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Conserving Forest Wildlife and other Ecosystem Services: Opportunity Costs and The Valuation of Alternative Logging Regimes

by

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Clem Tisdell[2]

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Conserving Forest Wildlife and Other Ecosystem Services: Opportunity Costs and the Valuation of Alternative Logging Regimes

ABSTRACT

Ecosystems supply a wide variety of valued commodities, including ecological services. Valuing these commodities and determining the implications of their valuation for the optimal management of ecosystems is challenging. This paper considers the optimal spatial use of forest ecosystems given that they can be utilised for conserving wildlife species and for producing logs. It takes into account the alternatives of selective logging and heavy (less selective) logging. It considers whether it is optimal to partition the use of a forest so that a portion of it is used exclusively for wildlife conservation with the remainder being utilised for heavy logging (a dominant use strategy) or to combine wildlife conservation and selective logging in at least part of the forest (a multiple use strategy) with any remainder of the forest being available for heavy logging. The assumed objective is to maximise the profit from logging subject to the population of a focal forest wildlife species being sustained at a particular level, that is at a level at least equal to its minimum viable population. The optimal use strategy cannot be determined *a priori* but requires alternatives forgone to be assessed. While orangutans are used as an example, the model can be applied to other species. It can also be applied (as is shown) to other ecological services such as the quality of water flowing from forested areas. Although the model may appear at first sight to be quite particular, its application can be extended in several ways mentioned. It demonstrates that the optimal spatial patterns of ecosystem use require individual assessment.

Keywords: ecosystem services, forests, orangutans, reduced impact logging, selective logging, spatial optimisation of ecosystem use, valuation of ecological services, wildlife conservation.

Conserving Forest Wildlife and Other Ecosystem Services: Opportunity Costs and the Valuation of Alternative Logging Regimes

1. The Purpose of This Exposition

A fundamental tenet of economics is that optimal economic choice requires the value of *alternative* possibilities to be taken into account. In other words, the opportunity cost of making one choice rather than others is an essential ingredient of optimal economic decision-making. From that point of view, studies that fail to compare the value of the ecosystem services produced by alternative forms of ecosystem use are of limited practical significance. With this in mind, this article concentrates on the economic value of services provided by the alternative spatial uses of ecosystems, in particular, forest ecosystems.

The commodities, including services, produced by different types of ecosystems (natural and man-made ones) are numerous and complex. Some of these outputs are produced 'on-site' (but may be valued off-site) and others are supplied 'off-site'. The latter are generally classified as externalities by economists and they may be favourable or unfavourable. For example, forests produce favourable externalities (for instance, reduce soil erosion and may have hydrological benefits (see, for example, Govorushko, 2012), but may also generate unfavourable externalities such as wild fires and harbour agricultural pests.

The main focus in this article is on commodities produced on-site by natural (non-plantation) forest ecosystems. For simplicity, only two types of commodities are initially considered: the maintenance of a forest dependent wildlife population and the production of wood for logging for timber. This is quite a simplified approach because forests also produce other commodities on site such as non-timber products and in some cases, are used for grazing livestock. Also, as was mentioned, forest ecosystems give rise to off-site benefits and disbenefits. In this context, a case involving water quality is also discussed in this article.

The central problem posed is as follows. Given an available area of forested land, the over-riding objective is to ensure that the use of this land is such that a minimum viable population (or a targeted level of population) of a focal wildlife species is conserved. Survival of the species at the desired population level requires certain characteristics of the forest's habitat to be preserved. If logging of the forest is allowed, these habitat requirements constrain the type of forestry that can be practiced. The question then is would it be most economical to conserve the forest area by combining conservation of the focal species with selective logging (a multiple land-use strategy) or would it be more economical to conserve the targeted viable population of the species in a portion of the forest free of logging and allow the remainder of the forest to be used for heavy (less selective) logging, that is to allocate the use of the forest by dominant purpose? Off-site environmental effects are not the main consideration in this analysis but the model can be extended to take account of these. This is illustrated by showing how logging can be managed in different ways to achieve a particular water quality standard in a water catchment and by considering the most economical logging regime to achieve that target. However, strategies for conserving the orangutan, a highly dependent forest species, are mostly used for illustrative purposes in this article.

Comparatively little attention has been given in the economic literature to the economics of selective (reduced impact) logging as a means to conserve forest dependent wildlife species and maintain other ecological services. However, the subject of the spatial optimisation of the use of ecosystems has received much greater attention by ecologists. For example, Hof and Bevers (1998; 2002) give considerable attention to the ecological and environmental consequences of the spatial use of forest ecosystems and the effects of logging regimes on their ecological services. Although they indicate that economic factors can be allowed for by adjusting their models, economic considerations are not central to their expositions. Their aim is to examine "the use of optimisation in the management of an ecosystem with the objective of directly capturing spatial ecosystem relationships and processes" (Hof and Bevers, 1998, p. 1). The problems posed by these authors are extremely complex; so complex that they often cannot be solved by mathematical optimisation methods but must rely on simulation approaches and approximations to search for an optimum. Often linear approximations are needed to solve these type of complex optimisation problems (see, for example, Hof and Bevers, 2002, Ch. 5). In fact, Hof and Bevers (2002) devote Chapter 15 to highlighting the advantages of using linear programming models to obtain practical solutions to these problems.

The model presented in this article for considering the spatial use of a forest is relatively simple but it is able to identify circumstances in which multiple use of a part of the forest is optimal and others in which the forest should be partitioned into dominant uses. An interesting result is that even if a forest is on average equally productive everywhere in producing its various valued services, circumstances can arise in which it is most economic to use at least a portion of it for multiple purposes.

If for example, two outputs of the forest are valued, namely the conservation of a focal wildlife species and the profit from logging, multiple use of at least part of the forest can be economic. This is more likely to be so the less is the sacrifice in wildlife density and the lower is the reduction in the profitability of logging when wildlife conservation and logging are pursued simultaneously in the same area rather than in separate areas of the forest. The model used here assumes that the spatial use of the forest should be such as to maximise the profit from logging but subject to the condition that a focal wildlife species continues to survive in the forest at a particular level of population.

To some extent, therefore, the valuation system adopted in this article is lexicographic. This is because the focal wildlife species is required to continue to exist at a targeted level of population, for example, a minimum viable population. This introduces a threshold into the valuation process. Of course, in some cases, there may be a demand for a higher level of population of particular wildlife species. On the other hand, some societies regard some wildlife species as pests or consider them to be obnoxious and would welcome their extinction. These complications are not taken into account in the model outlined here.

