiation budget is determined by the increase of the greenhouse gasses (water vapour, CO2) in the atmosphere and not so much determined by the increase of low cloudiness index (Russak, 2003).

Long term climate observations show that since year 1500 average winter temperature in Tallinn (capital city of Estonia in Northern Estonia) has increased +1.8º C and summer temperature in Tallinn has significant positive trend during 1737-1995 (Tarand and Eensaar, 1998). Increase in the temperature may be influenced by the increasing of the vicinity of the rural environment which, however, does not have the influence to the ice break on the sea which seems to occur about 15 days earlier than during the tree last centuries according to data from Palmse. Increase in air temperature is supported by the analysis of phenological data series indicating the budburst of Silver birch to appear about 15 days earlier than 1951 (Jaagus, *et al,* 2002).

There is a slight increasing trend in the spatial mean annual precipitation since 1865 (Jaagus and Tarand, 1998) and in mean wind speed in the last century (Kull and Meitern, 1998).

1.1.2. Impacts on ecosystem dynamics and functioning

1.1.2.1. Vegetation phenology

Vegetation phenology is related to the so called cumulative effective temperature which characterizes the duration of time suitable for plant growth. There is about two weeks shift in phenology in spring from South to North in Estonia caused by the cooling effect of the Baltic Sea. Analysis of long term phenological observations shows that the most pronounced impact on the plant growth is the earlier start of the spring and there is no remarkable increase in the vegetation season length in the autumn (Ahas, 1998, Jaagus, *et al,* 2002).

1.1.2.2. Vegetation distribution area

Plant growth conditions in Estonia are in general determined by the soil nutrient availability and water regime since there are no remarkable differences in relief and annual total precipitation. There are natural trends in the temperature and cloudiness related to the distance from the large water bodies (Baltic sea, lake Peipsi) but their influence is smaller compared to influence of soils. Main forest forming tree species in Estonia are almost in the optimum of their natural area and therefore the impact of climate change is rather negligible compared to forest management which is the most important factor designing the forest vegetation distribution in Estonia.

1.1.2.3. Insect phenology, fungi and their distribution area

There have been several mass outbreaks of bark beetles in Estonia during the history, none of them can be directly related to the climate conditions but rather the results of the storm damages where the damaged trees are left into the forest (Voolma, 2008). Drier and warmer summers support the increase of bark beetle population density and area. However, during the massive outbreaks the mild winters (long autumns) may have both positive and negative feedback to the population density of bark beetles, since second (third) generation will not achieve the physiological preparation to survive lower temperatures or the organisms do not switch fully to the hibernation mode which conserves energy.

Compared to the bark beetles which need the appearance of weekend trees the insects causing damages to needles and leafs (e.g. *Bupalus piniaria*) depend mostly on the climate conditions and there is increased possibility of their massive outbreaks (Voolma, 2008, Etverk, 2003).

Compared to insects fungi are probably even more problematic damage agents in Estonian forests. Root rot *Heterobasidion annosum* can be found in most of the middle aged and alder spruce stands and there are observations of damages on pine and birch trees. Higher soil temperature which is caused by increased air temperature and direct solar radiation penetrating through the sparser forest canopy after thinning cuttings in hand with transportation of infected soil by harvesters and forwarders when soil is unfrozen, facilitate spread of root rot. There are sings of increased damages of *Lophodermium seditiosum* on young pines and *Greminiella abietina* on older pines that can be directly linked to the more humid summers and milder winters (Drenkhan, and Hanso, 2006; Hanso and Drenkhan, 2007). However, some fungi spread on the contrary during drough periods from south to north and there are first observations of the most common and widely distributed pathogen on conifers *Diplodia pinea* in Estonia (Hanso and Drenkhan, 2009). New rather aggressive pathogens like red belt blight on pines (*Mycosphaerella pini*) are found in South Estonia (Hanso and Drenkhan, 2008).

Further climate warming will cause some changes, first of all, in the response of dendrofagous insects as cold-blooded animals. The following analysis includes the most important and numerous pest species in Estonia: pine looper and spruce bark beetle. Damage caused by pine looper has been relatively rare in the past. The first notes about it are by Daniel (1935), who described its damages in North-Estonia in 1910-1912 and in north and south-eastern Estonia in the end of the 1920s and at the beginning of the 1930s. The next outbreaks were in 1980-1981 in south-eastern and northern Estonia (Mihkelson, 1986). The following one was already registered in 1990 in south-eastern Estonia and in 1991 in northern Estonia. In Estonia area of dead or damaged pine stands designated for clear cutting have been the following: 15 ha in 1910-1912, 30 ha in 1930-1932, 49 ha in 1980-1982 and 30 ha in 1990-1991. Thus we can conclude that during different outbreaks the loss has been rather stable. If no pest control had been used, much more damage would have occurred during the last outbreak, we suppose.

By the beginning of the 1980s pine looper was clearly a stenotope species in North Estonia (Mihkelson, 1986). During that period of is massive reproduction out of all damaged stands 81.6% were of *Cladonia* site type, 14.6% of *Vaccinium* site type and 3.6% pine stands of other site types. During 1991-1993 in south-eastern Estonia, on the contrary it was *Vaccinium* site type that suffered most. Now pine looper can damage pine stands in temperate humid sites as well.

In Estonia the most numerous and dangerous trunk pest has always been spruce bark beetle (*Ips typographus*). Mortality due to low winter temperatures has regulated its numerousness; however, lately this pest has survived better during the more mild winter. Another factor important in its development is weather conditions in flying period in late April and early May. Even a short period of dry and warm weather is a good precondition for its successful development.

An analysis of changes in spruce grove areas damaged by spruce bark beetles reveals an increasing tendency. In the 1970s and the 1980s such damaged area made up 200 to 250 ha in Estonia. After the 1992 drought the damaged area has increased 7 to 8 times making up 1863 ha. This change is directly caused by warm and dry weather and indirectly by draught stress on trees.

Areas damaged by spruce bark beetles in Estonia occur mainly in eastern Estonia. Such a situation can be explained by geomorphologic peculiarities. Spruce stands grow there in such forest site types, where soil humidity directly depends on the amount of precipitation. In western Estonia the level of spruce roots is such that enables contact with ground water via good capillary connection and thus the negative influence of drought on trees is smoothed.

The most numerous cervines in Estonia are roe-deer *(Capreolus capreolus* L.), moose *(Alces alces* L.*)* and red deer (*Cervus elaphus* L.). The two first ones have been the main inhabitants in our forests. Red deer was introduced into Estonia in the end of the 19th century. The population of this species has increased due to the migration from the South. Essential preconditions for the migration can be thin snow cover and relatively mild winters.

