AVEC

Integrated Assessment of Vulnerable Ecosystems under Global Change
EU Concerted Action

International Summer School
Peyresq, Alpes de Haute-Provence, France
14 – 27 September 2003

A vulnerability assessment of Norrbotten, Northern Sweden

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This report was compiled by students during the AVEC Summer School 2003 as a case study

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1 Introduction

The research on global change and ecosystems can be regarded as a major contribution to the EU's strategy for sustainable development agreed upon at Gothenburg in 2001 and extended to an international scale in the context of the Johannesburg summit on sustainable development in 2002. The research will strengthen the necessary scientific knowledge for the future orientation of sustainable development strategy; it will also provide the socio-economic tools and assessments as well as overall management practices. Furthermore, it will contribute to their implementation at the enlarged EU level and, when relevant, at the world level.

Global changes include climate change, socio-economic change, land-use change, etc., which will indubitably change the whole planet's environment. Global warming, desertification and deforestation have already manifested the acute vulnerability of our environment. Therefore, the assessment of vulnerability and development of adaptation strategies are important steps towards sustainable development.

Vulnerability is typically described as a function of three overlapping elements: exposure, sensitivity and adaptive capacity (Schröter *et al.* 2003). Global-change vulnerability assessment includes not only the analysis of vulnerability but also the identification of specific options for stakeholders to reduce that vulnerability. Stakeholders are people and organisations with specific interests in the evolution of specific human-environment systems. Generally, vulnerability assessments roughly follow the procedure of defining the study area together with stakeholders; hypothesising who is vulnerable to what; finding indicators of vulnerability; and developing adaptation strategies. Vulnerability assessments are often carried out on a regional to sub-continental scale.

Our vulnerability assessment case study focused on Norrbotten county north of the Arctic Circle in Sweden. Sweden is one of the countries that developed various sustainability philosophies as early as the end of the 19th century. The structural adjustment of Sweden from an agrarian to an industrialised society and from an industrialised society to an information society, alongside the development of democracy and the building of a welfare state, are important historical experiences to draw on in future efforts towards sustainable development.

Norrbotten has characteristics that make it distinct from most other parts of Sweden and many other industrialised countries: it has large areas of pristine landscape, a Sami minority that has preserved a traditional way of life and a mining industry that is currently one of the main employers of the region but whose resources will soon be exhausted. This region-specific setting is likely to undergo drastic changes, many of them triggered by global changes.

2 Definition and conceptual framework of the study area

Norrbotten is the northernmost region of Sweden, covering an area of 98,911km^2 (approx. ¼ of Sweden). It stretches from the most northern coastline of the Baltic Sea along the borders between Sweden and Finland and Sweden and Norway. Roughly two thirds of the area lies north of the Arctic Circle (cf. Figure 1).

The focus of this study was the area of the county north of the Arctic Circle; coastal areas and some of the larger urban areas are therefore excluded to reduce the complexity of the assessment.

Figure 1: Overview map of northern Europe (left) and map of Norrbotten county with the main railway and road connections between the major settlements (right).

Norrbotten has a very low population density. 250,000 people live in the county, accounting for as little as 3% of the Swedish population. A Finnish-speaking minority lives mainly in the areas close to the Finnish border. The Sami population (approx. 8% of the county's population) represents a strong minority group that so far have preserved their traditional way of life and cultural heritage. Many Sami people still depend on traditional sources of income such as reindeer herding, hunting and fishing.

One of the biggest employers in the region is the LKAB (Luossavaara Kiirunavaara AB) mine in Kiruna. Its economic activity is based on iron ore resources that are predicted to be exhausted within the coming 2-3 decades. In addition, copper ore was discovered just south of Gällivare in 1933 and the Boliden Mineral AB company started to mine the area in 1968 after technology for using ore with a relatively low concentration had been developed. Unless new natural resources are found to be exploitable, the closure of the iron ore mine is a significant threat to the region. This event is likely to affect the socio-economic structure of the region considerably.

Also, as a measure to stimulate economic and social activity, scientific institutions were allocated to the region. These consist of various university institutions as well as an EU space rocket station.

