



**EVALUATION OF MOOSE HABITATS AND  
FOREST RECLAMATION IN ESTONIAN  
OIL SHALE MINING AREAS**

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## LIST OF PAPERS

The thesis is based on the following papers, which are referred to in the text with their Roman numerals:

- I **Luud A**, Remm K. 2001. Impact of human activities on the value of moose habitats on the example of spatial distribution of moose population in Ida-Viru county, Estonia. *Publicationes Instituti Geographici Universitatis Tartuensis*. 92: 460–465.
- II Remm K, **Luud A**. 2003. Regression and point pattern models of moose distribution in relation to habitat distribution and human influence in Ida-Viru County, Estonia. *The Journal for Nature Conservation*. 11: 197–211.
- III **Luud A**, Pensa M. 2004 a. Alternatives of reforesting oil shale opencasts in Estonia. *Oil Shale*. 21: 3–11
- IV Pensa M, Sellin A, **Luud A**, Valgma I. 2004. An Analysis of Vegetation Restoration on Opencast Oil Shale Mines in Estonia. *Restoration Ecology*. 12: 200–206

### Author's contribution

- I, III The author is the initiator of the study, and responsible for carrying out the fieldwork, data processing and preparation of the manuscript.
- II, IV The author is responsible for carrying out the fieldwork, the data collection and partially for the preparation of the manuscript (theoretical part, discussion)

## ABSTRACT

Multifunctional landscapes with natural and semi-natural ecosystems provide benefits to human society that are of great ecological, socio-cultural and economic value. Land use changes in Estonian oil shale mining areas endanger the sustainability of the ecological functions of the landscape.

This thesis examines the ecological evaluation of landscapes through the analysis of habitat suitability for moose (*Alces alces*) in the vicinity of mines, the assessment of different opencast reclamation alternatives from the point of view of vegetation productivity and diversity in mined out areas, and the environmental costs of reclamation activities.

According to the results, one of the most significant factors that determines moose population density in Ida-Viru county is the amount of habitat in the surroundings of a particular site. The total amount of moose habitats remains the same in reforested mined out areas, because young stands on spoils of opencast are suitable winter habitats for moose.

The preference of Scots pine (*Pinus sylvestris*) plantations on mined out areas is a rational choice for the meeting of economic needs. If vegetation diversity, the biomass of understory vegetation or soil recovery is kept in mind, the usage of different deciduous tree species or the preference of natural succession would have more advantages than the planting of Scots pine. Natural succession also has an advantage among other alternatives if the goal of the action is the reclamation of land productivity and ecosystems without increasing the direct and indirect environmental effects. It needs the least economic input, has the lowest ratio of costs to outcomes both on an energy-related and monetary basis, and has the lowest environmental load (indicated by the low proportion of economic inputs in total costs).

As a practical implication for reclamation, the results indicate that the establishment of mixed stands instead of monospecific plantations should be preferred in order to diversify vegetation on reclaimed opencasts. If the formation of diverse vegetation is one of the main goals of reclamation, spontaneous succession can be considered instead of planting trees in small areas adjacent to natural forests.

# 1. INTRODUCTION

Modern society is rapidly altering the environment of the Earth. As landscape is the stage on which all environmental interactions take place, the changes appear on the level of landscape. The changes may be the direct influence of mankind through land use changes (increase of agricultural areas, opencast mining) as well as the response to the larger and more hidden drift of environmental conditions (desertification, glacial regression).

As the environment and economic system are tightly interrelated, the ignoring of environmental laws in economic decisions creates more problems in the longer term. Such problems have a clear tendency to snowball and their resolution demands more and more resources from the economy and efforts from humans. The decay of the old civilisations of Babylon, the Mayas, Easter Island and many others are examples of similar ecodisasters (Ponting 1992, Diamond 2005, Hunt & Lipo 2006). The inability of economic models to evaluate services provided by ecosystems is one reason why past and modern societies are confronted by a complex of environmental problems. Although its weaknesses were already pointed out by Schumacher (1973) and Henderson (1978), classical economic theory still prevails in our everyday thinking.

Since the last decades of the 20<sup>th</sup> century, a different understanding forced by the increasing global ecological crisis arose about the unpaid environmental services of landscapes and ecosystems (Palmer et al. 2004). The accounting of environmental inputs to the economic system developed as “ecological economics”, which attempts to combine free environmental services and the economic system (Masood & Garwin 1998).

Multifunctional landscapes with natural and semi-natural ecosystems provide benefits to human society that are of great ecological, socio-cultural and economic value (Costanza et al. 1997; de Groot et al. 2002). In real planning and decision-making, however, these benefits are often not fully considered; multi-functional landscapes continue to be converted into more simple, often single-function land use types or wastelands. The holistic principle of contemporary landscape management and evaluation is indispensable for the sustaining of all different features on interacting spatial and temporal scales (Antrop 1997, 2000; Müller 2005). Also, the concepts of the transdisciplinary landscape and landscape ecology has aroused from the debate on sustainability (Tress & Tress 2001; Potschin & Haines-Young 2006).

The idea of multifunctional landscape has been developed in the urban planning of great metropolitan areas since the beginning of the 20<sup>th</sup> century. At the end of the century, the principle, known as a “green” or ecological network, was widely used in landscape planning, even at the international level (Jongman et al. 2004).

