Information Indexing in a Bayesian Network for Risk Assessment of Land-use Decisions on Threatened Species

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Abstract: It is evident that land-use decisions pose a risk to habitats, biodiversity and endangered species. However, a great challenge that decision makers and land-use managers are facing is to perform appropriate risk assessments. The challenge consist in the lack of information to build adequate models, the fact that biodiversity is not easily described in mathematical terms, and the problem of finding good endpoints. The current approach assesses the risk of loosing habitats for species included in the "Norwegian red list", by indexing information in a bayesian network. The Norwegian red list contains 3062 species encountered in Norway that are endangered either due to declining populations or simply because they are rare. By entering the current decision, region, and landscape type, the probability of loosing a habitat location for a threatened specie per affected area can be calculated. One of the two main types of information that are included in the network is the density of the threatened species depending on landscape type and region. This information could be obtained by consulting databases on reported observations of threatened species throughout the whole country. The other kind of information regards the effect on the species under the influence of different land-use decisions, based on the knowledge of habitat preferences of each species.

Keywords: *Biodiversity; Endangered species; Risk assessment; Norway; Bayesian network*

1. INTRODUCTION

Among the most important decision tools for conserving species is the IUCN Red List criteria (IUCN, 1994, 1996), applied by many countries to classify species with respect to their conservation status. A discussed question is how to use the threatened species lists in decision-making processes (Possingham et al., 2002). In Norway the main strategies for conserving biodiversity are mapping and conservation of sensitive nature types that contain high level of biodiversity in general, and registration of threatened species. Some of this information will be made available by Arealis – a national initiative on establishing a nation-wide Geographical Information System making environmental data and land use information available (Statens kartverk, 1997). The threatened species appear as spots on the GIS map. The current problem is the signification of these spots for a decision maker or a land-use manager. Avoidance of the spots in a more or less degree is certainly not adequate for biodiversity protection, since land-use decisions might have large impacts on biodiversity in general even though threatened species are not present (Possingham et al., 2002). In addition, avoidance is hardly adequate to protect threatened species either, since the presence of species also might depend on stability of the surrounding environment. Isolation of habitat patches reduces the probability that habitat patches may be recolonized after local extinction (Parker and Nally, 2002). The largest problem is however that the knowledge of occurrence of threatened species is still limited, giving no assertion that an area contains or not threatened species. The current approach uses the spatial distribution of threatened species to generate a probability of occurrence of threatened species in a certain region and landscape type. Based on some believes regarding the lack of data, a probability of occurrence could also be calculated for areas where threatened species have not yet been observed, thus giving a value to the entire land cover type. Based on the knowledge of habitat preferences, determining factors were developed for each species such that a probability of habitat destruction could be generated based on how the land-use decision affects the determining factors. The approach links the probability of occurrence together with the probability of habitat destruction arriving at the probability of loosing a threatened species per affected area.

2. SPATIAL DISTRIBUTION OF THREATENED SPECIES

2.1. Introduction

The threatened species are those listed in The Norwegian Red List (Directorate for nature management, 1999). The categories used in this list are the IUCN categories for national use (IUCN, 1994). The information on threatened species observations were available through the local authorities. In addition databases were consulted like the Norwegian mycological database and the Norwegian lichen database supported by The Natural History Museum and the Botanical Garden (2003).

2.2. Regions of Norway

The spatial distribution of threatened species in Norway is not homogenous. The density of observations is much higher in the southern parts, than in the north due to the different climate. It was therefore appropriate to divide the country into regions, where a region can be regarded as a reasonably large area of the Earth`s surface, with a more or less uniform physiography and climate. The regions could for example correspond to the counties of Norway. It could also be that an aggregation of counties arriving at four regions would be more appropriate. A node that listed the different regions of Norway was established named “Region” (Figure 1).

2.3. Mountains

Another important factor determining the spatial distribution of threatened species is the presence of mountains. Large areas in Norway are above the tree level, representing a completely different climate than the lowlands. Due to the sparse observations of threatened species in the mountains, the country was divided by below and above timberline areas. The timberline vary with the different regions. The node was named “Above timberline” (Figure 1).

2.4. Land cover typology

Land cover corresponds to a (bio)physical description of the earth`s surface. It is that which overlays or currently covers the ground. This description enables various biophysical categories to be distinguished, basically, areas of vegetation (trees, bushes, fields, lawns), bare soil, hard surfaces (rock, buildings), and wet areas and bodies of water (watercourses, wetland). Dividing the country into land cover types is useful since the various land cover types are found to support different levels of biodiversity (Köllner, 2000). For this case the CORINE land-cover typology is used, developed by European Environmental Agency (Büttner, 2002). A Norwegian version of the CORINE land-cover typology have been suggested (Statens kartverk, 1999). The land cover types are listed in the node named “Land cover” (Figure 1).

