Ecological knowledge in forest management planning

Kangas, A. S. & Kangas, J.

Finnish Forest Research Institute, Kannus Research Station, P.O.Box 44, FIN-69101 Kannus, Finland, annika.kangas@metla.fi, jyrki.kangas@metla.fi

Abstract

So far, models describing the development of animal populations have rarely been used in forest management planning. A few applications exist, where population models have been used for optimizing the expected size of population. There also exist some applications where expert judgment has been utilized in choosing the best management alternatives. In most of these applications, the uncertainty about the population development has not been taken into account. It is, however, important to know the risk that the sizes of populations fall below acceptable limits, with the management alternatives chosen. This is especially the case with rare species. It is possible to utilize also the information of population variation in planning, either to minimize the risk of the population size falling below a given threshold value, or by maximizing some objective function with the constraint that the population size remains above the given threshold value. In this paper, possible consequences of ignoring the uncertainty about the population development are discussed and an example of utilizing ecological knowledge in forest management planning is given.

1 Introduction

In forest management planning the target is to find the treatment schedule which is best according to all objectives of the decision maker. In the recent years, ecological aspects have been given more and more weight in forest management planning. Landscape ecological planning is a tool by which these aspects can be considered. One key target of the landscape ecological planning is to maintain the viability of the rare and vulnerable species persisting in the planning area. This objective can be dealt with in the planning situation with many different approaches. Each of these approaches have their own benefits and drawbacks.

With basic landscape ecological approach all the species are considered at the same time in a holistic manner, at the landscape level. In this approach the means to maintain the viability of the populations is to promote (or sustain) those forest characteristics that are considered critical for the species. Such characteristics may include, for example, the connections between suitable habitats (so called ecological corridors), amount of dead and decaying wood, or proportion of some hardwood species. The advantage of this approach is that it is (at least in principle) easy to understand and implement.

The basic landscape ecological approach has, however, some disadvantages. For example, when the objectives in the planning are contradicting, it may be difficult to say how much there is room for compromise in order to maintain the population viability. It may even be difficult to say if the viability can be maintained in the first place, even if no compromises are required. The uncertainty about the significance of certain characteristics is difficult to take into account, and the consequences of implementing alternative plans may be hard to predict.

For some species there exists very detailed information. Information about the most vulnerable species or species that represent the reactions of several other species can be utilized to complement the basic approach, to make the analysis more profound. This information can be especially useful for covering the parts that are problematic with holistic approach.

The species-wise knowledge available may include experts' judgments, models, empirical data etc. Utilizing species-wise knowledge has usually been considered as too complicated: the information about one rare species can include several models describing details of the species: its occurrence, fecundity, death rates, immigration, relationships with other species and so on. This huge amount of details is not easy to utilize in planning. In addition, characteristics having a positive effect on one parameter may have a negative effect on another. The information available may also be quite uncertain. On the other hand, using species-wise information gives the possibility to take into account all the information available and also to take into account the uncertainty about the development of the species.

If maintaining the population viability is taken as the main target in planning, the information about a certain species can be condensed so that it is easy to utilize in forest management planning. One such technique is the risk analysis. In the risk analysis, the possibility of the extinction of a population, with any treatment schedule, is assessed. This risk estimate can then be used as a constraint or as an objective in forest management planning.

2 Population models

A simple model by which the development of the population can be described can be presented as (e.g. Burgman et al. 1993)

$$N_{t+1} = N_t + N_t b - N_t d = N_t (1 + r)$$

In this model N_t is the size of the population at time t, b is the birth rate and d is the death rate. Thus, r is the growth rate (discrete time). This model may be used deterministically to predict the development of the population. If birth rate is larger than death rate, the population grows indefinitely, otherwise the population eventually becomes extinct.

The effect of forest management planning can be taken into account in the predictions of population development, if one or more of the vital parameters of the population depend on the characteristics of the forests in the area. For example, the birth rate may depend on the suitability of the area for the population at hand (e.g. Kurki et al. 1997). If the population parameters depend on forest characteristics, forest management has an effect on the development of population. Otherwise, it is assumed that all management options are equally good from the populations point of view.

The number of individuals may not, however, be interesting as such. More important is, whether the viability of the population can be maintained with a certain management schedule. This aspect can be studied by a risk analysis. If the demographic variation (i.e. variation between individuals) is taken into account, the number of individuals that die or born can be assumed to follow a binomial distribution. Then,

$N_{t+1}=N_{t,\mathrm{survived}}+N_{t,\mathrm{born}}$, where

$N_{t,\mathrm{born}} \sim \mathrm{BIN}(N_t,b)$ and

$N_{t,\ \mathrm{survived}} \sim \mathrm{BIN}(N_t,(1-d))$.