Environmental services and ecological land use are considered to be the basic pattern of ecology — natural capital. The services consist of soil, water,

climate, and biodiversity; ecological land use joins connected habitats, productive areas and compact urban settlement (Antrop 2006). The evaluation of landscapes using multidimensional approaches (Gómez-Sal et al. 2003) or, for example, a more detailed treatment of biodiversity and habitat suitability (Burnside et al. 2002; Gaines et al. 2005; Santos et al. 2006), has been an important topic of scientific research in recent decades.

The main questions of holistic conceptions of landscape evaluation are the choice of the suitable and optimal sets of indices, describing representatively and transparently the integrity of ecological systems (Müller 2005). There are several methods used to evaluate ecosystem functions. One possibility to integrate the economic system and free environmental services is to assign monetary value to ecosystems (Costanza et al. 1997), or evaluate the goods and services provided by ecosystems in monetary terms. A second way of evaluating environmental services is to find another common measure for both environmental and economic values. Such methods are based mostly on thermodynamic laws and energy flows, and consider economic system as a part of ecosystem. The most well known are concepts of exergy (Wall 1977, Chen 2006) and emergy (Odum 1988, 1996).

Distinctive conflicts between sustaining the environmental services of landscapes and achieving economic interests are intrinsic to industrial areas. Opencast mining is one of the most disruptive anthropogenic impacts from the point of view of the development of local ecosystems. As the utilization of natural resources continues, and opportunities to restore ecosystems damaged by human activities become more common, restoration is beginning to play an increasingly important role in environmental protection (Dobson et al. 1997; Prach et al. 2001; Ormerod 2003). A lot of effort has been devoted to integrating abandoned surface mines into the local ecological network (Sklenicka & Charvatova 2003) or to rehabilitating species diversity (Casselmann et al. 2006).

Public opinion mostly has an emotional attitude towards land degraded by mining activities and for most people the term opencast spoils includes land that has been left devoid of all topsoil, vegetation and any hope of regeneration in the short to medium term. The Convention on Biological Diversity that was signed by most countries in Rio de Janeiro in 1992 proposes the rehabilitation and ecologically sound restoration of degraded ecosystems as one of the measures to promote the recovery of local biodiversity (CBD 1992). Governments have therefore frequently devoted resources to restoring plant cover on degraded lands, believing that this would result in the restoration of the pre-existing ecological state and might add some economic value to degraded lands in the future (Hunter et al. 1998).

Questions of the evaluation of environmental services, their maintenance through balanced land-use, the preservation and restoration of the ecological network and species richness are urgent in Ida-Viru County in Estonia, where local oil shale mining has essentially changed the landscape.

## 1.1. The Ida-Viru oil shale mining area

Ida-Viru County (3370 km<sup>2</sup>) is situated in the north-east of Estonia, between the Gulf of Finland and Lake Peipsi, bordering Russia in the east (Figure 1 in II).

The general expression of the natural landscape of Ida-Viru County is formed by a plain plateau of limestone bedrock. The plateau reaches 30–50 m above the sea level and is covered postglacial sediments, the thickness of which is mostly less than 2 m. The largest commercially exploited oil shale deposit in the world lies within the county's territory.

The most essential changes of land use pattern occurred in Estonia during the 20th century. The main land use changes in Estonia involve the increase in the share of forest area from 20 to 50% and the decrease in that of agricultural land area from 65 to 20% (Mander & Palang 1994; Mander et al. 1998). The increase in oil shale mining during the Soviet period was the most relevant factor in the landscape change in Ida-Viru County (Toomik & Liblik 1998).

Present-day Ida-Viru County is remarkable for its contrasts. 97% of the human population (totalling about 193,200) inhabits 1/3 of the territory in the northern part of Ida-Viru County. This highly industrialised part of the county is the location of oil shale mining, the chemical industry, and large power plants that run on oil shale.

The southern part has a low population density and is dominated by extensive forests and bogs, which are in a relatively natural condition and were taken under protection as nature or landscape reserves. The dominant tree species in the forests of Ida-Viru County are the Scots pine (*Pinus sylvestris*), the Norway spruce (*Picea abies*), birch (*Betula pendula* and *Betula pubescens*) and riverine aspen (*Populus tremula*).

Estonian oil shale is a yellowish-brown sedimentary rock that originates from the Ordovician period. Its quality is high among oil shales due to unique composition, but its calorific value is relatively low (8.5–10 MJ/kg) in comparison with other fuels. The thickness of oil shale beds is around 2.8–3.2 m. The bedding outcrop of deposits is situated in the northern part of county, but its depth increases in a southern direction up to 100 m.

About 1,000 million tons of oil shale have been mined since 1918, when the first mine was opened. Today the mined area covers about 350 km<sup>2</sup>. Presently oil shale is excavated in two opencasts and two underground mines, and production of both types are equally divided. As oil shale deposits from the northern part of county have been depleted, the mines now seek to exploit resources from more southern areas. About 75% of oil shale is used as fuel in power plants, and the remainder is used by the chemical industry. Oil shale forms 60% of Estonia's primary energy supply and yields 90% of Estonian electricity. Thus oil shale is a major energy source, but the mining and processing of it are major sources of industrial pollution and environmental impacts in Estonia.