With large areas of pristine wilderness in the region, Norrbotten has not only potential for nature-related summer and winter tourism but also offers reason and concern for conserving the natural environment.

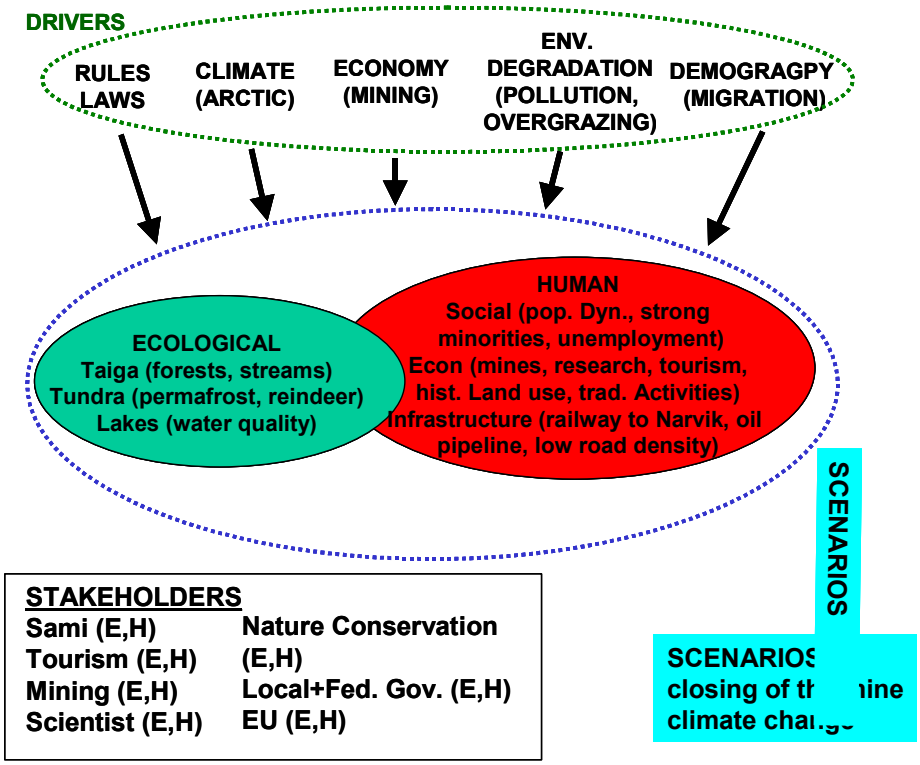

Figure 2: Conceptual model of Norrbotten for the vulnerability assessment.

In an attempt to describe some of the main features affecting the vulnerability of the study area, we prepared the conceptual model of Norrbotten shown in Figure 2. It lists the drivers of global change, which were identified as legislation, climate change, economic changes (with the mine in Kiruna possibly experiencing important changes in the future), environmental degradation, which may be driven by pollution (e.g. local water pollution and long-range air pollution) and pressures deriving from overgrazing of reindeer, and demographic changes.

These drivers have ecological effects on the natural environment consisting of taiga and tundra landscapes with numerous lakes. The drivers also affect the human-made environment, which can be described by the social and economic structure of the region.

The main stakeholder groups were identified as the Sami population, the tourist industry, the mine in Kiruna, the scientific institutions in the region, representatives from the national parks and other organisations concerned with nature conservation, as well as policy-makers from the different levels of government within and outside the region and country.

3 Scenarios

Two types of scenario were introduced that alter the pressures coming from the drivers and Norbotten's ability to respond (cf. Figure 2). The first scenario assumes the closure of the mine in Kiruna during the 2030s. In the second scenario, we looked at possible climate changes 30 years from now.

Our scenarios for the Norrbotten region are based on the SRES scenarios for Europe, in which they are called A1 (World Markets), A2 (Provincial Enterprise), B1 (Global Sustainability) and B2 (Local Stewardship). For a detailed description, see the EU ACACIA project (Parry 2000). The most likely trends and changes in these scenarios have been interpreted for Norrbotten and are summarised in Table 1.