Damages by game have had a great role in the forest health and productivity in the last decades. When in the 1960s till the 1980s moose caused damage in young pine stands, now their damage objectives have become more various. A sudden expansion of damages occurred in spruce stands in the second half of the 1970s. Then a drop followed in the first half of the 1980s. A new rise began in the end of the 1980s and the following drop in the beginning of the 1990s. Although hunting has reduced the damage by moose to spruce stands, the damaged stands are in a bad conditions. Beside the damages to “middle-aged” spruce woods, young stands suffer as well and normal reforestation is hindered. In many forest districts one cannot find any undamaged broad-leaved reforested area. Aspen improvement has completely terminated. All this has drastic role in species change in Estonian forests.

Although the population of cervines can be regulated by hunting depending mainly on decision making, weather conditions play an important part for the roe-deer and red deer. Continuous weather warming, especially in winter months, has obviously much influence on increasing the population of roe-deer and red deer. So we can prognosticate increasing damages by cervines mainly in young stands if not regulating their population by hunting.

Root rot (*Heterobasidion annosum*) with its cosmopolitan distribution can be regarded as the most dangerous fungal disease also in Estonian forest. Nearly 1/5 of the 1989-1994 clear cuttings were urgent cutting of stands damaged by root rot. The data indicate an increasing role of this disease.

Up to the middle of 20th century the disease was connected with spruce groves although some cases of infection were known with such species as pine, juniper and some broad-leaved trees. The spruce stands are even more damaged now, but also pine stands are suffering. Intensive death of pine trees due to root rot infection was registered already in the end of the 1950s and the beginning of the 1960s, mainly in south-eastern Estonia. Pine root rot had occurred even earlier in the more southern areas, including Lithuania. The global weather warming will make environmental conditions for root rot spreading more favorable. More damaged areas and hence heavier economic loss is supposed to occur in coniferous stands. Such a situation will not be realistic in broad-leaved stands in the near future.
The total area of damaged coniferous stands has been increasing more rapidly in eastern Estonia (Figure 2).

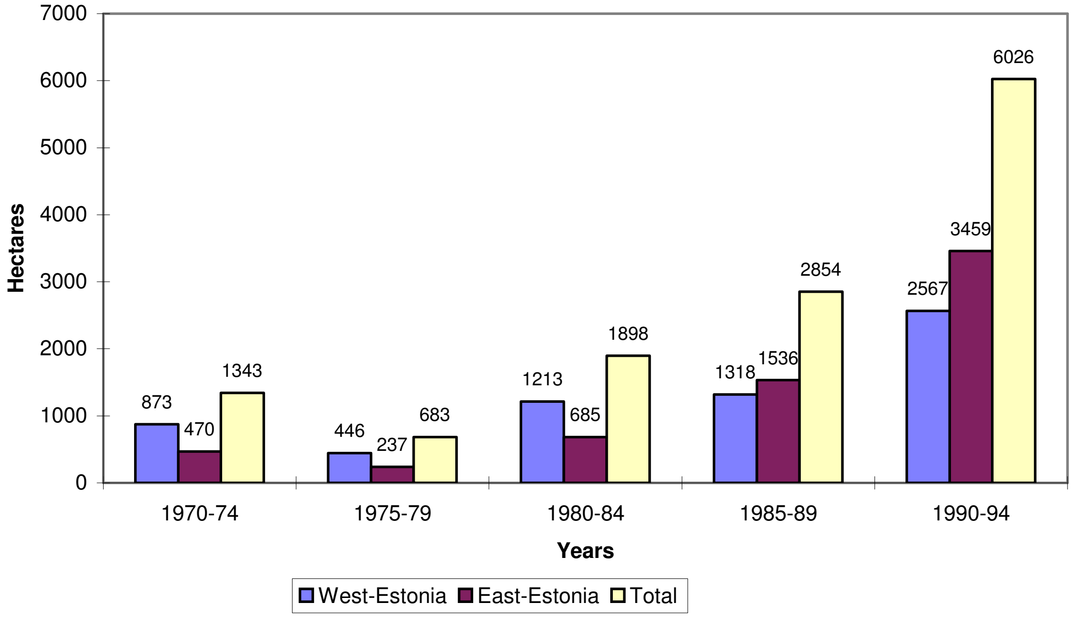


Figure 2. Dynamics of all biological damages in Estonian forests (hectares per year).

1.1.2.4. Global productivity

Forest inventory data recorded for all forest stands by 10-year intervals are the most reliable data about Estonian forest history which can be used to detect changes in forest growth and species composition. Two sets of forest inventory data from years 1951 and 1994 of selected forest districts were used. Site type with indicator of ditching, stand origin (cultivated or naturally regenerated), dominating tree species, age, height, diameter and volume of the first story and sub-compartment area as the most important sub-compartment data were copied from the current forest inventory database and entered from forest inventory record books of 1951. The data sets of both forest inventories (of 1951 and of 1994) were linked using maps. The inventory data of 20869 sub-compartments on 26817.3 hectares were prepared for analysis. Special complications arise in forest growth modeling in the case of changing growth conditions. The line fitting the values of stand characteristics (e.g. average height, DBH or volume) of the group of similar stands against their age will not any more reflect the real growth as it can be assumed in case of stabile growth conditions. At the same time the difference between such single-time measurement based models and repeated measurements based models can be used as indicator of fastening or slowing down growth (Nilson & Kiviste, 1984, 1986). The systemic difference equation of stand height depending on stand age and site factors was worked out (Kiviste, 1997) on the basis of static set of Estonian state forest inventory data from the period 1984-1993 (511514 sub-compartments on more than 1 million hectares, every stand presenting a single point on the age-height plane). This static model describing the state of stands in the period 1984-1993 was used to calculate two estimates of the site index as average height of every stand at the age 50, first of them (SI_{1951}) using as input values its age, height and other characteristics at 1951 and the second (SI_{1994}) the same at 1994.

Average increase in site index more than two meters was calculated according to Table 1. Increase in site index was higher in pine (2.35 m) and birch (2.47 m) stands while in spruce stands it was a meter lower (1.44 m). Average increase of site index in ditched forests was higher than in not ditched forests (2.43 m and 2.09 m respectively). Increase in site index in forests of the same generation was higher than in forests of different generations. This seeming surprise turns out to be one of the best proofs for fastening growth. The base age 50 years is almost in the center of the average rotation age. As shown earlier (Nilson & Kiviste, 1984,1986) in the case of fastening growth the static model will be distorted, remarkably more for older stands but not so much for young ones. Though the standard deviation of the site index increase 3.30 meters was calculated over that data set, the standard error of the mean increase was only 0.04 m. According to the GLM results a general linear model of all available factors has been created. The model was highly significant, however, according to the coefficient of determination R-Square = 0.15, only 15% of variation in site index increase can be described by the listed arguments. Most of factors except drainage fixed in 1951, stand origin fixed in 1994 and stand age fixed 1951 were significant (at level α = 0.05) in the general linear model. The increase of site index occurred to be most dependant on the thickness of organic layer of soil and on forest district.