Ida-Viru County is located between the Gulf of Finland and Lake Peipsi, forming a corridor of migration for wild animals like moose (*Alces alces*), and probably also for other species, between the taiga region of northern Russia and habitats in the rest of Estonia (Ling 1981). This corridor is essential in maintaining biodiversity in Estonia. Migration plays a significant role in supporting both the abundance and genetic diversity of a population. The expansion of the industrial region in the northern part of Ida-Viru County presents a threat for the corridor of natural habitats in the southern part of the county. The occurrence of a variety of ecological factors at various intensities as well as different habitat types in the county makes this region suitable for the investigation of the spatial pattern of moose distribution.

According to the land cover map, the total area of moose habitats in Ida-Viru County, is 228,000 ha. Most of the moose habitat is not fragmentary, and 97% of the habitat area belongs to one continuous matrix, assuming that roads do not to divide the habitat into separate patches.

Estonian oil shale opencasts are located in the middle of the narrowest part of the green corridor joining the northern forest areas of Russia with those of the rest of Estonia. The further management of mined out areas is essential for the functioning of the ecological network and in order to sustain species diversity. However, short-term reclamation projects are frequently practised instead of more complicated restoration in the opencast mining areas where the landscape is degraded to heaps of mine spoil.

The goal of opencast reclamation was to achieve intensive post-mining land use in the former Soviet Union (Vaus 1970). Experiments were therefore carried out to establish agricultural lands on the mine spoils, but similarly to the standard practice in opencasts in other parts of the world at that time, reclamation mainly meant planting of the most suitable tree species on levelled mine spoil. For example, plantations of pine were mainly established on the Estonian oil shale opencasts because this species was optimal in regard to timber production and the availability of planting material (Kaar et al. 1971). In total, more than 120 km<sup>2</sup> of land had been spoiled by oil shale opencasts by 2002; approximately 100 km<sup>2</sup> of that land has been reclaimed since 1960 (Kaar 2002a). Apart from pedogenesis (Reintam & Kaar 1999; Reintam 2001; Reintam et al. 2002), other long-term effects of reclamation have rarely been studied in the Estonian oil shale opencast areas. Laasimer (1973) and Reintam and Kaar (2002) studied spontaneous succession in oil shale opencasts, but they also emphasized the economic outcome, suggesting the establishment of plantations as the only way to achieve rapid recovery of vegetation on mined areas.

## 2. AIMS OF THE STUDY

Oil shale mining causes major losses of habitats and creates barriers amidst compact expanses of forest in Ida-Viru County. Moose abundance and density is a suitable indicator for the accounting of wildlife habitats in forest landscapes engaged by mining activities.

Opencast mining destroys local ecosystems, but forest recover spoils on mined out areas soon by way of natural succession or the planting of seedlings by humans. Questions about other qualities such as the species diversity and biomass productivity of recovered forests arise when the total amount of wildlife habitats remains nearly the same. When the choice of reclamation alternatives is discussed, economic profitability and optimal investments could also be considered.

These theses focus on the following aims.

1. To compare moose population density in oil shale mining areas with that in natural areas. It is hypothesised that oil shale mining has a negative effect on moose population density – although there might be suitable habitats in the vicinity of mines, the moose population density is smaller in these sites as compared with the habitats located far from mines. Moose are big migrating herbivores that need relatively large forest areas for living. Thus the spatial distribution of its population is presumably an appropriate tool for evaluating how oil shale mines affect the connectivity of habitats and green corridors. (Publications I and II).
2. To analyse the effect of reclamation on vegetation diversity in mined out oil shale opencasts. It was hypothesised that naturally developed vegetation is more diverse than the vegetation of plantations (i.e. the vegetation that has developed in forest stands planted by man on opencast spoils). Secondly, it was hypothesised that planted tree species have a different effect on the understory vegetation. (Publication IV).
3. To compare the sustainability of different reclamation methods — it was proposed that the establishment of plantations consumes more energy (expressed in units of solar energy) than that of naturally developed stands, but higher biomass yield compensates this disadvantage in the longer term (Publication III).



### 3.2. Moose habitats in oil shale mining landscapes

The distribution of moose habitats was estimated on the basis of the land cover data prepared by the European Union CORINE (Coordination of Information on the Environment) land cover project (Meiner 1999). The CORINE land cover classes: coniferous, mixed, broad-leaved forests, transitional woodland/open marsh and transitional woodland/scrub were classified as moose habitat. Woodland/open marsh mainly represents bogs covered by dwarf pine stands and the woodland/scrub class is mainly represented by felled areas and young forest plantations on the Estonian CORINE land cover map of Ida-Viru County.

A relational database in Microsoft Access format of one-hectare cells of Ida-Viru County and adjacent areas was created for this investigation. The database stores information about every square in a regular grid having a 100 m cutting interval. In addition to the land cover information, data about the following factors were included in the database as the properties of each hectare:

- 1) the shortest distance from human settlements,
- 2) the shortest distance from railways,
- 3) the shortest distance from blasting-works in mines,
- 4) the shortest distance from blasting-works in open mines,
- 5) the weighted coverage (share) of moose habitat in the neighbourhood,
- 6) the shortest distance from the border of nature protection areas,
- 7) the shortest distance from roads,
- 8) the shortest distance from larger roads,
- 9) the shortest distance from the border of moose habitat,
- 10) the area of a continuous habitat patch (roads dividing the patch),
- 11) the area of a continuous habitat patch (roads not dividing the patch).