This article proceeds as follows: first, background material relevant to this topic, such as the pre-existing literature, is considered and then the general nature of the chosen forest-use problem is outlined. Subsequently, a linear model is introduced to simplify the problem and solve it. It is argued that the model is not so restrictive as it may seem to be at first sight. Ways in which the model can be extended and applied to the assessment of other services (such as water quality) provided by forest ecosystems are suggested, and some of the complications raised by dynamics are highlighted.

Although the modelling used in this article is not all encompassing, its simplicity highlights several important issues that otherwise can be easily overlooked in valuing ecosystem services and in determining their implications for ecosystem use. Of particular interest is whether or not dominant or multiple land-use strategy is optimal in the supply of ecosystem services. A further aspect is that if there are economic grounds for multiple spatial use of an ecosystem, should the whole of the ecosystem be subject to multiple use or only a part of it.

Insufficient attention has been given by economists to the explorations of these spatial aspects of the valuation of the use of ecosystems. To reiterate: while the simple modelling used here is not all encompassing, its advantage is that it highlights several issues of importance for the optimal utilisation of ecosystems which are easily overlooked in less specific models.

2. Background Information

Expansion and intensification of the use of land (more generally of the biosphere) by human beings is a growing threat to biodiversity conservation. This is because it alters unfavourably the habitats on which many wildlife species depend and it reduces habitat diversity globally. Consequently, the variety of niches and sizes of suitable habitats required for conserving wildlife species declines. Several wildlife species depend for their existence on the presence of forests. Most forest species rely on the forest for the type of food they need and for shelter. The locomotion of some (such as the orangutan) is facilitated by the presence of a tree canopy. However, the ecological relationship between forest-dwelling species and forests varies, and the populations of some are less sensitive to forest disturbance (such as occurs for example as a result of logging) than others. Furthermore, their sensitivity varies with the type of forest disturbance that occurs.

Forests are continuing to disappear as forested land is converted to non-forest uses (such as agriculture) and many natural forests continue to be heavily logged, often as a prelude to the conversion of the land to agriculture. This threatens the conservation of forest species. For example, the survival of the endangered orangutan continues to be threatened by deforestation in Borneo and Sumatra and by the conversion of the forested land to agricultural use, mostly for the cultivation of oil palm (Swarna Nantha and Tisdell, 2009). However, orangutans (and several other forest species) can survive in selectively logged land or on land that is logged but not heavily (Husson *et al.*, 2008). In view of this relationship and the fact that strong political pressure exists in many developing countries to commercially use forested land and not lock it up in protected areas, some conservationists support non-intensive logging as a land use (for example, Payne and Prudente, 2008). Payne and Prudente (2008, p.145) state, for example: "Orangutans can survive and breed happily in natural forests that are well managed for timber production. This has already been proved since the 1990s in the 55,000 hectare Deramakot Forest in Sabah [Malaysia] certified under Forest Stewardship

Council principles and criteria." They go on to point out that this "forest sustains one of the highest recorded populations of densities of orangutans is logged lowland dipterocarp forest" and advocate the adoption of similar procedures for managing the logging of forests sustainably in other areas where orangutans occur. While not the best ecological solution, selective or low-intensity forestry enables some forest species to survive whereas virtually all will perish if forested land is converted to agricultural use.

The environmental requirements for the survival of the orangutan (*Pongo* spp.) are of particular interest because these species require a very large continuous forested area for their survival *in situ*. Therefore, the economic opportunity cost of conserving the orangutan by completely protecting forested areas is high. At the same time, because of their human-like features (see Plous, 1993; Tisdell *et al.*, 2005), there is probably strong support for conserving the orangutan among residents of higher income countries whereas in the developing countries where it is present support for conserving it by fully protecting forest areas is likely to be limited because of the high economic sacrifice involved. Rikjsen and Meijaard (1999) estimated that a minimum viable meta-population of 5,000 adult orangutans is needed for the survival of the species. They believe that this would typically require about 10,000 km^2 of suitable habitat. Orangutans are very sparsely distributed in their habitats and their densities in Borneo range from 0.1 to 3.6 per km^2 (Soehartono *et al.*, 2007, p.8). On the other hand, Singleton *et al.* (2004) state that a single population of at least 500 orangutans is needed for its long-term viability. If the carrying capacity of the conserved habitat is on average one orangutan per km^2, 500 km^2 is required (and if it is two on average 250 km^2) of suitable habitat is needed to reach the target suggested by Singleton *et al.* (2004). This means that the amount of forested area required to conserve this species is considerable and the opportunity cost of protecting it can be high. For example, if all the land involved is suitable for oil palm production, the pre-tax profit from oil palm production forgone is likely on average to be US$528-790 annually per ha (Swarna Nantha and Tisdell, 2009, p.490).

While some of the ecological aspects of selective logging have been explored for particular species, for example, by Lindenmayer and Possingham (1994) for the Leadbeater's Possum, little attention has been given to the economics of selective or low-intensity logging (sometimes also called reduced impact logging) as a strategy for conserving forest species but considerable attention has been given to the relationship between spatial ecology and the optimisation of managed ecosystems (for example, by Hof and Bevers, 1998; 2002). This is not to say that this problem has been entirely neglected by economists. For example, Bowes and Krutilla (1989, pp. 32-34 and pp. 36-37) compare the dominant-use management of forested areas with their multiple-use management and suggest that in many cases, the latter type of management is superior. The general nature and implications of possible trade-offs between timber harvests and wildlife services in multiple use situations are also considered at the forest stand level by Bowes and Krutilla (1989, pp. 71-87). Somewhat later, Vincent and Binkley (1993) argued that efficient multiple-use forestry may require land-use specialisation. Consequently, in contrast to Bowes and Krutilla, they appear to believe dominant use of forest areas is likely to be more efficient than their multiple use. They argue that when a fixed level of management effort can be allocated between identical forest stands, economies in the management of the stands should tend to favour specialisation in their purpose. “Multiple products are produced at the forest level, but management at the stand level tends towards dominant use” (Vincent and Binkley, 1993, p.373). Boscolo and Vincent (2003) develop this theme further. They argue that nonconvexities in timber production, biodiversity provision, and carbon sequestration are important and favour specialisation in land-use. They find that joint production of biodiversity and timber is likely to be less economic than the allocation of the forested area by dominant use. They find, using some data from Malaysia, that dominant use allocation of forested land, “is often likely to be superior to uniform management for the production of biodiversity and timber” (Boscolo and Vincent, 2003, p. 266). Despite this assertion by Boscolo and Vincent, it is important to consider the matter further and examine more specifically the trade-offs involved in mixed land-use compared to partitioned use of land (in this case, a forest). A simple linear model is presented in this article for this purpose. This model enables conditions to be found for which multiple use is optimal and others for which dominant use is optimal.

