Incorporating biological regeneration into economic assessments of mining in forest regions

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Government agencies in Australia are often asked to assess the economic, environmental and social consequences of either allowing mining to proceed within an area or disallowing it in favour of environmental conservation. These assessments have usually produced an estimate of the economic benefits that mining in the area would generate, with possible environmental costs being examined in physical terms only. As a result, decision makers will inevitably view the present value of economic benefits from mining in a 'threshold' fashion — that is, it represents the minimum size of the environmental cost of mining required to make conservation the socially optimal choice.

In this paper a theoretical framework for calculating the threshold environmental value of a defined area is developed, where both the potential mining benefits and the rate of biological regrowth following mine rehabilitation are known. Including the rate of biological regrowth allows for the calculation of a more meaningful figure, as the benefits generated by rehabilitation are explicitly considered.

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Introduction

As community concern about environmental issues grows, there is an increasing demand for benefit–cost analysis of proposed mining operations to include environmental impacts. In most studies of this type (see for example ABARE, AGSO and BRS 1993 and RAC 1991) the net economic benefits of mining are quantified, as the costs of mining and the prices received for future mine outputs can be estimated. On the other hand, environmental costs are often difficult to quantify, and are usually examined in physical terms only. When non-market values of the area in question are estimated (often through contingent valuation), such values are often assumed to be completely forgone in the event of mining — that is, regeneration of environmental damages is not considered.

When the net economic benefits of a proposed development can be estimated, but the non-market costs cannot, a 'threshold' approach is often developed, or implicitly adopted[1]. In these situations the measured economic benefits of mining often have the interpretation:

> 'unless the environmental costs (discussed qualitatively) are greater than the benefits from mining (estimated quantitatively), then mining should proceed.'

This approach is often the only option available, because of the difficulties associated with valuing both the current level of environmental benefits and the physical damages that may result from mining. For certain types of mining activities, however (such as bauxite mining, which covers wide areas and has minor offsite effects), the physical relationship between mining and environmental damages and subsequent regeneration is often measurable.

In this paper a model is developed to incorporate data on the biological regeneration of forest ecosystems following minesite rehabilitation (along with the estimated net economic benefits of mining) into the calculation of a threshold amenity value. Including the benefits from biological regeneration produces a more meaningful threshold amenity value, which, unlike the mining benefits alone, may justifiably be compared with estimates of the non-mining value of the area in its initial condition.

1 The threshold approach has been extended in a number of case studies to incorporate growing demand for environmental amenities (and hence growth in environmental values) over time (see for example Krutilla and Cicchetti 1972). The approach adopted here differs in that growth in environmental amenity values is tied to the biological regeneration of the forest ecosystem.

The model

If the area is mined, it is assumed that benefits from mining (which are measurable and known) and benefits from the environment after mining and rehabilitation (which are unknown) will accrue. If mining does not occur, it is assumed that only amenity benefits from the environment will accrue, which are unknown. Amenity benefits are taken to mean all of the non-mining values which are derived from the area.

The threshold value is defined as the amenity value of the forest ecosystem in its initial (premining) state that is required for the net benefits from mining and rehabilitation to equal the net benefits from conservation. This value will be at least equal to the mining benefits which represent the threshold value in the limiting case of no rehabilitation benefits.

The condition required to solve the threshold value can be expressed as:

1. $$M - X + \int_0^\infty a_t e^{-rt} dt = \int_0^\infty a_p e^{-rt} dt = A^T$$

where

M = net economic benefits from mining (in period 0);

X = total rehabilitation costs following mining (in period 0);

a_t = flow of amenity values at time t;

a_p = the flow of amenity benefits from the forest in its pristine (or initial) state (assumed to be constant over time);

r = discount rate;

A^T = threshold present value of amenity benefits.

Note that for simplicity, the net mining benefits and rehabilitation costs are assumed to occur instantaneously in period 0.

Assume that the floral and faunal species affected by mining are re-established in a standard logistic fashion following rehabilitation and that this function adequately describes the environmental characteristics that provide amenity benefits.[2]

2 Whilst almost any data for populations that increase to an asymptotic level will fit the logistic model to some degree, a better fit can be obtained in most cases with alternative models (Clark 1976).