Table 1. Descriptive statistics of increase in site index (SI_{1994}-SI_{1951}) by main species, by drainage and by generations on the basis of sub-compartment data with the same dominating species in 1951 and in 1994

Main species	Not drained forests			Drained forests			Total
	Same gene-rations	Different gene-rations	Total	Same gene-rations	Different gene-rations	Total	
Average of site index increase (SI_{1994}-SI_{1951})							
Pine	2.03	1.73	1.99	2.93	4.17	3.25	2.35
Spruce	1.49	1.38	1.45	1.38	1.39	1.39	1.44
Birch	3.02	1.50	2.64	2.50	1.46	2.13	2.47
Other	3.23	2.71	3.11	3.46	0.88	2.27	3.00
Total	2.30	1.55	2.09	2.61	2.10	2.43	2.18
Number of stands							
Pine	1382	248	1630	494	172	666	2296
Spruce	1178	852	2030	99	133	232	2262
Birch	1415	467	1882	645	355	1000	2882
Other	338	104	442	35	30	65	507
Total	4313	1671	5984	1273	690	1963	7947
Standard error of site index increase							
Pine	0.09	0.28	0.09	0.14	0.27	0.13	0.07
Spruce	0.07	0.11	0.06	0.25	0.32	0.21	0.06
Birch	0.09	0.19	0.08	0.11	0.18	0.10	0.06
Other	0.17	0.31	0.15	0.38	0.42	0.32	0.14
Total	0.05	0.09	0.04	0.08	0.14	0.07	0.04

The causes are mainly forest management activities, large scale melioration (swamping is one of main problems of Estonian soils, since precipitation is higher compared to evaporation) and the age distribution of forests. The elevated CO_2 content in the atmosphere facilitates plant growth. However, locally on the alvars and dry sandy soils occasional long summer droughts decrease productivity. Amortization and degradation of the drainage system in private forests can stipulate swamping and degrease the productivity (carbon sequestration potential) or forests in Estonia.

1.1.3. Disturbances and extreme events

Most pronounced extreme disturbance on forests in Estonia is the storm damage in August 1967 which directly broke or felled 6.1 million m^3 forest in the west and central Estonia followed by bark beetle outbreak after the storm that affected about 2 million m^3 of forest additionally (Etverk, 2003). Many impact stands were intensively managed by using shelter cutting method. In summer 2001 North East Estonian forests were severely damaged by storm (Figure 3) and in January 2005 there were storm damages overall in Estonian forests. The influence of the wind was powered by the unfrozen soil in January, 2005.

Damages due to forest fires have been increasing recently. There was a serious drought in 1992 and there was a rapid expansion of fire damaged areas as well. The jump up was more than 10 times comparing with average for 1971-1991. In 1993, 1994 and 1996 the area damaged by forest fire was also more than twice bigger than maximum for 1971-1991. As 60% of forest fires take place in May-June, obviously increasing spring-summer droughts will increase the danger of forest fires. The presented data suggest that the danger of forest fires will increase as a result of the predicted increase of droughts in the future.

Storm damages in Estonian forests have not been very frequent. This century the storms in August 1967 and October 1969 damaged 6.1 million solid cubic meters of forest. After 1969 no such storms have been registered in Estonia.

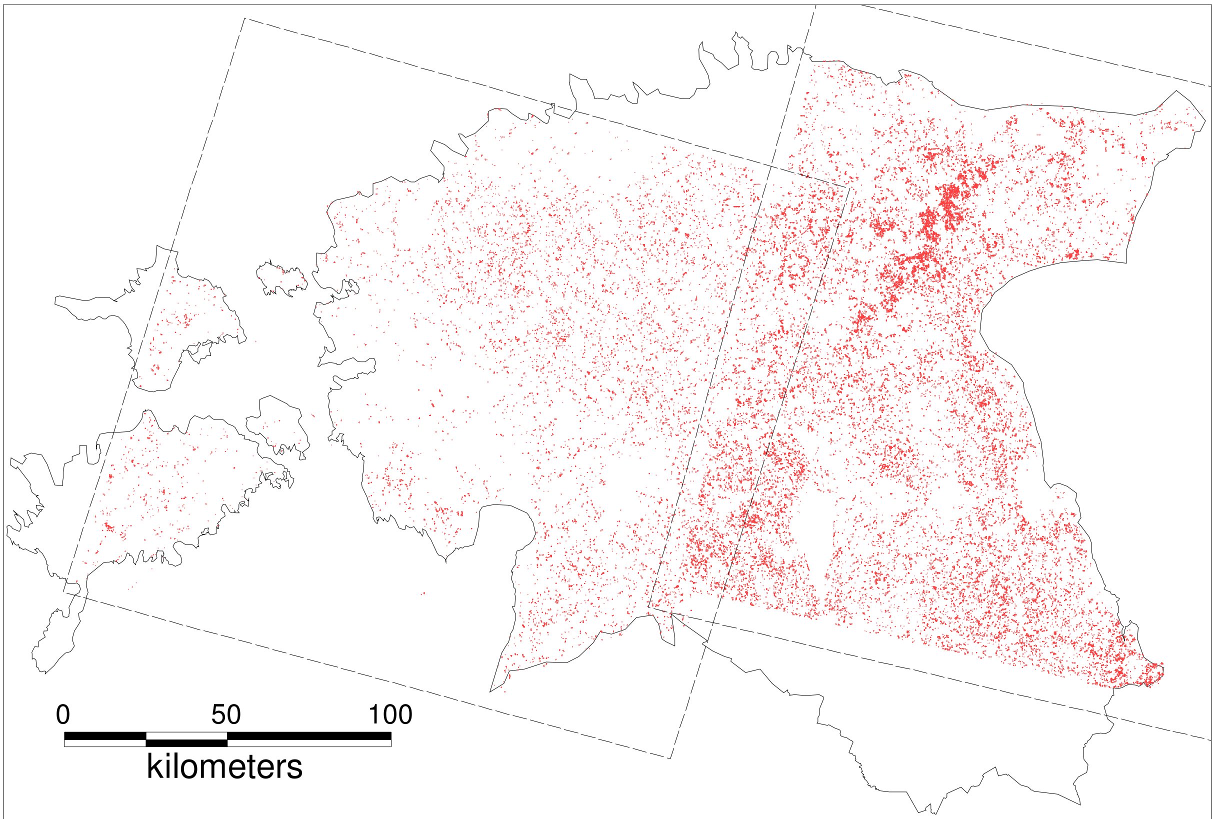


Figure 3: Wind damages in North-East Estonia in summer 2001 on the same map with clearcuts. The frames identify frames of Landsat TM and ETM+ images used for mapping changes. Time range is one year (August, 2001 - June, 2002) for left frame and two years (June, 2000 - August, 2002) for right frame.