3. An Introduction to the Modelling Used

The type of logging considered here is logging that is modified to assist the conservation of a focal wildlife species. It can be regarded as a form of reduced impact logging, but it is reduced impact in relation to the conservation of a particular species (or set of species). While this type of selective logging involves a modification of conventional logging, it is unclear whether this type of selective logging would be as financially demanding on loggers as reduced impact logging (RIL) or sustainable forest management (SFM), the economics of which is reviewed by Putz *et al.* (2008) and by Garciá-Fernández, Ruiz-Pérez, and Wunder (2008, p.1468).

This article focuses on determining the minimum opportunity cost of conserving a targeted population (level) of a forest dependent species. This could, for example, be its minimum viable level of population. It considers whether it is more economic to conserve a focal forest species by

1) Setting aside a fully protected area that enables a minimum viable population (or some other target-level of population) of the species to survive and then allow heavy logging of the remainder of the land or

2) Not to set aside a protected area and allow light (selective) logging (multiple use) over sufficient area to maintain a targeted viable population of the focal species.

Option 1 involves specialised partitioned use of the forested area by dominant purposes whereas Option 2 involves mixed (multiple) land use of a portion of the forested area with the remainder (if any) being used for a single purpose, namely heavy logging. Note that, in practice, the level of population of a species constituting a minimum viable population is not certain but usually the probability of its survival increases with the level of its population able to be supported by its environment (Hohl and Tisdell, 1993). Depending on the probability of survival of a focal species wanted by a policy-maker, the target level of the population of the focal species can be adjusted in the model detailed below – if a higher probability of survival is desired, its population threshold is adjusted upwards.

More specifically, a simple model is introduced in this article to determine the economics of choosing between the alternative strategies for utilising a forested area of (1) fully protecting a portion of it of sufficient size to conserve exactly the targeted number, K, of a forest-dependent species and allowing the remainder of the forested area to be used for intensive logging or (2) allowing this protected area plus a part of the non-protected area to be lightly (selectively) logged so as to conserve the targeted number (K) of the focal species with any remainder being available for intensive logging. In the second case, no portion of the forested area is fully protected – all of it is utilised either for light (selective) or heavy logging. Furthermore, the model introduced in this article enables calculations to be made of the opportunity cost (profit forgone) of relying on light or selective logging to conserve a targeted level of population of a desired forest species rather than allowing the heavy logging of an entire forested area which would result in the local extinction of this species.

Two objections might be raised to the model presented here, namely that it concentrates on the conservation a single desired species in a forested are and that it is linear. Consider each of these possible objections in turn.

First, in practice, often a single wildlife species or a small set of such species is the object of conservation in a particular geographical location.[1] Secondly, the model outlined can be extended to include the conservation of a focal set of wildlife species by specifying population targets for each of the species in the set. However, the larger the set, the greater are likely to be the conservation restraints on selective logging. Third, in some cases, the species to be conserved is an umbrella species. This implies that if the focal species is conserved, the habitats preserved by its conservation will also enable some other valued species to survive.

Fourth, the geographical dimensions of biodiversity conservation need to be considered. Boscolo and Vincent (2003) concentrate on the conservation of local biodiversity but the conservation of global biodiversity seems to be more important. If an endangered wildlife species is conserved in a locality at the expense of other common wildlife species not in danger of extinction, this helps to maintain global biodiversity even though local biodiversity is reduced. Consequently, the approach taken here can be consistent with support for global biodiversity conservation.

The fact that the main part of the modelling in this article assumes linear relationships is another possible criticism. However, linear relationships can be regarded as approximations to non-linear ones. They are also useful in that their coefficients can as a rule be readily approximated empirically. Therefore, the application of this modelling is facilitated. Furthermore, linear models can be regarded as an initial step towards developing non-linear ones. Hof and Bevers (1998, Ch. 5) make it quite clear that some important insights into spatial optimisation of the use of ecosystems can be obtained from linear models.

Analysis of above mentioned issues proceeds as follows: First the general relationships are explored between the density of a focal species and the intensity or selectivity of logging in its range as well as the profitability of logging in relation to logging intensity. In this exposition, logging intensity is treated as a continuous variable. The decision-making problem is then simplified by focusing on just two alternative intensities of logging, namely heavy logging and light (selective) logging. Choices based on these options are modelled and it is found that economic value of a dominant land-use policy compared to a mixed land-use policy cannot be determined *a priori*. The specific factors on which this optimal choice depends are identified and consequently, the main problem posed in this article is solved. The concluding discussion identifies some important limitations of the modelling used. For example, it shows that it would be desirable to extend this modelling to take account of dynamics, particularly the ability of a focal wildlife species to recover and recolonize a logged area once it starts to regenerate. It is also noted that the optimal pattern of land-use tends to alter when the number of species to be conserved locally rises, as the range of ecosystem services to be maintained is widened, and as a larger number of social objectives have to be taken into account when determining optimal land uses. These additional considerations make optimal land-use planning very complex. The presentation here partially unravels these complexities and effectively solves some of the choice issues that need to be resolved about optimal ecosystem use. In this exposition the importance of economic opportunity costs is stressed (see also Tisdell and Swarna Nantha, 2011), and aspects of the conservation of orangutans (an extremely forest-dependent species) are frequently used for illustrative purposes.

4. Relationships Between the Intensity (Selectivity) of Logging the Density of a Forest Species and the Profitability of Logging

The density of the population of some wildlife species depends on the intensity (or the selectivity) of logging and so too does the profitability of logging. A problem arises in specifying the relationships involved precisely because the process of logging can be diverse and has multiple attributes or characteristics. For simplicity, however, let us suppose that its intensity (or selectivity) can be represented by a variable x which falls in the range $0 < x < 1$ where zero means that logging is absent and 1 implies that it is at its maximum intensity. An alternative possible interpretation is that zero corresponds to an extremely high degree of selectivity so the survival of the focal species is not adversely affected by its changed habitat whereas one corresponds to a situation in which no selectivity is practiced in removing trees.