Particular distances were generated using the Modular GIS Environment (MGE) Grid Analyst module by Intergraph Corp. of Huntsville, Alabama. The source of topographical data, except for land cover data, was the Estonian 1:50,000 digital base map.

Pellet group counts from the winter period have been used as the most precise method of moose census (Червоный 1973). The method presumes the relative stability of the frequency of moose defecation and the length of the branch-feeding period when moose pellets are lignin-rich and persistent. Pellet data from the winter period are preferred because of the relative stability of the size and spatial distribution of the moose population in winter, and because these describe population abundance during the entire cold season.

Pellet groups were counted on 4 m x 100 m counting tracks at test sites in April and May 1999. The counting tracks were located along rides or dirt roads approximately 100 m off these in order to facilitate orientation. The total length of the counting tracks was 960 km.

The density of moose at every test site was estimated according to the following equation (Equation 1) (Червонный 1973):

$$D = \frac{1000 \times n}{A \times t \times e}, \quad (1)$$

where:  $D$  – density of moose per 10 km<sup>2</sup>,  
 $n$  – number of pellet groups at a test site,  
 $A$  – total area of transects at a test site [ha],  
 $t$  – duration of the branch-feeding period (200 days),  
 $e$  – mean number of defecations per 24 hours (14).

Estimates of moose population density were calculated per each hectare of the county using two different methods: 1) kriging interpolation, 2) regression analysis.

In this study, kriging with a Gaussian variogram model and the nugget effect was used. The nugget effect expresses modelled variance between observations from the same location. The estimated density of the moose population at a test site was assigned to the centre of the site. Interpolated densities were calculated for every node of the 100 m grid using Surfer 7.0 software by Golden Software, Inc. of Golden, Colorado. Each node of the grid was considered to represent the surrounding hectare.

In addition to the characteristics of the hectares listed above, the characteristics of the neighbourhood of each hectare-cell in the database of hectares were studied, assuming the importance of the adjacency of a site for moose. The neighbourhood of the test sites was divided into 100m wide distance zones up to 25 km from a test site. The following parameters of the neighbourhood were calculated from digital maps: 1) the coverage (share) of moose habitats; 2) the coverage of coniferous forest; 3) the coverage of felled areas and young forest stands; 4) the predominant land cover in the 1 km vicinity of a hectare. The coverage of young forest stands and shrubby habitats were studied because they provide ample food for moose; tall conifer-dominated stands are the preferred winter habitats for moose (Ling 1981; Puttock et al. 1996;). We compared the characteristics of every distance zone around the test sites in which moose pellets were found with the characteristics of the neighbourhood at the same distance from the sites where pellets were not found. Estimated moose density was included in comparison as the statistical weight of a site among sites where moose pellets were found. The difference between the means of these two datasets yielded the weight of a distance zone in further calculations of the integrated neighbourhood effect. The integrated estimate of the effect of a neighbourhood characteristic, as the amount of habitat in the vicinity, was calculated as the weighted mean of the characteristic for distance zones. Only the neighbourhood data up to the distance at which the vicinity of the two

groups of test sites (with and without moose) differed significantly ( $p < 0.05$ ) was taken into account.

The “best subset” method of the module Generalized Linear/Nonlinear Models in the STATISTICA 6.0 software package by StatSoft, Inc. (2001) was used for the development of a multiple regression model and for the selection of statistically significant factors predicting the suitability of moose habitats in Ida-Viru County. The model was calibrated on the basis of the census data from the test sites and was then implemented for the calculation of a suitability estimate in terms of the expected density of moose per 10 km<sup>2</sup> for every hectare-cell of the spatial database. The log-link and the Poisson distribution of the density of moose were used in the regression model. Zero densities from test sites were replaced by very small positive numbers to enable the use of the log-link. From the ecological point of view, the absence of moose pellets does not definitely mean that no moose have visited that place during the entire winter. We used the density values of 10<sup>-6</sup> moose per 10 km<sup>2</sup> instead of zeros, because these values gave a better fit of the regression model than larger or smaller values.

### 3.3. Reclamation of mined out landscapes

The vegetation was surveyed on the Narva mining field, which was reclaimed 30 years ago. We also took samples to describe spontaneously developed vegetation from the Küttejõu opencast, where mining spoil had been left unplanted (Figure 1). Four different types of forest stands were sampled: (1) a natural stand formed by spontaneous succession, (2) a plantation of *Pinus sylvestris* (referred to as pine stand), (3) a plantation of *Betula pendula* (birch stand), and (4) a plantation of *Alnus glutinosa* (alder stand). In June 2002 we established five 10 x 10 m randomly located sample plots in each stand type (20 plots in total). The stands were on average 30 years old according to forest inventory data, which was confirmed by taking tree cores using an increment borer from stems within each plot. We counted all trees with diameter at breast height (dbh) > 10 cm within the plots, and the estimated density of the understory (number of shrubs and tree saplings per 100 m<sup>2</sup>). We marked five small (0.4 x 0.5 m) randomly located quadrats within each plot to analyze ground vegetation. Thus ground cover in each stand type was represented by 25 quadrats (100 quadrats total). We harvested all vascular plants from within the quadrats and dried them at 60°C for 48 hr. We determined total above-ground biomass and biomass by species for each stand type (g/m<sup>2</sup>). We also calculated the mean number of species, mean species diversity (H) expressed by Shannon Wiener's index weighted with biomass and volume stock of trees.