2.
$$I_t = \frac{\beta I_p}{1+ce^{-gt}}$$
$$\frac{dI_t}{dt} = gI_t(1 - \frac{I_t}{\beta I_p});$$

where
$$c = \frac{(I_p - I_0)}{I_0}$$

I_p = maximum environmental index of forest in its 'pristine' (initial) state;
I_0 = minimum environmental index of forest (immediately after mining);
I_t = environmental index at time t;
g = instantaneous rate of growth when I_t is close to zero;
β = the 'success' of rehabilitation, where $0 < \beta < 1$. For example, $\beta = 0.8$ implies the index converges towards 80 per cent of the initial index number at an exponential rate as t approaches infinity.

Assume that the amenity values from the forest can be translated into dollar equivalents, and that there exists a continuous and well defined cardinal money utility function which relates dollar benefits to the level of the environmental index. It is not necessary to specify a specific cardinal utility function, however, a functional form for the utility function will be imposed.

3.
$$a_t = \lambda I_t^{\alpha}$$

where $0 < \alpha < 1$; and λ is any positive number

In equation (3) a value for α will be assumed (which will affect the rate at which utility diminishes); however, a value for λ will not be specified. Note that $\alpha < 1$ implies decreasing marginal utility, while $\alpha = 1$ implies constant marginal utility.

Substituting (3) and (2) into (1) gives:

$$M - X + \lambda \int_0^{\infty} \left(\frac{\beta I_p}{1+ce^{-gt}} \right)^{\alpha} e^{-rt} dt - \lambda \int_0^{\infty} I_p^{\alpha} e^{-rt} dt = 0$$

4.
$$M - X + \lambda \left[\left\{ \int_0^{\infty} \left(\frac{\beta I_p}{1+ce^{-gt}} \right)^{\alpha} e^{-rt} dt \right\} - \frac{I_p^{\alpha}}{r} \right] = 0$$

5. $$\text{define} \int_0^\infty \frac{e^{-rt}}{\left(1+ce^{-gt}\right)^\alpha} dt \equiv Y$$

Substituting (5) into (4):

6. $$\lambda = \frac{X-M}{I_p^{\alpha}(\beta^{\alpha}Y - \frac{1}{r})}$$

Notice that equation (6) can be solved and that it is possible to solve for a_p and a_r.

Substituting (2) into (3):

7. $$a_t = \lambda\left(\frac{\beta I_p}{1+ce^{-gt}}\right)^\alpha$$

Rearranging (6) and substituting into (3) in the case where $a_t = a_p$:

8 $$a_p = \frac{M-X}{\frac{1}{r} - \beta^\alpha Y}$$

Equation (8) is the threshold value expressed as a per unit time flow (in period 0 terms). Note that a_p is not changed if the environmental index is rescaled by any multiplicative constant. In this case, therefore, a_p is only affected by the relative difference between I_p and I_a, and not the choice of units.

In many cases it will be more appropriate to present the threshold value as the present value of all future amenity benefits resulting from conservation, that is:

9. $$\int_0^\infty a_p e^{-rt} dt = \frac{a_p}{r} = A^T$$

Case study: bauxite mining in jarrah forests

To provide a simplified example of how this approach may be used, the following case study utilises some actual and approximated data and relationships to calculate the threshold amenity value of a hypothetical deposit that is overlain by jarrah forest. In box 1 the nature and history of bauxite mining and rehabilitation in Western Australia's jarrah forests is provided.

Economic assumptions

For the actual application of this method, it would be necessary to estimate the economic value of the option to mine bauxite within the case study area. Unlike many types of mineral deposits, there are usually good resource estimates available for bauxite because of its surficial nature (see box 1), so that estimating this value would be feasible. In this case study, however, a threshold multiplier, s, has been constructed which illustrates the factor by which the net economic benefits $(M - X)$ must be multiplied by to obtain the threshold value.

That is,

10. $$a_p = (M - X)s$$

Where s is defined as the threshold multiplier.

Box 1: Bauxite mining

Bauxite mining involves the removal of an entire lateritic soil profile which is rich in iron and aluminium oxides. Most of Alcoa Australia Limited's bauxite reserves lie within a 4200 square kilometre area of state forest to the south east of Perth. With current production of around 20 million tonnes a year of bauxite, between 450 and 500 hectares of Jarrah forest is cleared in a year. Since 1966 Alcoa has rehabilitated 7120 hectares of the 9300 hectares which has been cleared since 1962 (Elliot, Gardner, Allen and Butcher 1996).