Suppose that y represents the density per km^2 of the focal forest dependent species (for example, orangutans). Then the long-term density of this species as a function of the intensity of logging might be like that shown by relationship ABCD in Figure 1. The long-term density of the species declines as logging intensity approaches x_1 and then falls to zero. However, it is conceivable that for some forest species, this density at first rises and then falls because they benefit from some forest disturbance. Also for some species, a precipitous decline at a threshold like that of x_1 in Figure 1 may not occur – the decline may be more gradual. Furthermore, the relationship involved may be non-linear. For instance, the density of the species may decline at an increasing rate as the intensity of logging increases.

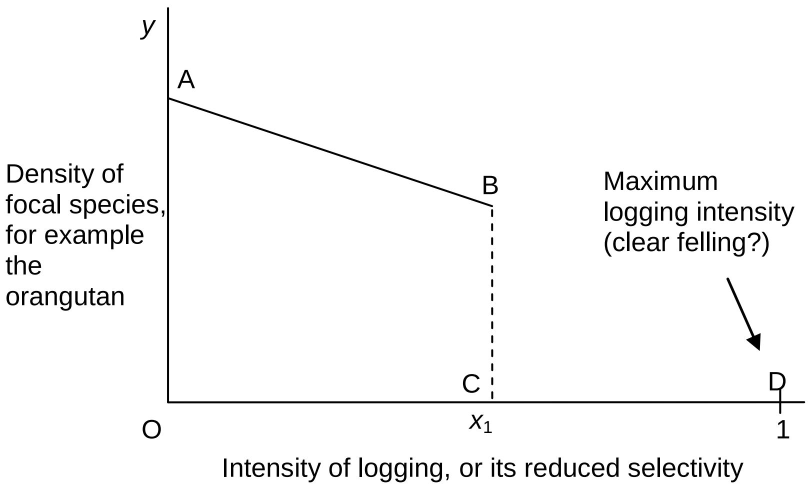

Figure 1 A hypothetical relationship between the density of a focal forest-dependent species and the intensity of logging (or its reduced selectivity) in its abode.

As mentioned above, alternative types of logging can be very diverse in their characteristics. Even light logging can be quite disadvantageous to some species if it targets the harvest of trees on which these species depend. It is implicitly assumed above that at a low intensity of logging, the loss of forest resources on which the focal species depends is low but increases with the intensity of logging. Husson, *et al*. (2008, p.92) found from their analysis that orangutan "densities are lower in moderately to heavily logged forest than in unlogged areas of comparable habitat, in accordance with the majority of studies already published on this subject". In general, they find that logged sites have a lower density of orangutans than unlogged sites (Husson *et al.*, 2008, p.93). Nevertheless, there appears to be little difference between the density of orangutans in unlogged areas and those in 'lightly' logged areas because when light logging occurs in the habitats of the orangutan, it is usually of trees of the Diptercarpaceae family which are not an important food source for primates, including orangutans (Husson *et al.*, 2008, p.83). Husson *et al*. come to the qualified conclusion that "a well-managed, selective-logging operation that only removes those species of trees and does minimal damage to the surrounding forest may not significantly alter the forest structure and food availability from an orangutan's perspective". (Husson *et al.*, 2008, p.83).

A similar situation sometimes occurs in other places and for other species. For example, John Williams, Commissioner, New South Wales Natural Resource Commission, in discussing an earlier version of the material in this article presented at the 9th Biennial Pacific Rim Conference of the Western Economic Association International on April 26, 2011 pointed out that cypress trees (*Callitris* spp.) used for timber production in New South Wales and other parts of Australia are not an important source of food and habitat for most animal species present in such forests but that other plant species interspersed within these cypress forests (such as acacia and grasses) are. Therefore, selective logging of cypress can be compatible with the conservation of several animal species that show little or no dependence on cypress trees.

Husson *et al*. (2008) in studying the relationship between orangutan density and the intensity of logging adopt the following scale of logging intensity: (1) unlogged, (2) lightly logged, (3) moderately logged and (4) heavily logged. To some extent, their scaling of logged areas into the different categories is subjective. For example, Husson, *et al*. (2008, p.95) state: "While it was difficult to empirically compare logging intensity between all the sites included in this study, sites with well-managed selective-logging operations were typically classed as lightly logged, and those subject to uncontrolled illegal logging as heavily logged". They go on to point out that mechanised logging is more destructive of a forest than is hand logging.

The profit per km^2 from logging also depends on the intensity of logging or how selective it is required to be. It is usually higher for conventional (higher intensities of logging) than for low intensity logging. One possible relationship between the profitability of logging and its intensity is shown in Figure 2 by curve ODEFG. In this case, logging at an intensity of less than x_0 is unprofitable. Profit is positive for intensities of logging greater than x_0 and is assumed to rise as the intensity (less selectivity) of logging increases.

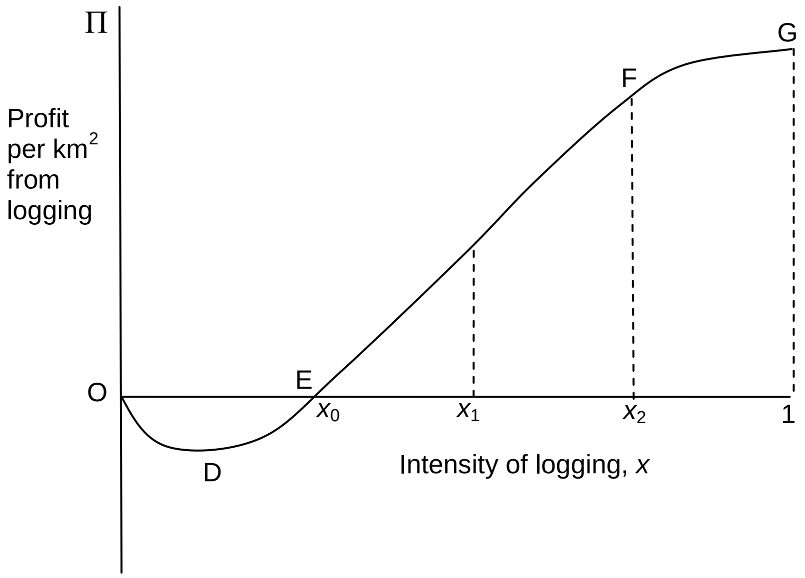

Figure 2 A possible relationship between the profitability per km² from logging and its intensity (or reduced selectivity).

In Figure 1, x_1 is the maximum intensity of logging potentially compatible with the long-term survival of the focal species. However, in reality, this threshold is likely to be uncertain. Therefore, to be on the safe side if the survival of the species is at stake, it may be wise to opt for a lower intensity of logging than this.