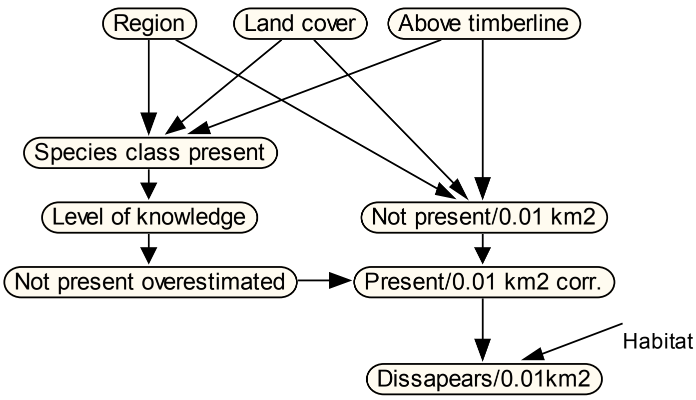

Figure 1. Bayesian network for risk assessment of land use decisions on endangered species. The figure is linked with Figure 2 indicated by the arrow “Habitat”.

2.5. Probability of occurrence

If a database like Arealis is consulted and it provides information that the area of interest is inhabited by one or several threatened species, the probability of presence is 100 % (In such a case the node “Present/0.01 km^2” in Figure 1 has the state “True”). The fact that no threatened species is observed in the area does not help us much, since the reason for that can be that nobody has been looking for them, or searched enough in the current area. It was assumed that the probability of occurrence in such a case depends on two factors; an expert evaluation of expected unobserved threatened species as described in 2.6, and the density of threatened species in the current land cover type and region. The calculation is based on a random spatial point pattern, where any point has an equal probability of occurring at any position on a plane, and the position of a point on the plane is independent of the position of any other point. In such a random spatial pattern the probability of finding *r* points in a square sub area of a land cover *a* is given by the following expression:

$$P(r) = \exp(-\lambda a)\frac{(\lambda a)^r}{r!}, (r = 0,1,2,....,). \quad (1)$$

where λ is the density (number of points per unit area) (Rogers, 1974). The node representing this information was named "No species present/0.01 km^2" (Figure 1). That means that the equation is solved for the case that r = 0. This node represents the density of observations in a certain land cover and region and has "Region" and "Land cover" as parental nodes.

2.6. Uncertainty and the precautionary principle

Unfortunately the knowledge about the occurrence and distribution of the species is not complete. This is exemplified by the fact that new species of insects are found yearly in Norway. For some classes of species, like Mammalia, the level of knowledge is good, but for other classes like Bryophyta it is less satisfactory. This reflects the fact that some classes have been regarded as more popular study objects, and that they have been prioritized by the government. There is however some information available regarding the unobserved occurrence of threatened species. For example, when new observations become more and more rare for a certain class of species, experts will have a belief that they have a high level of knowledge regarding the distribution and occurrence. Based on an expert judgement on the level of knowledge of occurrence and distribution for the different classes of threatened species (Table 1), the precautionary principle is applied on each class depending on the current level of knowledge. In the case with good, satisfactory, and less satisfactory level of knowledge, the probability that the node "Not present/0.01 km^2" is overestimated was set to 10 %, 50 % and 75 % respectively. These values are for the time being simply a suggestion by the author and need to be evaluated by several experts. Three nodes were established named "Species class present", "Level of knowledge" and "Not present overestimated" (Figure 1). The node "Species class present" gives the probability for that the area of interest contains the classes of species listed in Table 1, based on the occurrence in land cover type and region. The node "Level of knowledge" gives the probability for the three states good, satisfactory or less satisfactory, based on the node "Species class present". The node "Not present overestimated" gives the probability that the node "Not present/0.01 km^2" is overestimated. The probability that one or several threatened species inhabit the area of interest is dependent on the two nodes "Not present/0.01 km^2" and "Not present overestimated". This probability is given by the node "Present/0.01 km^2 corr." (Figure 1).

Table 1. Current level of knowledge regarding spatial distribution and occurrence for different classes of threatened species (The Norwegian Redlist 1998).