Prior to mining, overlying vegetation is cleared and sometimes used for timber. The topsoil is then stripped and stockpiled or immediately transferred to another site for later use. Following mining, the underlying clay is deeply ripped and the topsoil replaced. If the topsoil is replaced quickly it still contains living soil fungi, bacteria and microfauna (Hore-Lacy 1992). In Western Australia, initially exotic pine species and eucalyptus species native to the eastern states were planted. However since 1988 species which are indigenous to the areas being mined have been seeded, with the objective of restoring a self-sustaining jarrah forest ecosystem (Elliot, et al. 1996).

Ward and Koch (1996) recently examined the biomass and nutrient distributions in 15.5 year old forest growing on a rehabilitated bauxite minesite. The 9.85 hectare site had been seeded and planted with a mixture of eastern state Acacia understorey and Eucalyptus overstorey species, and fertilised with 150 kilograms per hectare mono-ammonium phosphate. Ward and Koch found that within 15.5 years the total biomass on the site had increased to 23 per cent of that in a nearby jarrah forest containing 60 year old pole-stand jarrah, compared to a biomass of around 10 per cent after 3.5 years (Ward and Koch 1996, pp. 312–13). (It should be noted, however, that forest cleared for bauxite mining is often regrowth forest.)

Substituing (8) into (10):

11. $$s = \frac{1}{\frac{1}{r} - \beta^{\alpha} Y(t)}$$

In this example it is assumed that the social discount rate is 6 per cent, and that as the ecosystem regenerates the rate at which social benefits increase is constant. That is, the social value function for the amenity benefits produced from the area displays constant marginal utility, so that α (equation 3) is set equal to one.

Biological assumptions

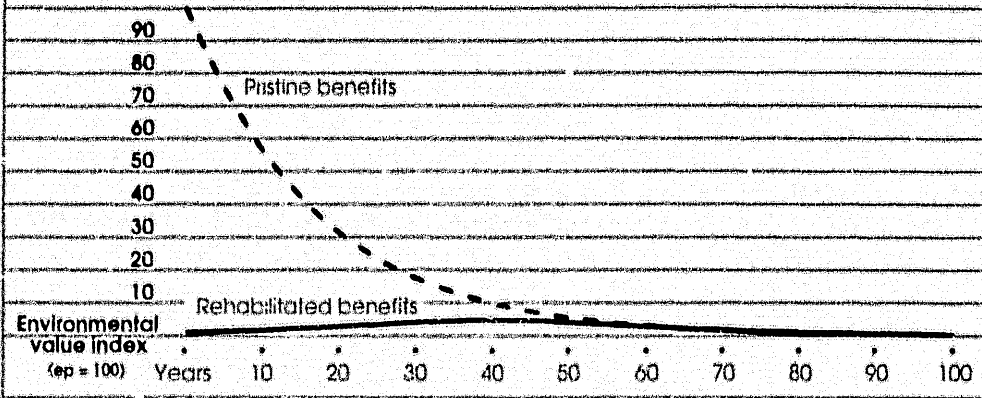
For simplicity, it is assumed that growth in environmental quality (on which non-market values are based) can be represented by an index of above ground cellulose biomass, using a logistic function as shown in equation 2. The growth function index is scaled such that $I_p = 100$ and $I_0 = 1$.

As mentioned in box 1, Ward and Koch (1996) recently measured the growth in above ground cellulose biomass on a rehabilitated minesite and compared this to the biomass in a nearby 60 year old pole-stand of jarrah. The Ward and Koch result of 23 per cent biomass regrowth within 15.5 years would be consistent with a growth rate of 0.22 for equation 2. However, because the Ward and Koch data were based on eastern state species (which grow somewhat faster than jarrah) and compared with only a 60 year old stand of trees, a growth rate of 0.12 is used in this example (implying 23 per cent regeneration after around 29 years and 80 per cent regeneration after around 50 years). In addition it is assumed that rehabilitation is completely successful, so that β is set equal to 1.