With these assumptions, it is possible to calculate the probability of the population to become extinct. Thus, the risk the population is facing due to demographic variation can be assessed.

The effect of demographic variation is usually relatively small, if the population is large. Variation that affects the whole population, for example weather conditions, may be much more important. Such variation can be described by assuming annual variation in the birth and death rates as (e.g. Burgman et al. 1993)

$$\begin{cases} b_t = b + \varepsilon_{bt} \\ d_t = d + \varepsilon_{dt} \end{cases}$$

In this case it is possible to calculate the risk the population is facing due to variation in the birth and death rates. This risk assessment may be useful in a sense that we know how the population will perform in average. It is, however, not useful in forest management planning unless the effect of forest management on the risk can be assessed (see also McKelvey 1996). Respectively, for assessing the sustainable level of hunting, the effect of hunting has to be taken into account in risk analysis (e.g. Kokko et al. 1997).

In the above mentioned model there is assumed to be only one population. In reality the population consists of several sub-populations. The combination of the sub-populations is called a metapopulation. In a metapopulation the individuals may emigrate from a sub-population to another. This may be described with (e.g. Burgman et al. 1993)

$$N_{i(t+1)} = N_{it}(1+r_i) - \sum_{j=1}^{n} Eij + \sum_{j=1}^{n} Eji.$$

With this model the effect of immigration and emigration on the risk metapopulation is facing can be assessed. If the emigration depends, for example, on the width of the ecological corridors, the width required for keeping the population viable can also be calculated.

3 Ecological knowledge in forest management planning

3.1 LP approach

Linear Programming (LP) is a common method used in forest management planning. In LP method the planning problem is described with an objective function which is to be maximized

$$\max \sum_{j=1}^{n} c_j x_j$$

subject to constraints

$$\sum_{j=1}^{n} a_{ij} x_j \geq b_i, i = 1,\ldots, p$$

In this formulation, x_j is the area treated with alternative j, c_j is the coefficient which tells how much this area produces the objective variable, a_{ij} is a coefficient which tells how much the area treated with treatment j produces or uses commodity i and b is a coefficient which tells how much of commodity i is required or can be consumed.

The population models can be used in a forest management planning task in several ways. The decision maker may take the size of the wildlife population as an objective or as a constraint. Applications, in which the forest management planning package used contains models also for wildlife populations, already exist. In one such package, FORPLAN, the population size of a few species can be taken as a decision variable (Burgman et al. 1994).

The sizes of animal populations as such may not be interesting, but, more probably, the decision maker would like to keep the populations viable although he/she manages the forests for wood production or recreational purposes. In this case the population size or the risk faced by the population can be used as an objective or as a constraint in planning. For northern spotted owl, there exist studies in which the risk faced by the population has been assessed as a function of the proportion of old growth forests (McKelvey 1996).

The usual LP approach does not consider the uncertainty about the development of animal populations. If this uncertainty is considerable, the obtained solutions may not be feasible. If the constraint is that the risk may not be larger than, say, 5 %, the uncertainty in the calculations may cause the risk in the chosen solution to be much bigger. This can be prevented, if the uncertainty is taken into account. This can be done by formulating the constraint

$$\sum_{j=1}^{n} a_{ij} x_j \geq b_i$$

again as (Hof & Pickens 1991)

$$P(\sum_{j=1}^{n} a_{ij} x_j \geq b_i) \geq \alpha_i \, .$$

In this formula the probability of the solution to be feasible is set to ♋$_i$, which may be, for instance, 95 %. This problem can be solved with the usual LP method, by taking a new constraint level $\tilde{b}_i$, from the 95 % percentage point of the cumulative distribution of b$_i$. With this formulation the constraint is increased to be on the safe side despite the uncertainty. This means that if a population size is used as a constraint, it needs to be the larger the more uncertain the future development about the population is (e.g. Haight & Travis 1997).

3.2 Utility function approach

If, instead of the LP method, a utility function approach is used in planning, each interesting variable, including the size of the population or the viability of the population, have to be taken into account in the utility function. If the objectives of the decision maker are interchangeable, so that a good gain in one objective can compensate for an inferior result in another, an additive utility function can be used. If the population size or the population viability is considered as a part of an additive utility function, there is no guarantee that the viability, for example, is above zero in the optimal treatment schedule.