In order to compare the effects of reclamation technique (spontaneous succession vs. plantations) and tree species on characteristics of the understory

and ground vegetation and tree layer, we applied univariate ANOVA using stand type as a fixed factor. Post hoc comparisons were carried out using the LSD test. The assumptions of normality and homogeneity of variances were checked using the Kolmogorov-Smirnov D-statistic and the Brown-Forsythe tests respectively. All statistical computations were made with the aid of the computer package Statistica'98 (StatSoft Inc. of Tulsa, OK, U.S.A.) at the significance level of  $\alpha=0.05$ .

### **3.4. Emergy accounting of reclamation alternatives**

Emergy is the universal measure of work being done by the environment as well as by people, and is not subject to the relations of demand and supply in the markets (Odum et al. 2000). The concept of emergy accounting enables choices to be made between different economic and environmental alternatives. This concept is based on the hierarchy of different kinds of energy. One joule of one kind of energy is not equivalent in its ability to do work to one joule of another kind of energy. By transforming all types of energy to one type, one can estimate the work done by the environment as well as by society or the economy. Emergy is a measure of the available energy of one kind that has previously been used up directly or indirectly to make a goods item or service (Odum 1988, 1996). Emergy has sometimes been referred as “energy memory” (Scienceman 1987).

For the emergy accounting of reclamation alternatives, we diagrammed the system of post-mining activities at opencasts to obtain an overview of the flows of energy and resources necessary for the creation and maintenance of the system (Figure 1 in III).

For the estimation of commercial and aboveground wood biomass production as an output of the system, we used data collected from Scots pine, black alder and naturally recovered stands in reforested opencasts, as described above (Table 1 in III).

In the next step, we transformed input values into solar energy equivalents, which is by definition equal to solar emergy value (sej – solar emergy joule) (Table 2 in III). Solar emergy is the amount of previously used up solar emergy required to make a goods item or service. Solar transformity as a measure of the amount of solar emergy per energy unit (sej/J) present in a goods items or services is used for the transformation of different kinds of energy into solar emergy (Odum 1996).

We also calculated the emergy/money ratios by dividing emergy production per capita of the Soviet Union in 1980–1987 (Odum 1996, p. 206) by Estonian gross domestic product in 2002 (ESA 2002). Dividing any particular emergy flow with an emergy/money ratio gives us an additional measure – em\$ for the purpose of comparison in monetary terms.

## **4. RESULTS**

### **4.1. Mining areas and moose habitats**

The kriging-interpolated mean density in habitats was 3.20 moose per 10 km<sup>2</sup> in Ida-Viru County in 1999. The regression model yields a somewhat higher estimate of population mean density in habitats compared with interpolation, namely 3.61 moose per 10 km<sup>2</sup>. The maps of the predicted moose density, calculated from both models, indicate higher values in the habitats on the southern part of Ida-Viru County (Figures 2 and 3 in II).

According to the Wald statistic of the parameters of the regression model, the amount of habitats in the neighbourhood is the most significant factor for the prediction of moose density (Table 1 in II). Distance from human settlements and distance from blasting activity in open quarries are the next important factors. The increase in moose density with increasing distance from underground mines where explosions are carried out may be related to the distribution of industrially affected landscapes in Ida-Viru County. The higher predicted density of moose closer to roads can be explained by an obstacle effect (moving particles tend to accumulate at obstacles to movement) or by the border effect of habitats located at forest boundaries near roads.

The difference in the coverage of habitats in the neighbourhood of sites with moose and without moose was found to be greatest at distances of 1 ... 10 km from a site (Figure 4 in II). The occurrence of moose at test sites is also related to the amount of coniferous forest and the amount of land cover of the class referred to as transitional woodland/open marshland. The effect of the amount of deciduous forest stands, mixed forest stands and transitional woodland/scrub in the surroundings was not significant. If data about the coverage of habitat in the neighbourhood are used for the prediction of moose density, the relative amount of habitat is most indicative at distances of 1 ... 10 km, according to our study.

### **4.2. Vegetation biomass and diversity on reclaimed opencasts**

The density of trees with dbh greater than 10 cm was significantly lower in the natural stands than in the plantations, whereas the species composition of the natural stands was more diverse than the plantations (Tables 2 & 3 in IV). There was one dominant tree species (abundance 90%) in all three plantations and a few co-dominant species with an abundance of more than 5%. Unlike the plantations, no one species dominated in the tree layer of the natural stands. Although nearly half of the trees were birches, which is the most common

specimen in secondary succession in fallow lands in Estonia, other species were also frequently represented.

The sparse tree layer in natural stands had a positive effect on the density of the understory (Table 2 in IV). In other stand types there were fewer than 50 saplings/100 m<sup>2</sup>, the only exception being a plot in a birch stand where *Caragana arborescens* had been densely planted (300 saplings/100 m<sup>2</sup>) under the tree layer. This is why mean understory density was high in the birch stands; however, the birch stands also had the highest degree of variation, with densities ranging from 20 to 300 saplings/100 m<sup>2</sup>. The species richness of the understory followed the same pattern as that of the tree layer, with the natural stands having significantly more species per plot than the plantations. Although trees were more sparsely distributed in the natural stands, the difference in the volume stock between the plantations and natural stands was not as clear. When compared with pine stands, natural stands would provide similar timber production, but when compared with birch and alder stands, the potential for timber production was much less.