Results and sensitivities

Using the above base case assumptions, it was found that the threshold multiplier was 1.17. Hence, the effect of including biological regeneration is to raise the threshold amenity value of the forest area by 17 per cent of the estimated net mining benefits. In figure 1 the present value of each of the annual amenity benefits (as an index with e_p = 100) from rehabilitation and preservation are shown from t_0 to t_{100}. Equation (8) is essentially setting the area in this diagram between the two curves equal to the net benefits of mining. It can be seen from this diagram that given a discount rate of 6 per cent, the initial regrowth is the most important, and that which occurs past 60 years does not affect the results significantly.

1 Present value of annual rehabilitated and pristine benefits in the threshold case

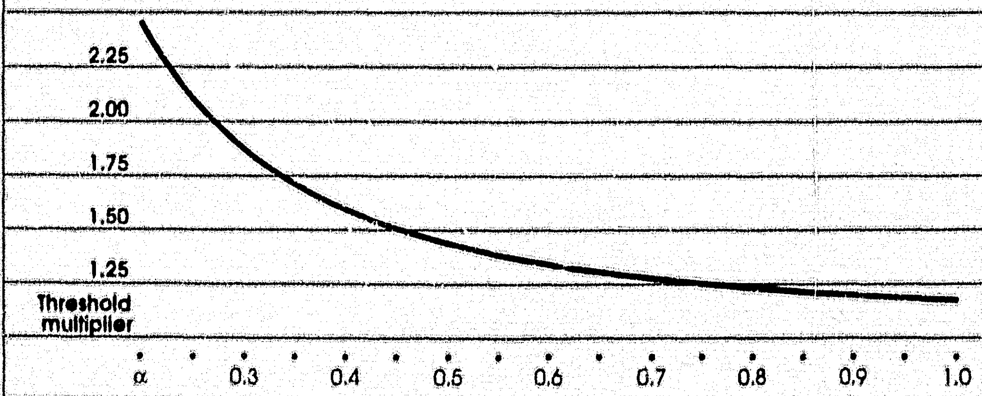


The following sensitivity analyses were run using the base case assumptions of the case study, whilst varying the key variables over a relevant range.

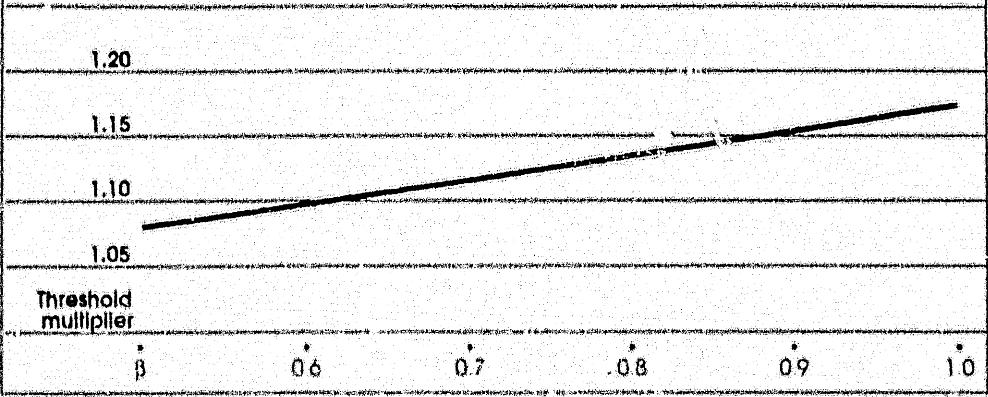
Sensitivity to α

Under the current assumption about the functional form of the utility function (given by equation 3), the threshold multiplier becomes less sensitive to α as α increases (figure 2). Setting α to 1, as was done in the case study, is the most conservative choice available under the current assumptions about the functional form of the utility function, as this produces the lowest threshold multiplier. The intuition behind this result is that diminishing marginal utility implies that initial increases in utility from unit increases in biomass are worth more than biomass growth in subsequent years. This effect is compounded by the positive discount rate.