Good	Satisfactory	Less satisfactory
Ascomycetes, Bacidomycetes	Porifera, Spongillidae	Bryophyta
Charophytes	Malacostraca	
Hirudinea	Ephemeroptera	
Tracheophyta	Plecoptera	
Mollusca	Orthoptera	
Macrolichenes	Hemiptera, Heteroptera	
Pisces	Coleoptera	
Amphibia	Planipenna, Megaloptera, Mecoptera	
Reptilia	Trichoptera	
Mammalia	Mymenoptera	
Aves	Butterflies	
	Sciaroidea	
	Lepidoptera	
	Odonata	

2.7. Habitat key factors

Two biological factors that are necessary for the threatened large blue butterfly (*Maculinea arion*) is presence of a certain food plant, and presence of host ants (Griebler and Seitz, 2002). A land use decision which includes land abandonment of sites by farmers, would lead to an increase in vegetation height and cover and a subsequent rapid loss of the host ant (Griebler and Seitz, 2002). This is a typical species that depends on the stability of ground conditions. Some species of lichens occur only as epiphytes on trees, and in addition they are dependent on moisture from a nearby river fall. Thus, features of the landscape like ground, trees, cliffs and caves constitute important habitat key factors for threatened species. By a revision of the habitat preferences of the threatened species in The Norwegian Red List, a set of habitat key factors was established that covered all the terrestrial and freshwater species (Table 2). Nodes were established for all key factors listed in Table 2, named “Dependent on ground”, “Dependent on trees”, and so on (Figure 2), giving the probability for the threatened species present to depend on the different factors. Due to the different level of knowledge regarding the occurrence and distribution regarding the species classes listed in Table 1, the precautionary values in 2.6 were applied on the data.

one should gather information from models or expert judgements giving the proper probability to the node “ground affected”. An advantage with Bayesian networks which should be mentioned in respect to this is the property to function as a meta-model including both causal, and empirical models (Varis, et al., 1997).

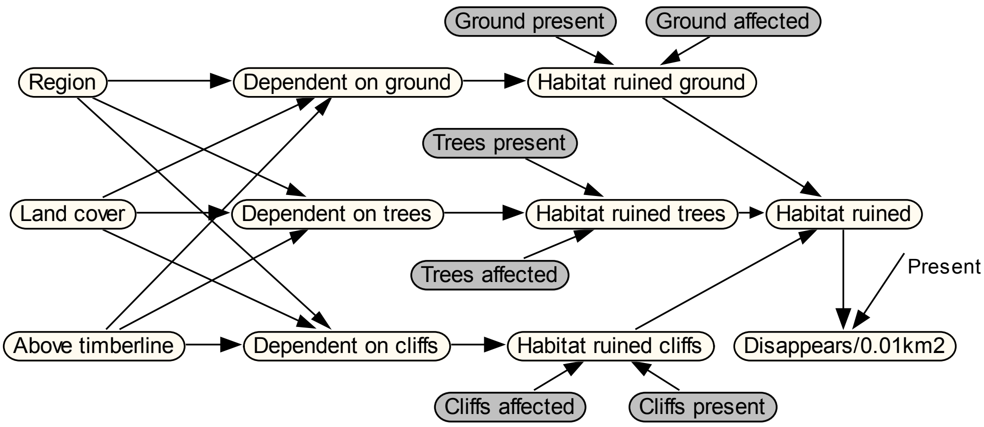

Figure 2. Bayesian network for risk assessment of land use decisions on endangered species. The figure is linked with Figure 1 indicated by the arrow “Present”. Only three of the habitat key factors were included in the figure to make it fit in the paper.

2.8. Habitat affected by decision

The probability that a certain land-use decision affects a habitat depends on the following matters; the presence of habitat key factors, and that the land-use decision target these factors. Decisions such as drainage or usage of a pesticide will change ground conditions, but will not affect buildings or caves. These matters needs to be assessed for each individual case. An example of such an impact assessment is shown in Table 2 where the current decision yields conversion of pastures and meadows into arable land. Nodes were established named “Habitat ruined ground”, “Habitat ruined trees”, and further on that give the probability of ruining the habitat for each of the key factors affected. The node “Habitat ruined ground” depends on the nodes “Dependent on ground”, which is described in 2.7, and the nodes “Ground present” and “Ground affected”, which is the result of an assessment such as the example shown in Table 2. Finally the overall impact on the habitat was summed up in a node named “Habitat ruined”, having all the sub habitat ruined nodes as parental (Figure 2). The nodes and relationships can be viewed in Figure 2. Regulation of an area for recreation might change ground conditions, but depends on factors such as intensity of visitors and duration. In such cases

2.9. Species looses habitat

The final node of the network is named “Disappear/0.01 km^2” and gives the probability that a habitat or habitats for threatened species disappear, based on the probability that species is present stated by the node “Present/0.01 km^2” and the probability that the habitat is ruined when exposed to a certain land-use decision. The node “Disappear/0.01 km^2” links figures 1 and 2 together and is shown in both.