The biomass of ground vegetation was significantly greater in alder stands than that in the other two plantations and in the natural stands (Table 2 in IV). Species richness was significantly higher in the alder stands than that in the pine and birch stands, where it averaged 7 species/m<sup>2</sup>. In natural stands, species richness was highly variable and did not differ clearly from that of any other stand type. Shannon Wiener's diversity index was smallest in the birch stands, while among other stand types its variation was not significant. *Calamagrostis arundinacea* (red grass) alone accounted for more than half of the cumulative biomass in birch stands, while five species in natural, four in alder, and two in pine stands accounted for more than half of the cumulative biomass.

The energy accounting results (Table 3 in III) indicate that the annual cost per biomass unit is lower in the case of natural succession, due to the absence of economic inputs, and higher in pine stands, where production is slower than in the alder stands. Both planted stands have a very similar and significant share of the economic load. The energy yield ratio shows how many times more real wealth goes into the economy than is received back. The production of natural stands has a twofold higher energy yield ratio and thus gives more real wealth.

As costs are lower in spontaneous succession, the emdollar values (em\$) per dollar cost are higher in natural stands, and thus they give more public benefit. The potential values of wood were used for calculating ratios of em\$/\$. This value depends on the market prices of timber and the diameters of logs. The birches that predominate in the natural stands have greater economic value than other species at the age of thirty.

## 5. DISCUSSION

### 5.1. Habitats in industrial landscapes

The environment capacity of species abundance depends on the properties and size of habitat. When the size of a population reaches environment capacity, several limiting mechanisms of population will apply, e.g. changes in fecundity and resistance to diseases will activate. Similar self-regulation processes of population size start in cases where habitat size decreases or its properties change.

An optimum density of 5 moose per 10 km<sup>2</sup> has been suggested in Estonia, considering forestry interests, to avoid major damage to pine plantations (Ling 1961). The optimum density of moose for timber production is presumably much lower than the carrying capacity of forest habitats. According to our results, the predicted density exceeds the optimum density only in the southern part of Ida-Viru County.

The connectivity of habitat is statistically related to the coverage of habitat in theoretical random landscapes. In real landscapes the connectivity, coverage, and size of habitat patches depends largely on the configuration as well as on the criteria determining which landscape features break connectivity and which linear features do not fragment the habitat. The coverage of habitat in the neighbourhood is not directly related to the size of the habitat patch. In our study, no significant relationship was found between the presence of moose and the size of the habitat patch. As noted by several authors (e.g. Язан & Глушков 1977, Филонов 1983, Ling 1981), moose are able to migrate outside their habitat of permanent residence. Therefore the spatial continuity of habitats is possibly less important to moose than the amount of habitat in the vicinity.

The current management practice of mined out opencasts increases the area of moose habitats, as pine plantations are preferred for reforestation. As young pine plantations are suitable winter habitats for moose (Kurttila et al. 2002), the excessive convergence of moose in the young stands increases the threat of damage to trees by copping the shoots. Thus other measures were needed for the maintenance of optimal moose abundance in reclaimed opencasts (e.g. increasing the area of natural reforestation – willows and aspens come in and offer better food for moose than pine plantations). Although the working zone of opencasts has a barrier effect on moose migration, the mined out parts are seamlessly connected with surrounding landscapes.

## **5.2. The productivity and diversity of vegetation on mined out opencasts**

The studied opencasts had different historical backgrounds that might have influenced the measured characteristics of vegetation. Mining activity at the Küttejõu mine ended 20 years earlier than at Narva; therefore Küttejõu was exposed to species immigration for a longer period. In studies of island colonization (Begon et al. 1996), a longer immigration period was found to enhance biodiversity. Differences in vegetation between the Narva and Küttejõu opencast mines, however, cannot be explained merely by species immigration. First, although less exposed to immigration, the ground vegetation in alder stands had the same average species richness as that of natural stands. Second, although the opencast mine in Küttejõu was older than that of Narva, the average age of the tree layer was 30 years in both areas. Thus there was a time lag of about 20 years in the development of woody stands at the Küttejõu mine. A similar time lag was characteristic of the formation of a tree layer by spontaneous succession in opencast lignite mines in Central Europe (Prach & Pyšek 1994, 2001; Prach 1994).

The second aspect to be considered when comparing study areas is their different locations; the Küttejõu mine is situated about 50 km west of the Narva mine. Although this distance does not result in climatic variation, it may affect propagule availability due to differences in surrounding plant communities. The Küttejõu mine is located in a diverse agricultural landscape (fields interspersed with small areas of forests and gardens), while the Narva mine is surrounded by natural ecosystems (swampy deciduous forests interspersed with pine bog forests). A more diverse landscape is probably the main reason why the ground vegetation at Küttejõu opencast has a greater total number of plant species, but spontaneous succession seems to be a necessary condition for maintaining that diversity. Although birch was the most abundant tree species in the natural stands, its dominance did not exceed 50%, and groups of other woody species were interspersed within gaps. The stochastic nature of spontaneous succession is thought to be the main reason for such spatial patterns (Rebele 1992). This variability creates the required conditions for the development of a forest understory (shrubs and tree saplings) and ground vegetation.