2 Sensitivity to α



3 **Sensitivity to β**



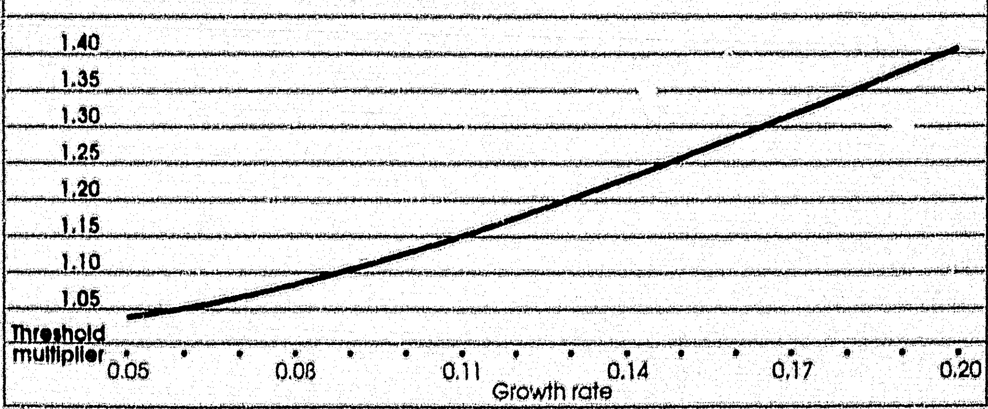
Sensitivity to the success of rehabilitation

The threshold multiplier increases with β from a value of 1 when $\beta = 0$ (no rehabilitation) to 1.17 when $\beta = 1$ (completely successful rehabilitation). As can be seen from figure 3, the threshold multiplier is relatively insensitive to changes in β for a large range of possible values of β (the threshold multiplier lies between 1.08 and 1.17 for values of β ranging from 0.5 to 1). However, as can be seen from equation (8), the sensitivity of the threshold to β would increase if α is set to a value less than 1.

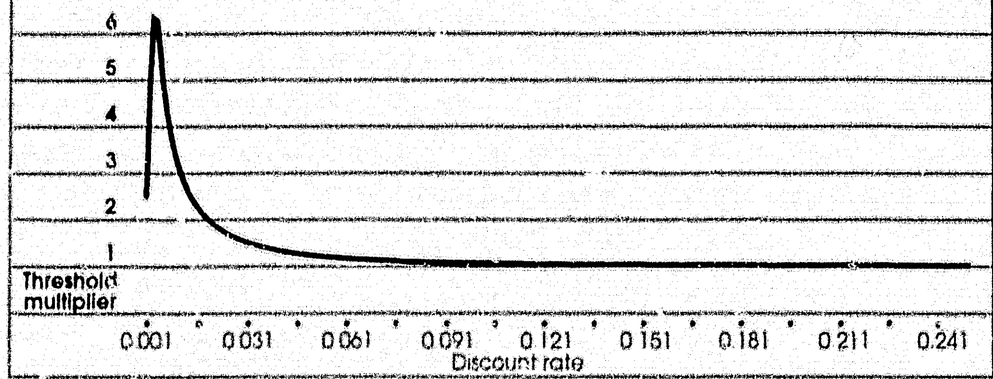
Sensitivity to the growth rate of the environmental index

It is apparent that the choice of growth rate has a significant affect on the threshold multiplier (figure 4). However, as this growth rate will generally be estimated from available data it will be possible to report the range of values of the threshold multiplier

4 **Sensitivity to growth rate**



5 **Sensitivity to discount rate**



associated with the variance in the estimate of the growth rate. In this example, for a growth rate of 0.1 (which implies 50 per cent regeneration after 46 years and 90 per cent regeneration after almost 70 years) the threshold multiplier is 1.12, while for a growth rate of 0.15 (which implies 50 per cent regeneration after 30 years and full regeneration after around 70 years) the threshold multiplier is 1.26.

Sensitivity to the discount rate
It is apparent that the choice of discount rate has an important bearing on the threshold multiplier. At $r = 0.05$ the threshold multiplier is 1.23; however, as r is increased to 0.1 and 0.15 the threshold multiplier falls to 1.06 and 1.03 respectively (figure 5). It can be seen that for most values of r (in this case $r > 0.003$), the threshold multiplier decreases as r increases.

Some issues in application

The preceding analysis demonstrated that, under certain circumstances, including regeneration can have a significant effect on the threshold amenity value required for mining to be considered suboptimal. Despite the potential importance of including this effect, there are some issues concerning the practical application of this concept which need to be considered. Many of these issues, however, such as the choice of discount rate, are endemic to environmental benefit–cost analysis and will not be detailed here.

The critical relationships underlying the model are the environmental quality regeneration function and the environmental value function. Although the issues concerning these two where a_e = 'irreversible' annual benefits which do not grow back following mining. As such, the annual threshold value, a_p, may now be written as:

13. $$a_p = \frac{M - X - \frac{a_e}{r}}{\frac{1}{r} - \beta^{\alpha} Y(t)}$$

It should be noted that including the effects of environmen... generation will still be an important factor in the overall analysis, even if these types of values cannot be estimated.