Table l: Overview of the SRES scenarios and how they affect the study area. The scenarios include changes and impacts from internal (e.g. permafrost) and external changes (e.g. market price for ore).

Scenario:	**A1**	**A2**	**B1**	**B2**	Which stakeholders are interested?
Values	Consumerist	Individualist	Conservationist	Conservative	
Governance	no change	strengthening	no change	Strengthening	Government
Fast growing sectors	Space science, tourism, mining [ore price +]	Tourism, mining [ore price up]	Forestry, space science	Reindeer herding, forestry	Econ Sectors
Declining sectors	Forestry, reindeer herding	Space	Mining [ore price goes down]	Tourism, space	Econ Sectors
Equity	Sami lose	Sami lose	Sami win	Sami win	Sami, regional Government
Pollution	+	+	-	-	Nat Con
Biodiversity	Under pressure	Less	Stable	More	Nat Con

The impacts on the region and the stakeholders vary largely depending on the scenario type. Due to the high diversity of stakeholder interests, winners and losers can be defined for each scenario. For the ecological part of our system, pollution and biodiversity are the important rows to look at, for the socio-economic part, impacts can be seen in the rows showing the growing and declining sectors. Social equity was only considered for the case of the Sami people.

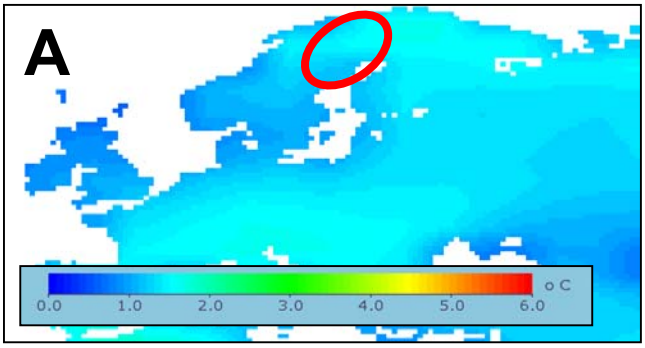

Figure 3. Change in temperature until 2035 in the study area is likely to occur, an increase of 2-3°C is expected. The same outcome is predicted for the other three SRES scenarios.

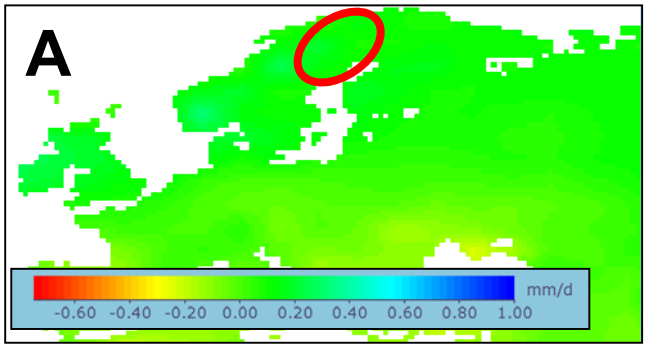

Figure 4. Expected change in annual precipitation over Europe and the study area in 2035 under the A1 scenario.

Our scenarios create changes in the environmental and economic drivers of the system. Climate model runs for each of the SRES scenarios were prepared with the IMAGE 2.2 model. In these, an increase in mean annual temperature of 2-3°C is shown for northern Sweden over the next 30 years, with only little differences between the four scenarios (Figure 3). As a consequence of warming, a longer growing season can be expected.

Almost no change can be expected for the annual precipitation in the region under all four models (Figure 4).

The results of the IMAGE 2.2 model for 'Threats to Bioreserves' in the region show a high danger for the protected areas in the western part of the study area. The highly increased threat was consistent for all four scenarios. Considering that this prediction does not take into account the expected increased pressure on the land after the closure of the mine, this might become a serious problem for the future.