Given that a compact forested area of size H km² exists, the envisaged spatial optimisation problem is to organise the management of the forest so that profit from logging is maximised subject to the condition that a focal wildlife species continues to survive at a population level K, where K is the targeted viable population of this species within this forested area. For simplicity, two discrete alternative spatial strategies for the allocation of the forested area (H km²) for logging and for the conservation of the focal species[2] are examined. These are:

(1) Completely protect a portion of the total available forested area so as to conserve just K of the focal species and allow the remaining portion to be used for high intensity logging.[3]

(2) Do not completely protect any part of the total forested area but allow light logging in a portion of it sufficient to conserve a population K of the focal species and permit heavy logging in the remainder. The level of light logging and heavy logging are assumed to be pre-specified.

Note that it is assumed that heavy logging is sufficiently heavy to extinguish the focal species. Further, it is supposed that light logging (which might also be designated moderate logging) reduces the density of the focal species compared to no logging. Given the two alternative strategies listed above, which is the most profitable alternative?

5. The Solution to this Choice Problem

In order to clearly visualise the problem, consider Figure 3. The total available forested area for allocation (H km^2) is equal to the area of the rectangle marked A plus that marked B and is shown in the top portion of Figure 3. The area is assumed (on average) to be uniform in the quality of its forest and in the density of the focal species it can carry.[4] Option 1 is illustrated by the top large rectangle and Option 2 by the lower one. In case 1, the area of the rectangle identified by A is fully protected so as to conserve K of the focal species and the remainder is used for heavy logging (or it could be used for plantations or other forms of agriculture). In case 2, the protected area is made available for light logging and an area indicated by the rectangle identified by C is withdrawn from heavy logging and used for light logging so as to ensure that the area lightly logged conserves K of the focal species.[5] The rectangular shapes of the forested land area and its uses are assumed for ease of exposition. The solution can be generalised to accord with other land patterns.

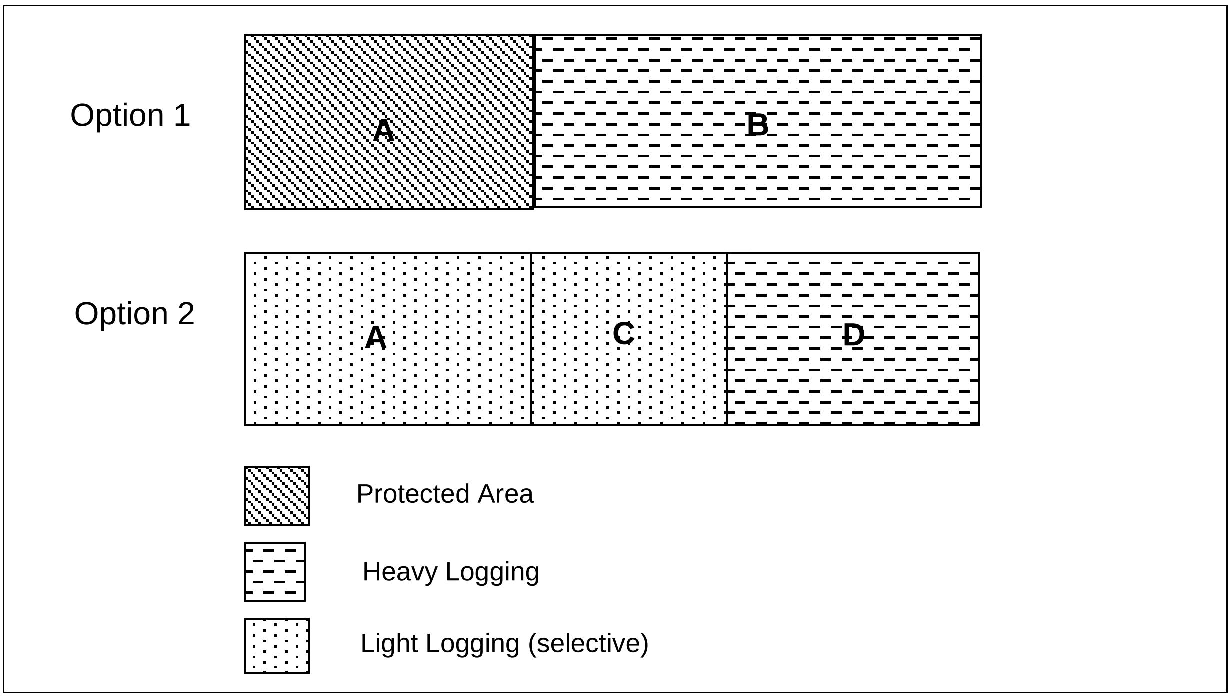

Figure 3 An illustration of the alternatives of (1) a combination of a protected area plus a heavily logged area and (2) a lightly logged (selective) area plus a heavily logged area (no protected area) as ways of conserving a targeted level of the population of a forest-dependent focal species.

The change in total profit from logging when Option 2 rather than Option 1 is adopted equals the increase in profit from being able to log area A less the reduction in profit from area C as a result of altering its use from heavy to light logging. If the former amount exceeds the latter amount, profit from logging rises as a result of the changed strategy for conserving the focal wildlife species. On the other hand, if the latter amount exceeds the former amount, profit from logging falls as a result of the change in strategy.

In order to analyse the matter further, consider a mathematical analysis of the issue. Let K represent the target population of the focal wildlife species, and let λ be its density per km^2 on protected land and $\theta\lambda$ be that on lightly logged land where $0 < \theta < 1$. The species is assumed to disappear in the long-term on heavily logged land. In this case, if Option 1 is adopted, the required size of protected area A in Figure 3 is K/λ km^2. If Option 2 is adopted and light logging occurs, the area needed to conserve K of the species (marked A plus C) is $K/\theta\lambda$ km^2. [It is assumed here that this $K/\theta\lambda$ km^2, is not greater than H km^2. If it is, light logging is not an option compatible with the survival of the targeted level, K, of the focal species.] Therefore, the area marked C equals (K/θλ – K/λ) km^2.