3. EXAMPLE WITH CONVERSION OF A PASTURE TO ARABLE LAND IN THE REGION OF VESTFOLD.

3.1. Pastures and meadows

According to the CORINE land cover typology, pastures and meadows have dense, predominantly graminoid grass cover, of floral composition, not under a rotation system. Pastures and meadows are mainly used for grazing, but the fodder may be harvested mechanically. They also includes areas with hedges. Fully developed CORINE land cover maps for Vestfold do not yet exist, therefore the data on land cover were taken from agricultural statistics of Norway. The total area of pastures and meadows in the county of Vestfold are close to 10 km^2 (Statistics Norway, 2002). In the county, 284 observations of threatened species were found associated with this kind of land cover. By associated it is meant that the literature suggest the land cover as a typical habitat. A consultation of the distribution of threatened species in a CORINE land cover map would tell us how far this is from reality.

3.2. Conversion to arable land

Sometimes farmers would like to intensify the production by putting it under a rotation system. The conversion of pastures and meadows to arable land is one of the most important threat to biodiversity. The process of ploughing and perhaps irrigation and application of fertilizer all contribute to modified ground conditions and loss of the species that were directly connected to the ground such as plants, fungi, moss and insects, and species indirectly connected to the ground as the insectivores. Conversion to arable land is also often followed by a destruction of the features of the old landscape like groves, edges, pits, and stone fences. Such features constitute important habitat factors for species like the hedgehog (Isaksen et al., 1998).

Table 2. Impact assessment of conversion of a certain pasture to arable land on habitat key factors.

Habitat key factors	Presence	Affected by decision
Ground	True	True
Edges	True	True
Cliffs	False	False
Caves/mines	False	False
Old buildings	False	False
Trees	False	False
Lake	False	False
River	False	False
Pond	False	False
Stream	False	False
Pit	False	False
Low human activity	False	False

In the current fictive example the risk of loosing a habitat for threatened species was calculated for a situation where an area of 100 × 100 m is to be converted to arable land. By consulting Arealis, the database for threatened species observations in Norway, it was found that no threatened species have been observed in this area. By a survey of the area it was found that it was separated by an edge consisting of pile of stones, small trees and bushes. To make way for the agriculture machines it was decided that the edge should be removed.

3.3. Results

Solving the equation 1 for the case where $r = 0$, gives a probability of 75.0 % that no species are present in the area based on the density of species described in 3.1. The uncertainty that this probability is overestimated is 28.9 %, given the distribution of species classes in the county. Hence, this gives us the probability of 7.2 % for a species or more being present. The probability for a species or more disappear from the area was also calculated to 7.2 %. This is due to the fact that all species have habitats associated with the ground, and therefore the probability for habitat destruction is 100 %. If the database had provided information of that a threatened species had been observed, the probability that this species disappears from the area would be 100 %. If the database of threatened species not is consulted, the probability of a species or more being present is 32.2 %. That is the probability of a species being present based on the density of observations + the probability that the density of observations is higher.

4. DISCUSSION

4.1. Sources of uncertainty

The observations of threatened species is mainly a result of activity of biologist and nature lovers the last hundred years. These observers have not paid the same attention to every area of Norway, but are often attracted to areas that they know as rich in species, or areas that are more available due to the infra structure. This could mean that the lack of data with respect to occurrence and distribution might not be the same for all regions and land covers. If information were available that certain areas have been investigated extensively, it could be added to the assessment. In addition there are observations where the location is not precisely reported, and there are other observations that have loosed actuality caused by land conversions or natural variation. Natural variation and mobility of species opens the possibility for delocalisation (Elith et al., 2002). However, all this uncertainty could be handled by adding more power to the precaution principle.

4.2. Use of land cover typology?

Nature does not arrange itself into strict classes, so sharp boundaries and homogenous classes do not represent reality (Elith et al., 2002). However, to catch some of the variation in the density of distribution of threatened species it is necessary to divide the country into a finite set of land cover types.

4.3. Land-use decisions

Land-use decisions that may be assessed by the system are all sorts of land-use decisions that bring about irreversible changes in the current conditions of land cover types and key habitat factors. Typical decisions are application of pesticides, plowing, building of roads or railways, construction of buildings, abandonment of land such as fields used for grazing or parks, restoration of old buildings, clear cutting, use of off road vehicles, water regulation and canalization of streams.

5. CONCLUSIONS

Information indexing by a bayesian network for risk assessment of land-use decisions on threatened species seems promising by several reasons. A single network can include information of all land cover types and regions of Norway, which makes it a good tool for land management and decision making. Operating in terms of probability makes it possible to include information of many types, such as distribution and habitat preferences. The approach highlights land cover types and structures within the land cover types such as cliffs and streams, which might be useful for landscape architects. The approach highlights also at which scale a land-use decision starts to become a threat, making it useful to predict future scenarios. Paying attention to land cover types based on the density of threatened species could most likely also function as a parapluie for biodiversity in general.

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