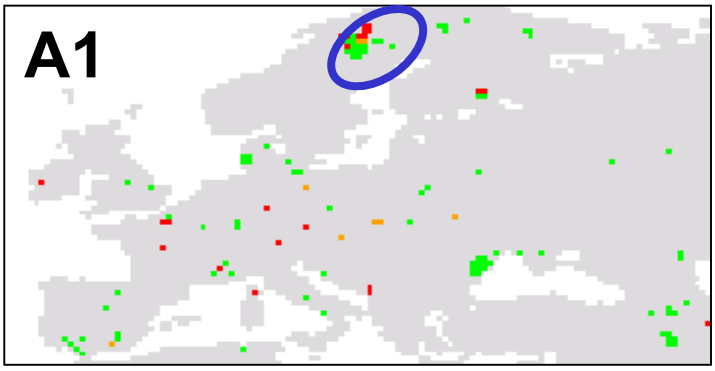

Figure 5. Threats to Bioreserves over the coming five decades (no change – green, change with adaptation – red, change without adaptation – orange).

The economic scenarios for the region mainly focus on the predictions for the closure of the ore mine. A closure under scenario B1 and B2 would not have only drastic consequences for the economic sector but would also affect the social structure of the region. We assume high unemployment rates, which lead to migration to the south of Sweden, higher pressure on nature areas and more intensive use of natural resources, such as hunting, reindeer herding and fishing.

4 The stakeholders in the region and their vulnerability

The interest groups which we think are of major importance and therefore have the greatest influence in the region were incorporated into the assessment. In the following, a short overview of these groups is presented, outlining their exposures to the main driving factors and potential changes, their sensitivities to these exposures and their adaptive capacities.

Sami. The Sami people are an indigenous group of people who rely heavily on natural resources for their traditional way of life. Although only 10% of the 20,000 Samis still live their traditional life, which is mainly based on reindeer herding, they are a politically influential group. They represent the cultural heritage of the Arctic region.

Exposures: economic changes (many of them work in the mining industry), pollution (the Samis live mainly on reindeer meat and fish, which accumulate significant levels of radiation and heavy metals) and climate change (reindeer herding is only possible with stable sources of forage; changes in the taiga/tundra ecosystem, such as northward tree invasion with a warmed climate, will potentially reduce grazing area).

Sensitivity: ompetition with other land uses, negative health effects, lower quality of reindeer/fish, loss of food resources, migration and altered reindeer grazing conditions.

Adaptive capacity: considered low, due to low education and weak economic activities.

LKAB mine. This mine is the largest ore mine in the world with an annual turnover of 4.5 billion SEK. It is the second largest employer in the region.

Exposures: the mining company is exposed to the finite availability of ore in the region. As it is also exposed to the world-market prices for mining products, the profitable exploitation of ore in the region can be of shorter or longer duration, depending on this factor.

Sensitivity: for the company the most sensitive part is whether it can still make a profit under less ore availability and fluctuating ore prices.

Adaptive capacity: considered medium to low as the mine relies on the presence of natural ore and would most likely react by closing the mine and moving elsewhere to new resources.

Scientists. Two major groups of scientific researchers are based in the region. An EU space science station with 400 employees is based north of Kiruna. Their main business consists of launching and monitoring weather balloons, sound rockets and satellites. For this purpose they use a large natural area between Kiruna and the northern border of Sweden. Since the station is owned by the Swedish government, its influence can be considerable. The second research group conducts ecological research. There are several field stations in the region, which are facilities of the Swedish Royal Academy of Sciences. Each year more than 500 scientists use their facilities to conduct research in the area.

Exposures: reliable funding is the basis for the research stations. Additionally, adequate soft site factors (such as cultural activities) are necessary to attract qualified personnel. Furthermore, legal restrictions for research fields are unwanted.

Sensitivities: the groups of scientists are highly sensitive to restrictions in their research activities and their scientific freedom. Furthermore, they require qualified employees from southern Sweden or other parts of the world.

Adaptive capacity: considered high since they can move to other working places.

Tourist industry. The region of Norrbotten accounts for only 4% of overnight stays in Sweden. Nevertheless, it is an important factor of income in the area. Tourists stay mostly on campsites (40%) or hotels (40%); most tourists come from Sweden and Germany.