Sparse tree distribution was the main reason for the small volume of growing stock in the natural stands, indicating that their economic value is relatively low compared with plantations. In the plantations, in contrast to the natural stands, the tree layer was dense, and dominance of the planted species was very high (90%). As previous studies (Kaar et al. 1971; Kaar 2002a) have shown, environmental conditions on the oil shale opencast spoil are ideal for the growth of pine and birch as well as alder. Thus dense stands of these species suppress the growth of other trees that could otherwise spontaneously become established on mined areas.

Although in some cases the establishment of plantations on degraded lands may promote the growth of other species (Lugo 1997; Singh et al. 2002), our results indicate that spontaneous succession may have several advantages in terms of the increased plant diversity on the calcareous and stony spoils of opencast oil shale mines. This increase in plant diversity may result in an increase in the diversity of other organisms, as variability in stand structure and species composition creates habitats for a variety of organisms. Our results also revealed differences in the ability of the tree species to modify growing conditions for other plants, as measured by the effect of woody species on ground vegetation. Alder, a species that forms symbiotic relationships with nitrogen-fixing bacteria from the genus *Frankia* (Wall & Huss-Danell 1997; Sprent & Parsons 2000), promotes the most ground vegetation growth. Vigorously growing herbaceous vegetation in turn suppresses woody seedlings, which seems to be the main reason why the understory density was lowest in the alder stands. Low-ground vegetation biomass in the pine stands is probably related to the poor soil-forming capabilities of coniferous monocultures, as shown by Kilian (1998).

The greatest biomass of ground vegetation observed in the alder stands was related to high species richness. Although mean species richness in the natural stands was 12 species/m<sup>2</sup>, it varied widely due to the high spatial heterogeneity of the stand structure. The variation in the species richness of the ground vegetation among plots in the natural stands, however, followed the same pattern as in forest plantations. In plots with a high dominance of pine, the number of species was low, while within the plots where deciduous tree species predominated, the species richness of the ground vegetation was higher. Similar results were obtained by Pitkänen (1998), who found that the number of coniferous and broad-leaved tree species had a significant effect on the diversity of vegetation in managed boreal forests. The high dominance of birch in the tree layer was accompanied by a high dominance of *Calamagrostis arundinacea* in the ground vegetation. This was obviously the main reason for the low diversity index of the ground vegetation in the birch stands, while in the other stand types no one species accounted for 50% or more of the total aboveground biomass.

We can conclude that spontaneous succession is an alternative to active reclamation supporting the biodiversity of small areas of the calcareous and stony spoils of opencast mines and may replace the typical reclamation technique of planting tree monocultures where diversity is the goal. Spontaneous succession enhances the establishment of diverse vegetation and may therefore create habitats for a wide range of organisms. If economic value is set as a priority, however, the creation of plantations or scattered colonization foci may assist in overcoming dispersal barriers and direct succession toward defined targets (Robinson & Handel 2000). The selection of tree species for planting has a significant impact on the development of the rest of the plant community. Among active reclamation practices in oil shale opencast mines, the planting of alder gave the best results in terms of the total number of

vascular species and the aboveground biomass of ground vegetation. Planting density may also affect the development of vegetation in plantations.

### **5.3. Environmentally gentle management of mined out opencasts**

The results show that spontaneous succession is the cheapest way of reclaiming plant cover in oil shale opencasts, as it does not incur expenses for planing and planting. These activities require fuel, electricity, and machinery. Omission of these makes spontaneous succession the most sustainable method. The vegetation recovers nearly as quickly in the case of spontaneous succession as in plantations, but its diversity is higher.

On the other hand, the spontaneously restored forest has lower economic value due to more difficult harvesting conditions and the poorer quality of the timber. The surface of opencast spoils is hilly and irregular before levelling, with maximum slopes of 20° and differences in heights varying from 10 to 25 m. Forest stands emerge randomly in such areas, trees are of different ages, their stems are often crooked and the canopies are unsteady. If the plantations are on a plane surface, the growing conditions are better and less variable. Trees in stands of the same age are easy to serve and harvest, but are more vulnerable to pest outbreaks and fires.

Market demand and value are important factors in the choice of the tree species for planting. In the opencast spoils, fast-growing species of good wood quality, such as Scots pine and silver birch, are most preferable (Kaar 2002b). The forestry industry is also interested in planting different introduced trees, such as larch species (*Larix* sp.), hybrids of poplar (*Populus* sp.), and hybrid aspen (*Populus tremula* L. x *P. tremuloides* Michx.) (Pungas 2002). The establishment of plantation requires financial investments, human work and environmental resources, and thus the activity is guided by economic purposes rather than by the need for ecological restoration. The use of introduced species is also at odds with Estonian Forest Law and the Convention on Biological Diversity (CBD 1992). A balance between economic interest and sustainable reforestation is attainable by leaving more land to natural succession and by increasing the proportion of alder and mixed stands. More areas could be left unlevelled.