Aside from these aggregation issues, there is also the issue of the actual form of the aggregate environmental utility function. In the model presented it was assumed that the cardinal utility function took a particular functional form (equation 3), with the only parameter requiring specification being α, which determines the rate at which marginal utility diminishes. However, it could be expected that the utility function could take a variety of functional forms, depending on the nature of benefits associated with the forest. For example, it may be the case that at least initially aesthetic and recreational values exhibit increasing marginal utility with respect to increases in environmental quality. In the long run, however, it could be expected that as the forest matures, marginal utility for most types of direct use and non-use amenity benefits would decline. This would imply a functional form similar to the logistic function assumed for the environmental index.

Despite these uncertainties, it could be expected that there will be less restrictions in estimating the general functional form of environmental valuation functions (as required in the threshold approach), than in estimating an exact point on such a schedule for a specific level of environmental quality (as required in a full benefit–cost analysis). Further work on the nature of cardinal environmental value functional forms, perhaps derived from revealed preference and contingent rating studies, may shed more light on this issue. The applicability of the contingent ranking approach has not yet been fully established; however, it could be useful for this purpose and appears theoretically valid (Department of Environment, Sport and Territories, the Commonwealth Department of Finance and the Resource Assessment Commission 1995). In addition, Mackenzie (1993) found the contingent rating method was informationaly more efficient than standard contingent valuation.

assumptions are closely related, they are dealt with separately below in order to differentiate problems of physical measurement from problems of economic valuation.

The choice of environmental index

In the preceding model it was assumed that the environmental index effectively captured all of the relevant use and non-use benefits. As a first order approximation, the index was derived from data on the regrowth of above ground cellulose biomass on rehabilitated minesites. It must be noted, however, that this type of index is unlikely to successfully aggregate those characteristics of the forest from which all benefits are derived. Some physical benefits, such as the water generative capacity of the area, may not be related in a positive and linear fashion to an index based on biomass regrowth. Where these effects are likely to be significant, separate indexes which account for divergent growth rates of different aspects of environmental quality should be used. Correspondingly, separate value functions will be required; however, they need not take a different form to those used with other indexes.

The choice of the utility function's form

As with the environmental index, an important issue concerning the value function is what sort of amenity benefits the specified form is likely to capture — and not capture. Although aesthetic and recreational values could be expected to display a reasonably linear relationship to some index of environmental quality, it is possible to think of some values which may well be discontinuous with respect to such an index. For example, there may be some use and non-use values attached to a forest simply because people are aware that the trees predate European settlement (see Randall 1991 for a taxonomy of resource values).

However, the interpretation of the threshold value changes in such circumstances where these types of values are likely to be significant and cannot be estimated. The minimum environmental cost required for mining to be suboptimal in this case will be equal to the threshold value (as described here) less the values not accounted for in the specified utility function and environmental index. If the existence value of preEuropean forest could be estimated however, this could then be subtracted from the estimated threshold and included in the analysis. In this case, the threshold expression (equation 1) may now be written:

12. $$M - X + \int_{C}^{\infty} a_t e^{-rt} dt = \int_{0}^{\infty} a_p e^{-rt} dt + \int_{0}^{\infty} a_e e^{-rt} dt;$$

Disaggregating the threshold analysis and other extensions

The issues identified above are to a large extent problems associated with the aggregation of non-mining benefits into one index of environmental quality and one function of environmental value. In the threshold model presented, the only benefits which were assumed to be able to be measured were the potential mining benefits. In some cases, however, it may be possible to measure certain non-market benefits associated with forest use. For example, it may be possible to estimate the value of recreational demand for the forest in its current state using the travel cost method, and then this could be used to calculate the net reduction in recreational benefits associated with mining.

The effect of separately identifying the recreational benefits and netting them out would be to lower the threshold value, as some of the environmental costs would now be quantified. It is expected that this would make the interpretation of the resultant threshold value easier for two reasons. First, the value would now pertain to a smaller subset of the non-market values (possibly only non-use values), and therefore have greater decision making practicability. Second, the index function and valuation functions would be less aggregated, and therefore potentially more accurate as some of the aggregation problems mentioned earlier would be mitigated to some extent.