Exposures: climate change can have an influence on the tourist sector as most tourists come to see the unique nature of the area. Cultural changes can also reduce the attraction of the region. Additionally, tourism relies heavily on good infrastructure both to reach the region and also within the region.

Sensitivities: in particular, a reduced snow cover impacts on winter tourism; the loss of tourist attraction (e.g. the Sami cultural heritage) and low accessibility to preferred tourist places can create disadvantages in the future.

Adaptive capacity: considered medium since it depends on climatic conditions but has a high potential to foster business in rural areas.

Nature conservation is another major player in the region since the region under study consists of 91% non-developed land; 23% of the region is protected by federal law. There are five National Parks in the region.

Exposures: climate change will have a strong impact on the composition and structure of fauna and flora in the region. In the short-term, land-use change will have an even stronger effect if it occurs on large scales. Nature conservation might also be exposed to economic decline as less funding will be available and the pressure on nature reserves will increase (fishing, hunting, reindeer grazing as substitutes for industrial work).

Sensitivities: the loss of unique ecosystems was identified as a main sensitivity, especially with the loss of permafrost areas under a warmer climate. Problems can be caused due to overgrazing of the area by reindeer and the intensive exploitation of natural resources.

Adaptive capacity: considered medium since they manage large areas of protected areas and are valuable for tourism. But climate change cannot be stopped by them.

The **Forest industry** was considered a further major player in the region since 38% of the region is forested land. It is the biggest employer in the region and contributes the greater part of the region's GDP.

Exposures: climate change will influence the forestry sector as well as global market prices and nature-conservation policies.

Sensitivities: climate change is likely to lead to insect infestations and more frequent fire outbreaks but also to increased tree growth. The sector is highly sensitive to market prices of pulp and timber but also to legal restrictions in forest management.

Adaptive capacity: considered medium; high demand for forest products and possibilities of reducing production costs. But there remains uncertainty about the impacts of climate change on soils and trees.

Local and regional **government** is responsible for steering the economic and ecological development of the region. Since it is a democratic government, re-election is its main focus.

Exposures: economic change will occur in the region as soon as the mine closes. Coping with this intensive change will be a great challenge for the government.

Sensitivities: main sensitivities are unemployment and social inequity and consequently migration and loss of faith in the government.

Adaptive capacity: considered medium to high since, while options for local authorities are limited, they are not so limited for regional and national government.

This overview of the stakeholders shows the large diversity of their interests and fields of business, ranging from scientists who launch rockets with 50G and velocities of up to 3,600m/s, to the forest industry, which grows trees for 80 years and plans on a much longer time horizon. Nevertheless, several interfaces and conflicts of interest exist between these groups, for example, land use in the region: the area used by the rocket-launching facility could also be used by the forestry sector or by the Sami for reindeer grazing. Tourist industry personnel and nature conservationists are likely to try to reduce the impact of any land-use form on the unique ecosystems in the region. Nevertheless, most stakeholders should have an interest in reducing and mitigating the impacts of global change since most of their interests will be exposed to these changes.

Table 2: Options for adaptation and their effect on indicators of vulnerability (+: increase of the indicator, 0: no change, -: decrease.

	Adaptation option							
	Ecological adaptation	Ecological adaptation	Ecological adaptation	Economic adaptation	Economic adaptation	Economic adaptation	Economic adaptation	Economic adaptation
Indicators	Implement forest health management techniques	Control overgrazing	Protection measure for endangered species (e.g. competitors in the hunt for Arctic fox and supply winter food)	Invest in educational institutions	Invest in scientific institutions	Invest in transport infrastructure	Try to find new natural resources	Subsidise tourism
	A1,A2	B2	A1,A2,B2	A1,A2,B1	A2,B1,B2	B2	A1,B1	B1,B2
Reindeer population	-	-	-	-	0	-	0	-
Suicide rate among Sami	0	+	+	-	0	-	0	-
Unemployment rate	0	+	0	-	-	-	-	-
Number of employees in scientific institutions	0	0	0	+	+	+	0	0
Road density (km^2)	0	0	-	+	+	+	+ (?)	+
GDP/capita	+	-	0	+	+	+	+	+
Production of the mine	0	0	-	0	0	0	+	0
Number of Arctic foxes	+	+	+	0	+	-	-	-
% of protected areas	+	+	+	0	+	0	-	+
Forestry production	+	0	-	0	0	+	-	0
Number of overnight stays (hotel/camping)	0	0	+	0	+	+	0	+