Suppose that the profit from heavy logging is Π per km^2 and that from light logging it is εΠ where $0 < \varepsilon < 1$. The total change in returns from logging when Option 2 is adopted rather than Option 1 can be expressed as:

$$\Delta R = \frac{K}{\lambda}\varepsilon\Pi - \left(\frac{K}{\theta\lambda} - \frac{K}{\lambda}\right)(\Pi - \varepsilon\Pi) \tag{1}$$

$$= \frac{K}{\lambda}\varepsilon\Pi - \left(\frac{K}{\theta\lambda} - \frac{K}{\lambda}\right)(1-\varepsilon)\Pi \tag{2}$$

The first term on the right hand side of this equation is the increased profit from being able to lightly log the previously protected area and the second term is the reduction in profit from having to forgo heavy logging in an area corresponding to area C in Figure 3.

Other things being held constant, it is observed that the likelihood that ΔR is negative (that is that light logging is less financially rewarding than the alternative) increases as ε becomes smaller, that is the greater is the reduction in profit per km^2 from light logging compared to that from heavy logging. Secondly, other things held constant, the smaller is θ (that is, the larger the reduction in the density of the focal species when light logging occurs compared to no logging) the more likely is the light logging strategy to give lower returns from logging than Option 1. This is because the co-efficient $\left(\frac{K}{\theta\lambda} - \frac{K}{\lambda}\right)$ in Equation (2) increases as θ becomes smaller.

6. The Sensitivity of the Optimal Choice of Land-use to Changed Parameters

The above analysis identifies conditions under which it is economically optimal to follow a fully protected land policy for a portion of forested land compared to a light logging type of policy to ensure the survival of a focal forest-dependent wildlife species. Only a few parameters need to be estimated to make an optimal economic choice. This is a practical advantage. Note that (given the wildlife conservation constraint) it cannot be decided *a priori* whether a protected area policy combined with heavy logging or a light logging type of policy is the most profitable land-use policy from the point of view of loggers. This can be illustrated by the following simple examples. If both θ and ε equal 0.5, Expression (2) reduces to zero. In this case, light logging results in both a halving of the density of the focal species per km^2 and a halving of profit per km^2 compared to heavy logging. In Figure 3, it implies that the area marked by C equals the area identified by A.

Now consider the example in which, $\varepsilon > 0.5$, (that is the profit per km^2 from light logging in less than half that from heavy logging,) and $\theta = 0.5$ (the density of the focal species is halved compared to that in the absence of logging). The light logging option raises returns from logging compared to Option 1 in this case, other things being unchanged. If $\varepsilon < 0.5$ and $\theta = 0.5$, then the opposite result follows.

Consider now variations in θ (the density of the focal species) when ε (the light logging profitability coefficient) is set at 0.5. If the $\theta > 0.5$, the density of the focal species falls by less than a half when light logging occurs compared to no logging, and the returns from Option 2 exceed those from Option 1. On the other hand, if $\theta < 0.5$, the returns from Option 2 are less than those for Option 1.

In general, the lower is the reduction in the density of a focal species under conditions of light logging compared to its density when no logging occurs, and the smaller is the reduction in profit from logging per km^2 when light rather than heavy logging is practiced, the greater is the likelihood that the light logging option (Option 2) gives greater total returns from forestry than the protected area option (Option 1). This is on the assumption that a given targeted level of the focal species is to be conserved. The opposite relationship also holds.

The model presented here is relevant in the context of conserving a single species, such as the orangutan, at minimum economic cost in terms of profit forgone. Therefore, it concentrates on maintaining a single ecosystem service. If a wider range of ecosystem services are desired, this may strengthen the case for setting aside fully protected areas. On the other hand, there might also be circumstances in which it is socially defensible to support the light logging option even when it is not the least cost one in terms of profit forgone. The light logging option may, for example, ensure greater employment spread over a wider geographical area than setting aside a fully protected area and allowing intensive land use outside of it. This may also be politically more acceptable in some jurisdictions.

Several different allocations of the spatial use of the forest can be considered for conserving the focal wildlife species if there is a political preference for not setting aside a fully protected area of the forest for conservation purposes. In this case, the political intention is to subject the whole of the forest to logging. For example, just a sufficient area of the forest might be selectively logged at a low intensity so that the target level of the population of the focal species is achieved. The remainder of the forest is then heavily logged. Or the whole area of the forest could be selectively logged at an intensity which ensures that the target level of the species is met. Assuming that dominant-use partitioning of the forest area maximises profits from logging, the profits foregone by these multiple-use strategies can be computed. Other things being held constant, this loss will be greater:

- The larger is the targeted level of the population of the wildlife species;
- The lower is the profitability (per unit area) of selective logging compared to heavy logging; and
- The lower is the density of the species to be conserved in a selectively logged forested area compared to a fully protected forested area.

7. Further Discussion and Conclusions

The modelling in the previous section involves static spatial relationships and corresponds to that discussed by Hof and Bevers (1998) in Part I of *Spatial Optimization for Managerial Ecosystems*. While such models do have some applications to the optimal provision of ecological services, they do not always capture all relevant relationships. For instance, Hof and Bevers (2002, Ch. 5) point out that for species dependent for their survival on the conservation of old growth forests, such as the Northern Spotted Owl, static models are useful for making spatial optimisation decisions. However, dynamic changes in habitat availability can be important in considering the conservation of many wildlife species. Static models represent special cases and therefore, the above analysis should be extended to increase their generality. However, such extensions add significantly to the complexity of this type of modelling, as is evident from the work of Hof and Bevers (1998; 2002).

For instance, the simplified relationship (illustrated in Figure 1) showing the density of a forest species as a function of the intensity of logging should be extended to take account of the passage of time and to allow for additional spatial dimensions of environmental change.

For example, the relationship ABCD shown in Figure 1 (replicated by relationship ABCD in Figure 4) might apply to the density of orangutans soon after an area has been logged. However, after a longer period of time, the forest will start to regenerate and a relationship like that shown in Figure 4 by AECD might apply if the population of the focal species in the area is not subject to migration. If immigration of members of the focal forest species, e.g. orangutans, from other areas is possible, then after enough time elapses, a relationship such as that shown by AEFG in Figure 4 might apply on previously logged land. The detailed cross sectional study of Husson *et al*. (2008) of the impacts of forestry on the density of orangutans might have been usefully extended by taking such factors into account. Failure to do this, limits the conclusion that can be safely drawn from their cross sectional statistical analysis of the relationship between the intensity of logging and the density of orangutans.