Summer drought affected forests in 2006 (Kuusk*, et al.*, 2009). There have been forest fires in Estonia, which have reached the extent of being detectable from coarse spatial resolution MODIS data (*rapidfire.sci.gsfc.nasa.gov/*). There is definely correlation between the summer temperature ant the amount of forest fires in Estonia. In years when summer has been warmer and drier and with smaller amount of precipitation (Russak, 2003, Kuusk *et al.*, 2009) like years 1992, 2002 and 2006 the number and extent of forest fires grows significantly and ranges up to 2000-3000 hectares in total (http://www.metsad.ee/avalik_m_tulekaitse_tk.html). All fires are with some rare exception are caused by anthropogenic factors.

1.1.3.1. Impact cost

No comprehensive country wide studies on estimating impacts costs have been carried out in Estonia.

1.2. Expected impacts

1.2.1. Expected climatic evolution

By summarizing the changes in air temperature, snow cover duration, precipitation and wind speed effects the climate in Estonia is slightly shifting from continental to more typical to maritime regions characterized mainly by milder wintertime and earlier start of the spring. However there can by rather large fluctuations like drought in summer or harsh winters during the sequential years because of location of Estonia is still close to the border of maritime and continental climate zone.

1.2.2. Impacts on ecosystem dynamics and functioning

1.2.2.1. Vegetation phenology

If the forest ecosystems follow the current trend of earlier start of the vegetation season in the spring then there well be higher probability of late frost damages.

1.2.2.2. Vegetation distribution area

If the current trends of precipitation and wind speed increase and soil and air temperature rise continues there can be rather controversial results on the forest ecosystems in Estonia. The impact to the vegetation area comes mainly from changing soil water and nutrient regime (Oja, 1998). However, the impact is probably small compared to the silvicultural activities which tend to increase the share of coniferous species.

1.2.2.3. Insects, parasites, pathogens

New pathogens invade and their impact can be rather tremendous on the coincidence of suitable weather conditions. There are no signs of decrease of the extent and influence of existing pathogens and insects.

1.2.2.4. Global productivity

Productivity is determined by the availability of water, nutrients, CO_2, temperature, photosynthetically active radiation (PAR) and the ecosystem ability to use the available resource and resist to biotic and abiotic impacts. Productivity may easily depend on only one limiting factor. The ecosystems reaching their climax do produce (segregate carbon) almost in the same amount as they release.

Soil and air temperature are assumed to stay rather close to present situation which is rather optimal or rise slightly. Global warming does probably increase the amount of precipitation in Estonia. Productivity of soils will be not much affected by the present trends of climate variables. Elevated CO_2 level stipulates plant growth. Increased atmosphere transparency and decreased cloudiness increase the incoming solar radiation and its part PAR (Kallis, 2003). The age distribution of Estonian forests is skewed to older stands and older stands and this tendency seems to continue since the forest regeneration fellings are done in smaller amounts than is the increment. To summarise all these influences then productivity of Estonian forest will slightly still increase in the future, but it might be at its maximum productivity level at present already. This question needs further research.

1.2.3. Disturbances and extreme events

Probably increases slightly in correlation with the fluctuation amplitude of variables determining weather and climate conditions in Estonia.

1.3. Impact monitoring

1.3.1. Usual monitoring system/network

Data over Estonian forests are collected regularly through forest inventory and sample plot based National Forest Inventory. Satellite remote sensing is used only occasionally and mainly to monitor forest fellings (Lang *et al.*, 2006). All regular forest inventory data are archived and accessible via web-gis based user interface http://register.metsad.ee/avalik/. ICP monitoring plots are mantained by the Centre of Forest Protection and Silviculture.

2. Adaptation

2.1. General adaptation strategy and policy

Some tendencies of climate change (raise of average temperature, lengthening of growth period etc.) have been observed in Estonia during recent decades and the same tendencies are predicted for the next century. On this background, recent changes in forest composition, health, growth, and site conditions can be used for the future predictions. The genetic diversity of main tree species as the adaptation tool is analyzed.

2.2. Forest adaptation measures

The variety of forest site types, stands and their functions in Estonia makes useless to give classic recommendations for adaptation as definite choice of tree species, rotation period, cutting methods etc. These tasks are the part of continuous forest management planning on stand level and the general recommendations will be drawn out from the stand-level decisions made in accordance with the most important criteria and variables.

The fastening forest growth, increase of diversity of acceptable forestry solutions in the case of increasing growth rate, increase of the risks of forest damage by game, insects, diseases, fire and sometimes by heavy pollution will lead to increase of diversity, promptness and effectiveness of decision making in forestry. There is a possibility that in future we will have the negative changes of forest growth rate especially due to forest damage in premature stage. Then the growth curve will be distorted and the optimum cutting age (OCA) of the stand can arrive much earlier but fastening growth without damage will prolong the optimum rotation length vice versa. The vagueness in long term predictions of OCA will increase and more attention has to be paid on continuous monitoring of stands health and growth in the future.

Diversity and dynamic are the key words for decision making in Estonian forestry. The combination of the two words can be called dynamic diversity of decisions. It is very important to follow this continuity in the models used in computer aided decision support system (CADSS) to handle all the variety without pointless pressure on biodiversity and to avoid the losses due to quantifying of continuous variables (Nilson, 1994). More modern tools and methods are needed in operational forest planning and it has to become continuous, both in time and in the abstract space of variables. The only reasonable answer for this challenge will be CADSS able to handle all the changing diversity of combinations of about one million stands, different technologies, needs, local and global environment including the climate and environment to minimize the losses caused by poor adaptation.

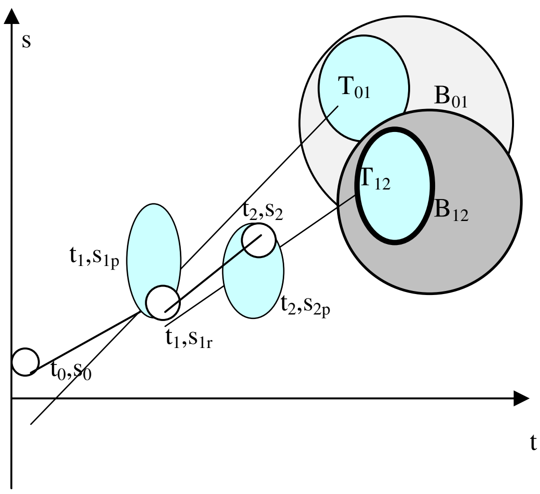
Sliding-scale planning is inevitable in forestry because of unpredictable changes of natural and man-made conditions during the long forest rotation. The real result of forest works differ from the planned one often or the result can turn out not to be the best one on the background of changed conditions. Accordingly the plans have to be corrected on the stand level as well as on the national forestry level repeatedly during the forest rotation. This kind of planning is illustrated on Figure 4. The result will never be optimal in strict sense. Some kind of sub-optimality can be the only realistic hope.