If the viabilities are taken into account as multiplicative parts of an utility function, as

$$U = \left(\sum_{i=1}^{p} U_i \right) \prod_{j=p}^{q} U_j$$

the viabilities are already better guaranteed in the optimal solution. A given threshold can be obtained by forming a separate function R (Kangas & Kangas 1998)(Fig 1).

$$R = \begin{cases} 0, & \textit{if the given condition is not fulfilled} \\ 1, & \textit{otherwise} \end{cases}$$

When this function R is used as a multiplicative part of an utility function, its effect is similar as the effect of a constraint in the LP problem, rejecting all the treatment schedules not meeting the given requirements. Thus, an effective way to guarantee the population viability in an optimal solution is to form a risk function, which takes value zero if the population viability is below a given threshold, say, 95 %, and value one if the viability is at least the given threshold.

Of course, also in this approach the uncertainty needs to be accounted for. If the threshold for the population viability is not accurate, the threshold is assumed to be between given minimum and maximum values. When this is the case, using the maximum value of the threshold maintains the plans always in the safe side. If the probabilities of the possible threshold values are assumed to be known, the function R may be formulated to be fuzzy: if there is a 0.5 probability that the true threshold is at most a given value, the value of R function is also 0.5. Thus, optimal solution may be found among the solutions which fulfill the minimum threshold value. If all the values are as probable, the R function between the minimum and maximum value is linear. Otherwise, the distribution of the threshold value may be, for example, a normal distribution (Fig. 1).

3.3 Utilizing expert judgments

In many cases the available empirical information is not detailed enough to form a simulation model describing the population dynamics or to perform a risk analysis. In that case it is possible to use expert judgment to assess the missing parameters. In spite of utilizing empirical data, expert judgment is always required, for example, for choosing the shapes of fitted models etc. If most of the required parameters are missing, it is possible to apply expert judgment to assess the (possible) threshold values directly. Another possibility is to holistically rank the plans from the population's point of view (e.g. Kangas et al. 1993).

If the information available for planning is based on pure expert judgments, the uncertainty is especially difficult, but especially important, to take into account. The uncertainty in expert judgments can be analyzed from the internal consistency of the expert's opinions or from the differences between a group of experts (Alho et al. 1996, Alho &

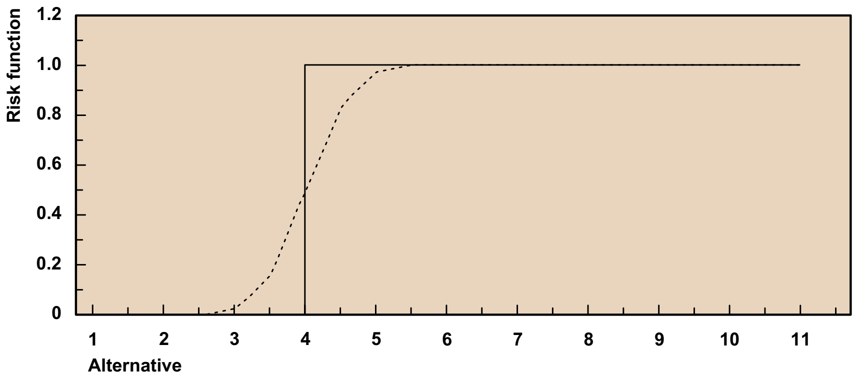

Fig 1. Risk function. The exact risk function is presented with a solid line and the fuzzy risk function with a dotted line.

Kangas 1997). The expert may also be asked to assess, how certain he/ she is about his/her judgments (Leskinen & Kangas 1998). These sources of uncertainty do not, however, cover all the uncertainty in the judgments.

4 An example

In the example, the threshold value is not obtained from a risk analysis but on a predictive model which tells the critical value in the proportion of old forest for the capercaillie (*Tetrao urogallus*). It is assumed that the critical proportion is about 25 % in a fine-grained habitat (Rolstad & Wegge 1989). This threshold value is used to form a risk function R (presented above) which is used as a multiplicative partial-utility function.

In the example it is assumed that the utility of the decision maker consists of net income and the viability of the capercaillie population. Net income is assumed to be the larger the smaller the proportion of old growth forest after the planning period (Fig 2.). In the first case, the capercaillie population is assumed to be viable if the proportion of old growth forest is above the critical value. In the second case the true threshold value is assumed to be between 15–35 %, with 50 % probability that it is larger than 25 % (see also Kangas & Kangas 1998).

In the first case the function R is assumed to be exact. In this case the optimal solution is to maintain the proportion of old growth forests at 25 %. If the value of the true threshold is assumed uncertain, a fuzzy function R is assumed. In this case, the optimal solution is to maintain the proportion of old forests at higher level, to be on the safe side if the true threshold value turns out to be more than 25 %. In the case of the example, the optimal level was 30 % (Fig. 3).