5 Options for adaptation

An important step in the vulnerability assessment are analyses of the stakeholders' adaptive options, based on the knowledge of vulnerability, causal structure and the adaptive capacity level. In the context of the four SRES scenarios, a set of adaptive options has been established for each vulnerable group/sector from the region under study.

Thus, in the A1 scenario (globalised and market-oriented) forest industry and nature conservation have to take measures to protect endangered species and implement forest health management techniques. In the A2 scenario the most probable adaptation options will be measures for nature conservation and investments in educational and scientific institutions.

In the B1 scenario the decline of the mining industry requires efforts to find new natural resources and measures to sustain the development of other sectors (subsidising tourism, investments in educational and scientific institutions). In the B2 scenario the adaptation options will emphasise nature conservation and investments in transport infrastructure as well as in the development of the tourist industry.

In the next step representative indicators have been established for each vulnerable group/sector, e.g. the reindeer population and the suicide rate among the Sami people, the number of Arctic foxes and the percent of protected area for nature conservation, the number of overnight stays for the tourist industry, etc. The impact of the adaptation options on the vulnerable groups was quantified by the indicators' tendencies: decrease (-), increase (+) or no significant impact (0).

The ecological adaptation options will positively influence the nature conservation indicators and may generate decreases for reindeer herding, GDP/capita and mining activities. *The investments in education, science, tourism and infrastructure will increase* the employment rate, the GDP/capita and will improve the accessibility of the area; on the other hand, some of those measures (like the development of tourism and transport) may affect the endangered species. Reindeer herding will decrease as an effect of almost all adaptive options. The suicide rate among the Sami will increase only if the adaptive options affect their traditional activities and traditional lands, but this impact can be reduced by investment in educational institutions for this minority. The percentage of protected areas will probably be influenced positively by the adaptive options, except in the case of the extension of mining activities.

The analysis of these indicators' tendencies will help the stakeholders and decisions makers to choose the best solutions to increase the adaptive capacity of the vulnerable parts of the system.

6 Conclusions

The Norrbotten region in northern Sweden is an economically strong and environmentally unique system at present. It is the fifth most productive county (on a GDP basis) in Sweden with a strong orientation towards export. However, the future is likely to see strong changes in the region.

Climate change will have an impact, mostly due to increasing temperature, which will lead to environmental changes (prolonged vegetation period, reduction in areas with permafrost and invasion of trees in former tundra areas). These changes will mostly affect forestry and traditional reindeer grazing.

The Sami, as the most vulnerable group of stakeholders in the region, are predicted to face serious problems in the future. They are exposed to several drivers and their low adaptive capacity makes them highly vulnerable. All other stakeholders are likely to be able to adapt to changes more easily.

A much stronger impact than climate change will be induced by the closure of the ore mine in the near future (up to 2035). Under the different scenarios, we either expected the closure to occur within, or after, the scenario period up to 2035 but it cannot be avoided in the long run. The consequences will be drastic: a major part of the income of the region will break away, with a strong increase in unemployment and potential migration to the south. Additionally, the closure will increase the importance of the other sectors in the region. While the science and forestry sectors have limited potential for offering more employment, tourism could help to mitigate the economic breakdown.

The Norrbotten region is likely to lose a lot of its stability over the coming decades, with many consequences for the eco-socio-economic system. We expect it to become dependent on subsidies from Sweden and/or the EU in the future. For the values at stake, it is important to take effective measures to mitigate the negative impacts on the system and to adapt to changes. From our results we conclude that adaptation strategies ought to start soon.

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