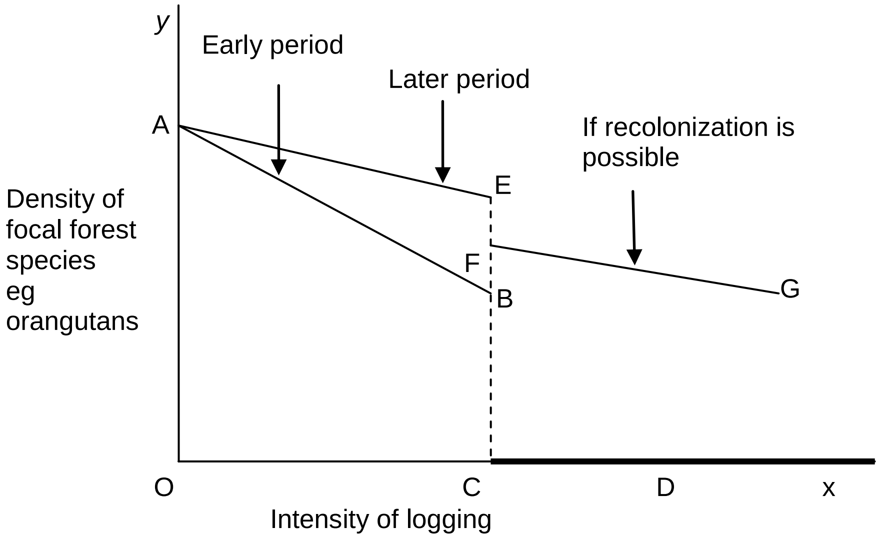

Figure 4 Diagram used to highlight the fact that the density of a forest species following logging depends on the passage of time and the scope for a species to recolonize a logged area.

Ideally spatial and dynamic factors should be incorporated in the above analysis. For example, the conservation of selected small fully protected reserves (refuges) in logged landscapes can be valuable in facilitating recolonization of a logged area once it begins to regenerate. While these refuges may not (on their own) support minimum viable populations of focal forest species in the long-term, they may support the populations for sufficient time to enable recolonization of nearby logged areas to occur. Consequently, they can increase the chances of survival of the species locally. The provision of such refuges can be regarded as another form of selective logging and is also amenable to economic analysis. The appropriate selective spatial conservation patterns will, however, vary with the ecology of the forest species to be conserved. Therefore, extension of the analysis is probably best done by specifying the requirements for the conservation of specific forest species or groups of these in logging environments rather than by listing the myriad of general abstract possibilities.

Available evidence indicates that light-to-moderate logging which is selective does not endanger the orangutan. However, logging which is intense, rapid and present over a large area is a serious threat to its survival as is the geographical spread of agriculture (Tisdell and Swarna Nantha, 2008; 2009). The spread of agriculture in Indonesia is often associated with the occurrence of forest fires which also negatively impact on orangutan populations which are slow to reproduce. Climate change does not appear to be a major threat to this species, although as a result of sea level rise, the land mass available for its population would be reduced. Measures to subsidise forests to sequestrate carbon will only be of advantage to this species if the areas involved include the species of trees on which the orangutan depends on for food. This species will not benefit from subsidies to forest plantations because this will probably lack the food trees and tree canopies required by this species. Since biodiversity is socially valuable, measures to reduce global warming (for example, to encourage the continuous provision of forests) should also take account of their consequences for biodiversity conservation. Policies to reduce greenhouse gases should serve multiple objectives.

There are also forest species other than the orangutan for which selective logging is compatible with their conservation. As the number of different forest species to be conserved at a minimum viable population (or a higher target level) increases when selective logging is practiced, the economic returns from selective logging are likely to decrease. This is because as the number of forest species to be conserved increases the number of the habitats that need to be conserved usually widens. Consequently, loggers will be required to be ever more selective in logging and to take increasing care of the environment. For example, more restrictions may be placed on the type of trees which are to be harvested and on landscape patterns to be preserved. This can be expected to reduce the profitability of selective logging.

A stage is therefore, likely to be reached where selective logging is no longer a viable economic option for conserving the set of focal species and dominant use at the landscape level is likely to be a more economic solution than selective logging.

Note that the modelling used here does not provide a complete total social cost-benefit analysis of the economics of the use of forest ecosystems. Most forests have uses other than for logging and wildlife conservation and the economic value of these can be expected to vary with the intensity and selectivity of logging. For example, forests provide ecoservices (such as hydrological services, carbon sequestration), may cater for ecotourism, in some cases have visual value (see, for example, Haight *et al.*, 1992) and can provide subsistence products to local villagers in developing countries. While intense logging is likely to reduce the economic value of these services substantially, this need not be the case if light selective logging is practiced. When multiple-use values are many, optimising forest use, even at the landscape level, can be quite complicated as the study by Haight *et al*. (1992) shows.

Overhead costs (not considered in my simple model) can also be important as pointed out by Boscolo and Vincent (2003) and Vincent and Binkley (1993). They suggest that overhead costs are likely to favour the allocation of forested land by dominant (specialised) use rather than multiple use at the landscape level. For example, the cost of building access roads to extract timber are likely to be higher where light logging is practiced, and administration costs may also increase. On the other hand, employment intensities in logging are likely to be higher than in fully protected areas and light logging would spread employment over a wider geographical area than heavy logging than would occur if the dominant-use allocation of forests is adopted. This may be politically important in the case of the orangutan which can require 250-500 km^2 of suitable fully protected forest habitat to survive (Singleton *et al.*, 2004).

The agency costs of enforcing environmental regulations should also be considered in deciding whether the conservation of forest wildlife species should be combined with logging or whether these ought to be spatially separated. The agency costs of monitoring and enforcing environmental regulations are likely to be higher when forests are jointly used for multiple purposes than when the forested area is partitioned and each portion is only used for a single purpose. Furthermore, when the available funds for the supervision of forest-use and the enforcement of relevant environmental regulations are limited, the prevalence of illegal logging is likely to increase if the use of the forest is not partitioned.

An additional factor which may have to be taken into account when forestry is combined with wildlife conservation is its effect on the resilience and robustness of habitats required to conserve a focal species. If these disturbed habitats are less resilient and less robust than in undisturbed forests, this can be relevant to deciding whether multiple or single purpose use of portions of the forest is desirable. For example, it has been argued that populations of many wildlife species show less persistence in fragmented habitats (Hof and Bevers, 1998, p.3). Where multiple-use is practised a margin of safety may have to be built into the logging regime as a precaution to address this problem. This would place extra constraints on selective logging, add to its costs, and reduce the returns from logging.