## 6. CONCLUSIONS

1. The most significant ecological factors that determine moose population density in Ida-Viru were found to be the amount of habitat in the indicative neighbourhood, distance from blasting activity in opencasts, distance from blasting activity in underground mines, distance from settlements and distance from roads. According to the results, current oil shale mining from opencasts has an essential impact on local wildlife habitats and disturbs the functioning of the ecological network. As the amount of habitats in surroundings is the most significant factor that determine moose abundance, the rapid reforestation of mined out areas forestalls the problems of habitat loss and population decline. The current preference for pine plantations increases the area of suitable winter habitats for moose.
2. The preference of pine plantations in mined out areas is a rational choice in order to meet economic needs, even despite greater volume stock in birch and alder plantations at the age of thirty. If species diversity and productivity of understory vegetation or soil recovery has been kept in mind, the usage of different deciduous tree species or the preference of natural succession would have more advantages.
3. Natural succession also has another advantage among other alternatives, if the goal of actions to dissolve direct impacts is the restoration of land productivity and ecosystems without increasing indirect environmental effects. This needs the least inputs, has the lowest ratio of costs to outcomes both energy-wise and financially, and has the lowest environmental load (indicated by the low proportion of economic inputs in total costs).

As a practical implication for reclamation, the results indicate that the establishment of mixed-stands instead of monospecific plantations should be preferred in order to diversify vegetation on reclaimed opencasts. In small areas adjacent to natural forests, spontaneous succession can be considered instead of planting trees, if the formation of diverse vegetation is one of the main goals of reclamation.

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## SUMMARY IN ESTONIAN

### Maastiku ökoloogiline hindamine Ida-Virumaa kaevandusaladel.

Tänapäeva keskkonnaprobleemid on suures osas põhjustatud majandussüsteemi suutmatusest väärtustada tasuta keskkonnateenuseid, nagu puhas õhk, vesi, biomass, liigiline mitmekesisus jne. Säästva arengu eesmärgiks on viia ressursikasutus piiridesse, mis ei vähendaks tulevaste inim põlvkondade võimalusi kasutada neidsamu ressursse. Nii on kerkinud üles vajadus hinnata tasuta keskkonnateenuseid ja planeerida nende kasutamist säästva arengu põhimõtetega kooskõlas.

Mitmekesine ja polüfunktsionaalne maastik varustab ühiskonda tasuta keskkonnateenustega ja seega on suure ökoloogilise, kultuurilise, sotsiaalse, kui ka majandusliku väärtusega. Ometi on tavapärasem suundumus, kus algset mitmekesine maastik muudetakse monofunktsionaalseks. Säästliku maakasutuse planeerimine eeldab holistilist maastikukäsitlust ja erinevate väärtuste arvessevõtmist.

Käesolevas töös on käsitletud kaevandusalade maastiku ökoloogilise väärtusega funktsioone tasuta keskkonnateenuste pakkujana. Töö eesmärkideks oli:

1. Võrrelda põdrapopulatsiooni asustustihedust erinevatel kaugustel kaevandavatest aladest. Eeldati, et kaevandamine mõjutab lähemal asuvate elupaikade kvaliteeti ja häirib ökoloogilise võrgustiku toimimist suurimetajate levikul.
2. Võrrelda erinevate karjääriala taimestamisviiside mõju biomassi produktiivsuse ja liigilise mitmekesisuse taastamise aspektist. Eeldati, et looduslikult taastunud koosluse liigiline mitmekesisus on suurem kui istutatud puistus, kuid biomassi produktsioon on väiksem.
3. Võrrelda erinevate rekultiveerimisalternatiivide ressursikasutust ja selle efektiivsust biomassi tootmisel.

Põdra elupaikade kvaliteedi kriteeriumiks valiti põtrade asustustihedus, mida hinnati ekskremendiloenduse põhjal. Karjääripuistangute taimekoosluste võrdlemiseks kasutati taimkatte analüüsi 30 aasta vanustes hariliku männi, arukase, musta lepa istandustes Narva karjääri aladel ja looduslikult taastunud kooslustes Küttejõu karjääris. Rekultiveerimisalternatiivide ressursikasutuse hindamiseks kasutati emergia-kontseptsiooni (emergia on toote või teenuse valmimise käigus otseselt või kaudselt ära kulutatud energia)

Töö tulemused võimaldavad teha järgmiseid järeldusi:

1. Ehkki põdra elupaiga kvaliteet sõltub leitud regressioonimudeli järgi paiga kaugusest lõhketöödest karjäärides ja allmaakaevandustes, asulatest ja maanteedest, on olulisimaks faktoriks eelkõige elupaikade pindala antud koha ümbruses. Põlevkivikarjäärid küll hävitavad maapealse koosluse täiesti, kuid

ammendatud karjääriala rekultiveeritakse või taasmetsastub looduslikult, ja seega elupaikade arv pikemas perspektiivis ei vähene.

2. Mäniistanduse eelistamine rekultiveerimispraktikas tuleneb majanduslikest eesmärkidest – rajada tulundusmets. Kui pidada oluliseks liigilise mitmekesisuse suurendamist või alusmetsa biomassi suurendamist, siis paremaid tulemusi annavad lehtpuukultuurid ja looduslikult uuenenud kooslused
3. Karjäärialade taasmetsastamisel on kõige väiksema otsese ja kaudse keskkonnamoormusega alternatiiviks ala jätmise looduslikule uuenemisele.

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## **PUBLICATIONS**

**Luud A**, Remm K. 2001. Impact of human activities on the value of moose habitats on the example of spatial distribution of moose population in Ida-Viru county, Estonia. *Publicationes Instituti Geographici Universitatis Tartuensis*. 92: 460–465.

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