The traditional long term forecasts can fail in unstable forests with rapid growth changes and high risk of damage. So more attention has to be paid on continuous monitoring of the growth and health of every single forest stand for corrections of the long term objective, tactical and operational decision making. This decision making, overlapping in time, has to be repeated again and again.

The knowledge put into forestry information system will include some elements derived from analysis of climate change and its consequences for forestry. The most important lessons will result in:

- improved continuous monitoring and systematic recording the data about the actual forest health and growth, forming archives of the records for later analysis;
- using sliding-scale plans for short, medium and long term taking into account the errors of predictions;
- orientation on sustainable rotation with maximum average price or profit increment without discounting as suggested by C. Price (1993) leading to slightly prolonged rotation;
- increase of amount of carbon stored in stands and decrease of its sink in commercial forests, using flexible CADSS for planning of thinning, final cut and forest renewal.

Figure 4. The principle scheme of step-by-step adaptive decision making. At the moment t0 the state of the system is s0. There is the future background B01 and target T01 on it. To achieve it we plan the state s1p for the time t1 but we achieve state s1r instead. From the point t1,s1r the new predictions B12 and T12 are made for short time decision for the time interval t1…t2. And so on… The ellipses indicate the estimated confidence area on the time-state plain.



We have treated the adaptation to changes as man's direct answer to changes so far. The other aspect is the adaptability of forest itself. The adaptability of the stand is based on the growth potential of sufficient number of trees in it. What more growth resources is available for growth of the tree the bigger is its adaptation potential. The same is true for the stand as the whole.

The natural adaptability of more diverse stands (mixed, random spacing of trees, micro-variation of site conditions, large variation of tree size etc.) is high since the diversity guarantees the smooth and well-timed self-thinning of the stand and enough growth factors for the trees remaining. The planted pure stands have reduced diversity and reduced adaptability. The well-timed moderate thinning has to be planned there using CADSS to avoid the over-stocking and lack of free resources for growth and adaptation. The last approach, looking the system forest and man together instead of forest only, is closer to the principle of MSY in the case of smooth changes. The over-forced attention on diversity and natural adaptability as absolute provision in commercial forests is the result of restricted and non systemic understanding of forestry. The optimum combination of natural and regulatory adaptability is the goal.

Gadow et al. (2007, 2008) have developed adaptive forest management planning ideas into the Forest Design (FD) concept (Korjus, 2009). All forests are nowadays managed under continuous change of site conditions and human environment. The demands of society change, often several times within the lifetime of a tree, but the forest is an inert system. The traditional planning concept assumes long-term stability in forest management, but it would be more justified to assume continuous changes.

In traditional Rotation Forest Management and Continuous–cover Forestry systems, standard treatment schedules are developed for specific forest types as optimal for assumed conditions. Such uniform silviculture creates standardized forest stands and it is not flexible if site or market conditions change. “Harvest Event Analysis” method (Gadow et al., 2008) creates realistic individual forest management paths for all stands taking into account possible forest uses. FD is based on the “Multiple Path” theory. This theory assumes that a stand can be managed by multiple choices of management activities (different management paths). Even for very complicated and uneven forest structures, the realistic management paths can be proposed and simulated in a computer system and afterwards optimal solution for the whole entity can be found with linear programming method or heuristics. In participatory planning, the objective function can be defined with the AHP method (Kangas et al., 1996). In such a way, tree or stand level data and models are linked to landscape level decisions in FD.

The FD method integrates the assessment of risks and uncertainty into the planning process. The hazard potential includes all the potential threats within a given hazard domain. Potential hazards, their factors and risks can be assessed with probability models as well as in monetary terms (Gadow, 2000).

In the FD concept, strategic and tactical planning levels are integrated. Temporal discrepancies in forest planning are mostly addressed by modelling the tactical and strategic issues simultaneously (Andersson, 2005). As the stand level approach and the “Time Window” principle are both used for tactical and strategic purposes, it is possible to integrate these levels and remove inconsistency in planning levels.

The theory of sustainable forest management provides a range of well-developed techniques for practical applications. However, even the best theory implemented in a computer system does not guarantee good management. It is often necessary to establish a set of management demonstration plots for presenting different silvicultural objectives and management options (Gadow et al., 2008, Korjus, 2009). It is practical and worthwhile to connect demonstration purpose with research activities on these plots. In addition, long-term research on sample plots and experimental areas is extremely important for understanding and modelling forest growth and management events.

2.3. Research studies as regards forest adaptation

Estonian Country Case study of the UNEP/GEF funded project GF/2200-96-45 on climate change and adaptation was carried out in 1998-1999. It showed that climate change will not override its adaptability for forestry for the next 100 years in this region (Nilson et al, 1999). The growth of forests is quickening and forest management risks in Estonia are increasing (Kiviste & Korjus, 1998). The more efficient decision-making process involving risk assessment and biological diversity monitoring should be implemented as flexible planning tool (Korjus, 2009).

Forest productivity. The nutrient cycling and forest productivity model RipFor (Oja, 1998) has been used to analyze possible changes in nutrient availability in Estonian forests during the next century. Generally, nutrient availability showed increase for all major nutrients (N, P, Ca, Mg, K, S) resulting from increased nutrient moveability in soil-vegetation system resulting from growing water fluxes through soil and higher organic matter decomposition rates at increasing temperature. Also, nutrient moveability is additionally increased due to higher growth rates of forest species at increasing atmospheric CO_2 concentration and warmer temperature. Simulated nitrogen uptake is also shown to increase with the changing climate scenarios, but nitrogen leaching is calculated to remain more or less the same for the period analyzed except some possible increase in the during the stand becoming old. The higher leaching rates from the older stand can be partly related to staring degradation of the stand and growth potential of becoming lower. Increased uptake means faster biogeochemical cycling of nitrogen in the stand. Similar increase in uptakes can be seen for all nutrients.