It might also be noted that the basic model introduced in this article can be adapted so that it applies to other environmental problems of a similar nature. For example, suppose there is a forested watershed and that it is decided that the quality of water flowing from this area should be of a particular standard. This quality is assumed to depend on the nature of the tree cover in the watershed. Different combinations of heavy and selective logging on the forested land may result in the water quality standard being satisfied. The problem then is to determine the spatial combination of logging (selective and otherwise) which supplies the environmental service required (a specified level of water quality) and which also maximises the return from logging. [A more detailed analysis of this type of problem is available in Hof and Bevers (2002, Chs. 2 and 3)]. The solution cannot be determined *a priori*. In particular, multi-purpose (multifunctional) use of all the forested land may not be the most economical way to achieve the valued environmental service. This is also likely to be so for other types of land-use, for example, the use of land for agriculture (see, for example, Tisdell, 2009).

8. Concluding Comments

The United Nations Earth Summit held in Rio de Janeiro in 1992 stated in Chapter XI of Agenda 21 "the need for sustaining the multiple roles and functions of forests, and for enhancing their protection, sustainable management and conservation. This need was further reaffirmed in 2000 in the United Nations Millennium Declaration (Chapter IV) and at the second Earth Summit held in Johannesburg in 2002 …." (Sist *et al.*, 2008, p.vii). While the development of methods for reduced impact logging (RIL) pays some attention to these objectives, this development pays little or no attention to the conservation of species. Sist *et al*. (2008, p.vii) observe: “Most RIL operations are still based, as all other selective logging systems operating in the tropics, on a very simple rule: the minimum diameter cutting, which is applied to all other commercial species. These cutting limits are set to accommodate processing technologies and market demands, rather than the biology and conservation of the harvested species (Sist *et al.*, 2003).” In addition, RIL methods fail to take account of the conservation of non-harvested species, such as forest wildlife species; some of which may nevertheless indirectly benefit from RIL. Therefore, an even more holistic approach to managing tropical forest than that envisaged by Sist *et al.* (2008) is called for.

Clearly, the desirability of selective logging or RIL can be assessed from different points of view. One point of view of particular interest to foresters is the ability of RIL to maximise the (discounted) economic yield from forests when only a forest’s value for commercial logging is considered. This ignores the value of other commodities produced by forest ecosystems, including their provision of many environmental services. Nevertheless, as the case outlined in this article shows, the above mentioned objective of RIL can be appropriate goal on forested land allocated exclusively for logging, if the use of the forested land has been optimally partitioned in a manner which maximises the overall net value of the forest ecosystem in satisfying environmental constraints and in producing logs.

This analysis can also be applied to considering the optimal utilisation of other ecosystems. It is, however, pertinent to note that it has been simplified by the use of environmental standards. This approach to valuing environmental services is sometimes justified on the grounds that bounded nationality is important.

A couple of quite general conclusions flow from this analysis. First, economic optimisation is unlikely to require the supply of *all* ecosystem services in *all* places where they are capable of being supplied. In fact, this is likely to be inconsistent with maximising the total economic value obtained from an ecosystem as a whole. [6] It may be optimal to sue different portions of the ecosystem to supply different *sets* of services. In some portions of an ecosystem, it may be optimal to supply sets of ecosystem services jointly but in other portions it can be best to focus on supplying a single service. In some cases, it can even be optimal from an economic point of view to suitably partition an ecosystem to ensure that each of its portions optimally supplies a single ecosystem service. In this case, different single ecosystem services are provided by different portions of the ecosystem. Secondly, there is an interdependence issue. This is because the economic value of ecosystem services supplied in any portion of an ecosystem depends upon the quantity supplied of these services by other portions of the ecosystem as well as on the demand for these services. It is essential that such factors be taken into account when valuing the supply of ecosystem services from an economic point of view. In most cases, the economic value of the services provided by any part of an ecosystem cannot be assessed without taking into account the value of the services supplied by other parts of this ecosystem.

Therefore, determining the optimal spatial use of forest ecosystems (and other ecosystems) in order to optimise the economic value of the supply of ecological services can be very challenging. It requires the use of both scientific and economic knowledge and can be further complicated by uncertainty about the relevant scientific and economic relationships in particular applied situations. Because of our bounded rationality, we may consequently only be able to make modest progress in determining the spatial use of ecosystems which maximises the economic value (benefits) flowing from their environmental and other services.

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Notes

1. In this type of analysis, it is not unusual to concentrate on spatial management of the use of forests to conserve particular wildlife species. For example, Hof and Bevers (2002) do this in considering the conservation of the Northern Spotted Owl and the Western Prairie Fringed Orchid.

2. Although the consequences of only two alternative forestry regimes are examined here, a larger number of alternatives can be considered by means of iteration and search procedures using computation.

3. The model outlined here assumes that a particular level of the population of a focal wildlife species should be conserved or more generally, that a desired environmental service provided by an ecosystem should be of a specified value. However, this requirement (a standard) in many cases may also be expressed as an inequality. For example, there may be an overarching requirement that the population of a selected wildlife species should equal or exceed a particular level. Or in relation to an example introduced later in this article, the quality of run-off water from a catchment should equal or exceed a specified standard. In the situations considered here these inequalities become binding. This is because it is supposed that as logging becomes less selective, the economic returns from logging increase but the supply of the focal environmental service is reduced. Therefore, the assumption that a given environmental standard should be achieved is not restrictive in this context.

4. This assumption can be consistent with some heterogeneity within subdivisions (cells) of the forest.

5. The possibility set for land use shown in Figure 3 assumes that the whole of the forested area does not have to be fully protected to conserve the focal wildlife species. For example, if λ is the average diversity per km^2 of the focal wildlife species within a completely protected forested area, it is assumed that $K/\lambda < H$. If K/λ equals H, there is no scope for logging in this model. Where $\theta\lambda$ is the density of the focal wildlife species on selectively logged land and $0 < \theta < 1$, it is also supposed that $K/\theta\lambda \leq H$. If this expression exceeds H, there is no scope for conserving the focal species at its targeted level of

population by engaging jointly in selective logging. In the case, where this expression equals H, set D in Figure 3 is empty, because all the forested area must be used to serve multiple purposes, if the focal wildlife species is to attain its targeted level of population. In any particular case, these boundary possibilities should be checked.

6. The presence of infra-marginal externalities contributes to such results. (See for example, Tisdell, 1970; 2005, Ch. 5; Tisdell, 2009; Walsh and Tisdell, 1973). Note that if the supply of a favourable environmental service is infra-marginal, there is *no case* from a Paretian efficiency point of view to pay for this benefit. Payment for an environmental service is misplaced, in this case. Furthermore, in this case, the *marginal value* of the supply of such an environmental service beyond some threshold value *is zero*.

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