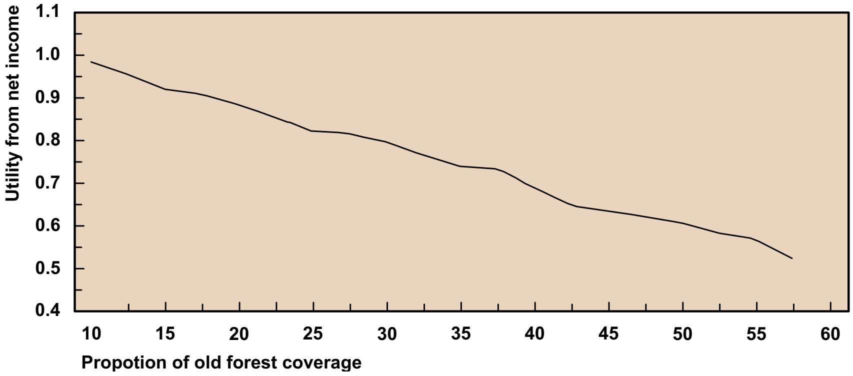

Fig 2. The border of the production possibilities in the example.

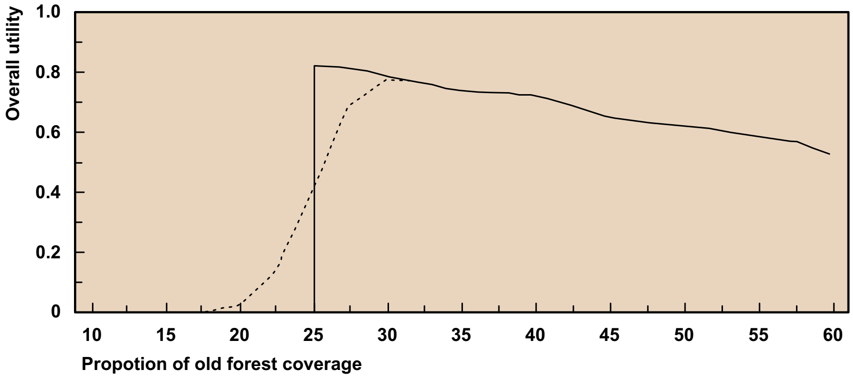

Fig 3.The overall utility with exact risk function (solid line) and fuzzy risk function (dotted line).

5 Discussion

It has often been stated that information about the wildlife populations is too scarce to be effectively used in forest management planning. Information about wildlife populations can, however, be used in forest management planning in several ways, and it need not necessarily be complete. The plans can be compared with respect to the whole ecosystem holistically. Another possibility is to utilize the available knowledge about each species separately. Empirical models or species-wise information are not necessarily required, but the planning may be based on expert knowledge as well.

Models describing population dynamics can be used to optimize the population sizes. If the models are considered too complicated for planning purposes, or if the population size as such is not considered as a relevant decision variable, the information can be utilized in risk analyses. The results of the risk analysis, for example in the form of critical thresholds of certain forest characteristics, can then be used in searching for means to maintain or increase the population viability.

It is also possible to combine expert judgment and empirical information in each of these approaches. In risk analysis, for example, a part of the parameters may be based on experts' opinions. The empirical data available on the occurrence of the species could be used in supporting expert judgments about the critical values of the habitat.

The information about the wildlife populations may also be considered as too uncertain to be useful in planning. Undoubtedly, the uncertainty has to be taken into account in order to obtain useful plans. Uncertainty does not prevent planning: it is not wise to ignore the available information because of uncertainty in it. Plans based on no information at all are, most likely, not better than plans based on uncertain information, provided that the uncertainty is not ignored.

The uncertainty in the ecological considerations has two main sources: the variability, which is due to the stochastic nature of the system, and ignorance, which is due to the incomplete knowledge about the system (e.g. Ferson & Ginzburg 1996). In risk analysis, the demographic variation and annual variation of birth rate are examples of variability that cannot be reduced. The uncertainty in experts' judgments, on the other hand, is more or less due to ignorance and can be reduced with additional studies. Both of these sources need to be accounted for in planning, but in the most in-depth analysis their effects should be distinguished.

The uncertainty can be taken into account by assessing the probabilities of the possible outcomes and then comparing alternative plans according to this information. When risk and uncertainty is dealt with in a proper way probabilities of a certain plan being better than the others, with respect to the objectives set, can be calculated (Alho & Kangas 1997). And furthermore, also the decision-makers attitude towards risk is possible to consider (Pukkala & Kangas 1996).

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