Increased nutrient availability, in particular those of nitrogen, clearly favor further increase in forest biomass. Growth rates of wood biomass under four different scenarios are presented in Figure 5 for an example of Norway spruce stand in Vooremaa (Eastern part of Estonia). Stable growth without cutting and natural disasters like diseases or storm events was assumed for all calculations. Wood biomass in these calculations includes also branches, stump and bigger roots.In Figure 6 the differences between the additional increase of wood biomass under the four different climate change scenarios compared to growth under actual (meaning today's) climate conditions are presented. As we can see, the additional wood biomass growth during a 100-year period is predicted to reach from 2.5 to almost 9%. Increase in harvestable timber can be assumed to be similar as it forms a proportional part of all woody biomass. We may conclude that change in climatic conditions in Estonia is favorable for the forest growth conditions and results in increased productivity. Possible decrease in productivity may occur in longer term as a result of increased base cation losses on soils with lower parent material weatherability and base cation content. However, the probability of such cases is fairly low in Estonia. Theoretically possible lowering of the timber quality – softening of it under faster growth and increased nitrogen availability is presumably not going to be a problem as the availability of base cations is also increased and supports keeping the nutrient balance in building up the timber.

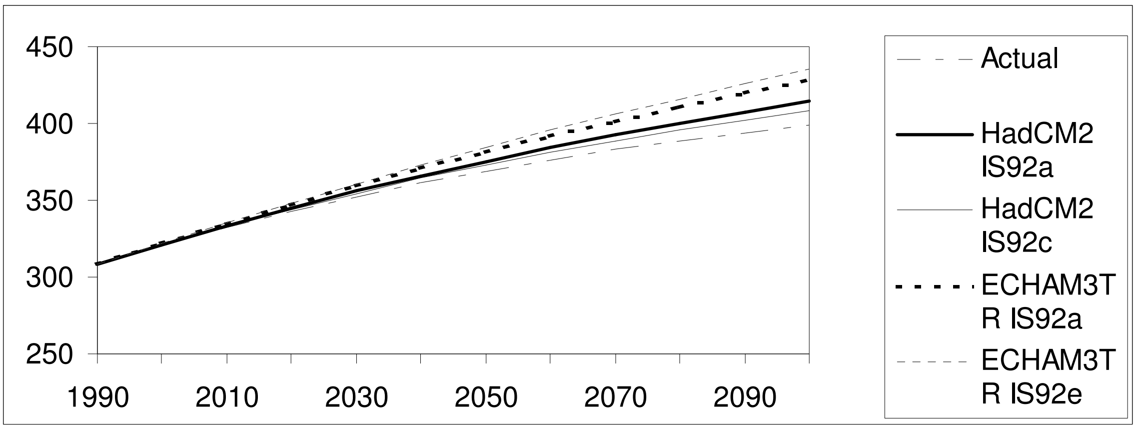


Figure 5. Wood biomass growth in Norway spruce forest in Vooremaa (Eastern Estonia) under four different climate change scenarios - HadCM2 IS92a, HadCM2 IS92c, ECHAM3TR IS92a and ECHAM3TR IS92e.

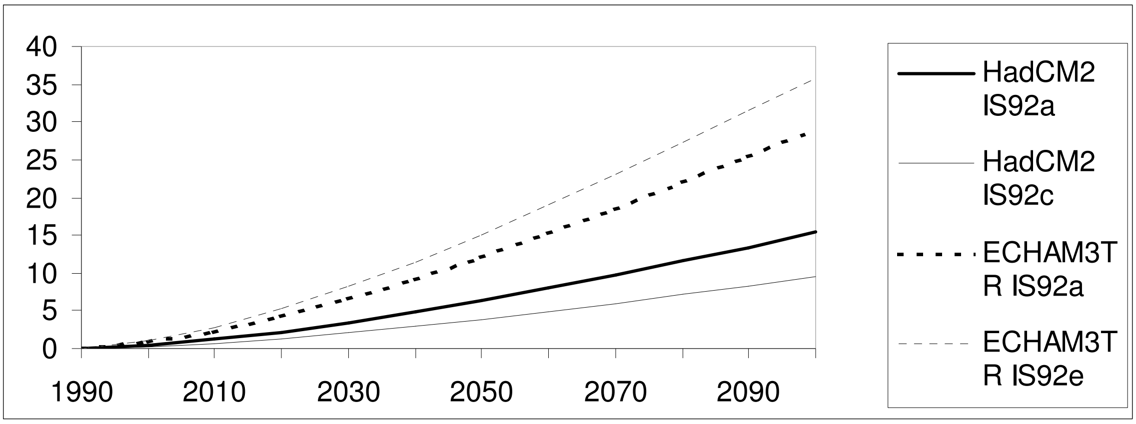


Figure 6. Additional woody biomass growth (tons per hectare) in a Norway spruce stand in Vooremaa under the four climate change *scenarios compared to growth under current climatic conditions during the next century.*

Scenario modelling. The results about the fastening forest growth in the past and predictions for the fastening growth in the future raise the need to estimate the possible consequences for the forest management in Estonia. For this the model MELA (Ojansuu et al., 1991, Siitonen et al., 1995) was used with different change of forest growth rate. The Estonian forest resources in current prognosis were described by the representative sample of 4000 sample stands. From sample stand data were generated sample plots: one plot per one sample stand and sample trees. The sample plots and trees were furnished with site and tree variables according to the Finnish National Forest Inventory rules (Siitonen et al. 1996). A forest growth and management simulation and optimization software MELA-JLP was used for the prognosis. The problem of forest growth rate change is redefined for MELA-JLP system as a growth calibration problem in this study. A dynamic change has been redefined to a static problem with average forest growth rate values. Six different growth rates 75%-125% from actual tree growth rate were used. The simulation period was chosen 60 years from 1997 to 2057. The constraints of non-decreasing timber removal and non-decreasing total volume were applied to fulfill sustainability requirements of forestry. The tree growth rate has remarkable influence to forest growth rate as well as stem number changes are predicted by tree mortality model and treatment models in the MELA system. The tree growth rate 125% corresponds approximately to 3 m increase of forest site index in 50 years. Forest management activities and timber production are depending from tree growth rate. Table 2 illustrates the prognosis of maximum timber production for Estonian forests as the function of tree growth rate. It is assumed that forest area will remain the same as in 1996. Relative structure of potential timber production was analyzed. With lower forest growth rate is most affected thinning potential and with higher forest growth rate are most affected regeneration cutting potential and logging residues. The regeneration cutting area is less influenced, changing from 86.5% to 117.5% with tree growth rate changes from 75% to 125%.

The influence of forest growth rate to forest management can be illustrated with number of management alternatives in the simulation phase of this study. With higher forest growth rate more reasonable alternatives were generated. As the study was limited with branching options for alternatives we have got quite realistic picture of management options and complexity of decision making in forest management. Depending from different optimization algorithms different timber production potentials could be predicted. A decision complexity index (DCI), describing the number of generated alternatives and variation of possible timber production was calculated. With tree growth rate 75% the DCI was 46% and with tree growth rate 125% DCI was 195% comparing with DCI of current forest growth rate. The faster forest growth leads to more complicated and diverse forest management decisions.

Table 2. Timber production potential of Estonian forests (mill. m³/yr.) depending on tree growth rate.