Another possible extension to the model presented here is to incorporate some uncertainty into the whole valuation procedure. This could be achieved by making β (the rehabilitation success rate) a random variable. The distribution for β could be obtained from data on the successfulness of rehabilitation of ecosystems elsewhere following mining.

Conclusion

When considering the economic benefits of a proposed mining activity against the environmental costs of that activity a threshold approach is often adopted, where the net economic benefits of mining are taken to represent the minimum environmental costs that are required for mining to be suboptimal. It has been shown that for mining operations which cover large areas of land, and therefore have environmental impacts which are largely contained onsite, including the level of environmental regeneration following minesite rehabilitation can have a significant impact on the threshold value.

The example of bauxite mining and rehabilitation developed here found that the threshold value is 17 per cent higher (under base case assumptions) when environmental regeneration is included in the analysis. The results are sensitive to the rate of environmental regrowth, the discount rate and the functional form of the utility function for non-market forest goods. The dynamics of regeneration has a crucial bearing on the economic value of regrowth, with the benefits from regeneration after sixty years not affecting the threshold value significantly.

The threshold approach was used as the vehicle to incorporate environmental regeneration for two main reasons. First, it is often the case that non-market values are unavailable. Second, the threshold approach enables environmental regrowth to be incorporated into the analysis without having to estimate actual dollar values for different levels of amenity. The importance of including regenerative effects discussed here also applies in situations where non-market benefits are estimated.

As with all environmental valuation techniques there are a number of issues which emerge in the practical application of this method, most notably the aggregation of environmental values. Certain types of benefits (such as the preservation of old growth forest) would not be captured in this analysis because they will not grow back in proportion to biological regeneration of the forest. The inclusion of these types of benefits changes the interpretation of the threshold value calculated here. However, the inclusion of environmental regeneration is still an important aspect of the analysis.

If an area is expected to provide benefits for aesthetic and recreational use purposes which can be related to the environmental quality of the forest, then it is important that the benefit of these values increasing as the forest regenerates is considered when examining land use alternatives. A valuation of mining benefits alone is misleading when viewed as a threshold, because it is often compared (directly or by implication) with the perceived current non-market value of the resource, and not the change in non-market value of the resource that would occur following mining and rehabilitation. Including the regeneration of environmental values results in a threshold value which is directly comparable to what the perceived or estimated current non-market value of the resource in question is, and therefore has the potential to enable better land use decisions.

References

ABARE, AGSO and the BRS 1993, *Shoalwater Bay Military Training Area Resource Assessment*, ABARE, Canberra.

Commonwealth Department of Environment, Sport and Territories, the Commonwealth Department of Finance and the Resource Assessment Commission 1995, *Techniques to Value Environmental Resources: An Introductory Handbook*, AGPS, Canberra.

Clark, C.W. 1976, *Mathematical Bioeconomics: The Optimal Management of Renewable Resources*, John Wiley & Sons, New York.

Elliot, P., Gardner, J., Allen, D. and Butcher, G. 1996, Completion criteria for Alcoa of Australia Limited's bauxite mine rehabilitation, Paper presented at the 3rd International 21st Annual Minerals Council of Australia Environmental Workshop, Newcastle, 14–18 October.

Hore-Lacy, I. 1992, *Mining and the Environment*, Australian Mining Industry Council, Canberra.

Krutilla, J.V. and Cicchetti, C.J. 1972, 'Evaluating benefits of environmental resources with special reference to the Hells Canyon', *Natural Resources Journal*, vol. 12, pp. 1–29.

Mackenzie, J. 1993, 'A comparison of contingent preference models', *American Journal of Agricultural Economics*, vol. 75, pp. 593–603.

RAC (Resource Assessment Commission) 1991, *Kakadu Conservation Zone Inquiry*, vol. 1, *Final Report*, AGPS, Canberra.

Randall, A. 1991, 'Total and nonuse values', in Braden, J.B. and Kolstad, C.D.(eds), *Measuring the Demand for Environmental Quality*, North Holland, Amsterdam.

Ward, S.C. and Koch, J.M. 1996, 'Biomass and nutrient distribution in a 15.5 year old forest growing on a rehabilitated bauxite mine', *Australian Journal of Ecology*, vol. 21, pp. 309–15.