Tree growth rate	YEARS						Average for 1997-2057
	1997-2007	2007-2017	2017-2027	2027-2037	2037-2047	2047-2057	
125.0%	11.28	11.34	11.30	11.39	11.50	11.57	11.40/**133.6 %**
112.5%	9.84	9.90	9.86	9.91	10.04	10.11	9.94/**116.5 %**
100.0%	8.45	8.50	8.48	8.48	8.58	8.70	8.53/**100.0 %**
93.8%	7.91	7.95	7.94	7.75	7.80	7.97	7.88/ **92.4 %**
84.4%	6.95	6.99	6.98	6.97	7.01	7.18	7.01/ **82.2 %**
75.0%	6.05	6.07	6.08	6.07	6.09	6.24	6.10/ **71.5 %**

Diversity of the population of Norway spruce in Estonia. Norway spruce is the most common tree species in Estonia. Although spruce dominated stands are by area in the third place in Estonia, spruce is present in the composition of most Estonian stands. In total volume of final cut the timber of spruce comes first. Having important economic role its diversity inside species has been carefully studied. Up to 130 lower taxonomic units have been described within the species. The area of Norway spruce (*Picea abies sensu lato)* is 9500 km from West to East and 2500 km from South to North including different altitudes. It is assumed that Norway spruce as a young species in phylogenetic sense is still remarkably improving its adaptability. Therefore spruce can enlarge its area and that is what is happening in Europe. Estonia is situated close to the center of the area of Norway spruce (*Picea abies sensu stricto*). Consequently, the growth conditions here are close to optimum and the diversity within the species is remarkable.
The probability of shifting the areas of main forest trees so that Estonia, now close to the center of the area, will be close to its border, will be low.

The species is able to adapt to climate change having more genetic diversity than needed to survive in fixed locus and climate. We base our study on the hypothesis of the presence in close to the center of the area most of the genetic funds of the species and the generations of different origin include almost all the diversity of genotypes and they differ mainly in the frequency of different genotypes in the phase of seeds. The most fitting genotypes will survive and the rest will be eliminated. In case of some extreme climatic factors like extra low temperature or very heavy storm the eliminating level of the factor can occur again once a century and so the adaptation process of trees will take a long time.
Analyzing distribution of variables of seedlings from different parts of the area of Norway spruce we found proof of the initial hypothesis. Having in mind that in natural process 20 to 40 thousand seeds are needed to have one cone baring spruce (Etverk, 1976) one can conclude that there is no need to treat a species like a constant in the adaptation process. It can be described like a distribution large enough to cover the results of moderate climate change.
There are data indicating that in Scandinavia spruce originating 400-600 km southwards has a higher growth speed than the local ones (Günzl, 1969). The same was observed in Estonia not only for spruce but also for Scots pine (Pihelgas, 1980). This difference will become more

important with predicted climate warming. The interpretation of the results by Tomson (1984) indicates the preference of spruce from Lithuania upon Estonian local spruce.

Reforestation and selection in case of climate change. Seeding is preferable to planting for improving the role of natural selection fitting with the final growth conditions. Until there are no varieties matching with certain growth conditions it is recommended to use possibly diverse seeds from the region with growth conditions similar to the ones predicted here. It is useful to use the approach recommended as flowing selection districting (Etverk, 1983) basing on climatic characteristics and direction of seed transport (in or out).
Selection and tree breeding are efficient tools to have the genome and climate conditions balanced. In case of pollution not increasing and the area of forest remains unchanged the predicted climate warming will not cause drastic changes in the species composition of Estonian forests. An increasing role of oak is possible. The man-made changes will still be more important than changes caused by climate warming. Several authors modeling the change of tree species due to the climate change conclude that their results are very doubtful (Mandre & Klysheiko 1996).

3. Mitigation

3.1. Carbon accounts

3.1.1. Kyoto Protocol and Estonian position

Estonia jointed with Kyoto protocol in 1998 and Estonia should to reduce greenhouse gas emissions 8% during 2008-2012.

3.1.2. Estonian carbon account

According to inventory data of Estonian greenhouse gases (GHG) was emission of GHG in 1990 and 2007 42 milj. t and 22 milj. t, respectively. It is due mainly from the reducing of oil-shale industry and also from wide use of new technology. The main source of CO2 in Estonia is oil-shale industry. In 2004 was extracted 13 milj. t oil-shale and 80% from total production was used for energy.

3.2. Political processes, instruments and strategies for mitigation

There is general policy to support bioenergy and mitigation measures in Estonia.

3.3. Forestry as a source of bio-energy

The nearest goal in the European Union is to increase the share of energy generated from renewable sources from 5% to 12% by 2010 (Kuiper et al. 1998; EU Commission 1997). By 2020 renewable energy should account for 20% of the total energy consumption of European Union. Being a member of the EU since 2004, Estonia has to follow EU Energy policy and raise the share of energy from renewable resources to 20% by 2020. The development plan of the Estonian energy industry foresees a reduction in the use of fossil fuels (primarily oil shale) and an increase in the share of biofuels: the nearest coal is increase renewable energy consumption for 5.1% by the year 2010 and potential amount of annual energy from woody biomass up to 2015 is 5,72 TWh.

Forest trees biomass is the most important bioenergy sources in Estonia. The annual amount of fellings formed about 6.5-7.5 milj m3 yr-1 and annual demand of timber for renewable energy in Estonia is 3.6 milj m3 yr-1. The annual felling amount in Estonia is decreased significantly during last five years (fig. 5).
The consumption of wood for energy in Estonia increased in nearest future due to establishment new boiler-houses and combined power plants-boiler houses. Also in oil-shale power plants started to use woody biomass as additional fuel for producing of energy. For cover increased demand of woody biomass are different possibilities:

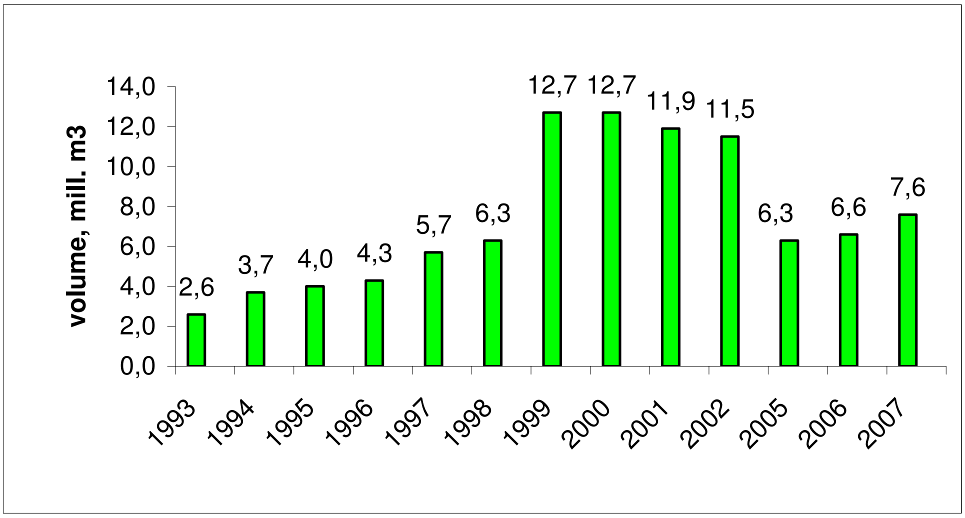
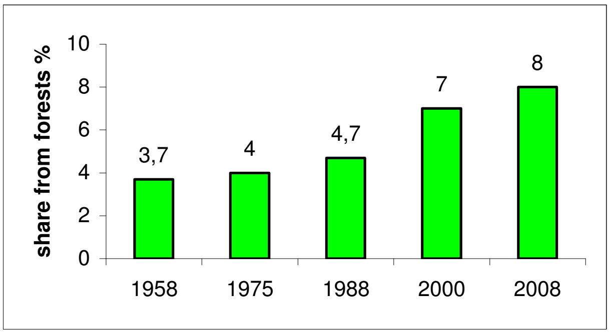
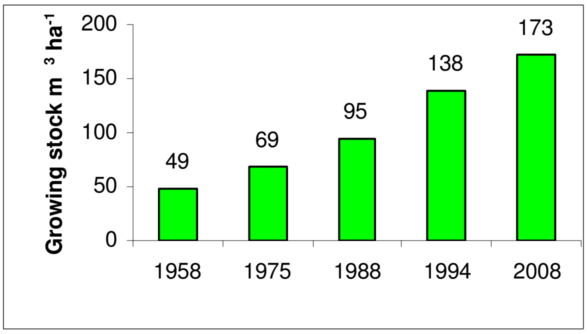


Figure 7. Intensity of fellings in 1995-2007

Firstly, in present moment the existing forest resource for bioenergy is quite considerable. One possible markedly biomass resource in Estonian forests are grey alder stands. During last half century the share of grey alder stands and also growing stock of these stands are increased significantly (Fig. 8 A and B) which is due to mainly from low management intensity.



A



B

Figure 8. The dynamics of the share of grey alder stands area (A) and growing stock (B) in Estonia during last half century.

As grey alder wood is with low quality, the forest industry did not used this resource and both the growing stock and area of alder stands increased. According to last statistical data (Yearbook Forest 2008) total volume of grey alder stands growing in Estonia is approximately 31 mill.. m3 and large part of them are matured or over-matured.

Thus one possible way for increase woody biomass use in forestry is more intensive management (cuttings) of grey alder stands and it is possible to cut 1.5-2 mill. m3 grey alder timber every year instead present 0.5 1.5-2 mill. m3.

As the share of grey alder stands in private forests is about 12% and in state forests 1.4% thus just private forests act as main sources of fuelwood.

The second opportunity is to take to use logging residues. Logging residues are raw material mainly for heating of boiler houses. The use of logging residues increasing in the nearest future and Estonian State Forest Management Centre (RMK) (manages Estonian state forests) estimated the potential amount of logging residues approximately 220,000 m^3yr-1. RMK has not sold any considerable amounts of cutting waste, as the demand for it has been rather low. Due to the growing importance of renewable energy sources in Estonia, the demand for cutting waste will start to increase. Resource analyses for the development of new projects have been ordered. Due to the restrictions set by forest protection rules, in case of types of forest where the removal of cutting waste is authorized the corresponding amount is ca 145
thousand solid cubic metres. The objective of RMK is to offer cutting waste for sale as the demand increases and contribute to efforts of increasing the importance of renewable energy sources in energy balance.
The potential amount of cutting wastes in private forest is at least in same magnitude as in state forests.

The third issue is usage of below-ground biomass of forests. This activity not yet started in Estonia but it is on prospective way. However, the economical calculations and possible environmental risks evaluations needed before more intensive use of stumps for biomass.

The fourth issue is short-rotation forestry. Due to large unused timber amount in forests, the establishment of short-rotation plantations for produce biomass was not in agenda. Now the situation is changed and in conditions of increased demand of woody biomass the establishment of fast-growing tree plantations is actual. From other hand we have large area of abandoned agricultural lands, which are considerable land resource for short-rotation forestry. The area of arable land fallowed during the last decade in Estonia is estimated about 400 000 ha (Estonian Rural Development Plan). In Estonia still not considerable amount of short-rotation plantations. We have some experimental sites but large scale production plantations are missing.

3.3.1. Salix plantations

In Estonia, the first energy willow plantations were established during 1993-1995 in co-operation with the Swedish University of Agricultural Sciences (Koppel et al., 1996). Some plantations are combined as filter systems for buffering nutrients from waste water and producing biomass. The results about biomass production capacity are very variable but potential biomass production in favourable conditions may be markedly high. Main problems related to willow plantations are missing of harvesting machines in this region and high nutrient demand of plants.

3.3.2. Alder plantations

Biomass production in the studied stands was high, which shows that short rotation grey alder stand on abandoned agricultural land can be a promising source of bioenergy. Land use change from abandoned agricultural land to grey alder stand is ecologically relevant. Owing to symbiotic dinitrogen fixation, afforestation of abandoned agricultural land by grey alder affects significantly N cycling and the soil N status. As there occurs appreciable carbon sequestration in the topsoil layer, grey alder stand on abandoned agricultural land acts as a C sink both for soil and tree biomass. Grey alder is a potential resource of bioenergy and large scale establishment of alder stands on abandoned fields does not involve considerable environmental risks.

3.3.3. Hybrid aspen plantations

Approximately 700 ha of hybrid aspen plantations established on abandoned agricultural lands. Due to high potential biomass production, this hybrid may have prospective use as biomass source.

3.3.4. Birch stands

The productivity of silver birch stands growing on abandoned agricultural land is high and silver birch is prospective tree species for short-rotation biomass production.
The afforestation of low fertility agricultural land with birch is positive both in the environmental and economic aspects: there occurs biomass accumulation and soil nutrient content increases. Afforestation of abandoned agricultural land by silver birch does not bring about possible risks from the environmental viewpoint.

3.4. Research studies on mitigation

During last decade several research projects were supported by Estonian Science Foundation and by the Ministry of Education and Research, Estonia. Several topics, related to biomass production, short-rotation forestry, carbon sequestration and nutrient cycling are highlighted.

4. Conclusion

Estonia has started focusing on climate change issues. The use of forestry measures for carbon sink and mitigation are recently under discussion. Adaptation issues should be brought to wider discussions in forestry.

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