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# Integrating conservation and forestry production: effective trade-offs between biodiversity and production in regional land-use assessment

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Abstract
Integrating biodiversity conservation with production requires effective use of surrogate information for regional biodiversity and a strategy to explore trade-offs between the two at the regional level. In this study we combine a method for using environmental data as a surrogate for species-level biodiversity with a recently-developed procedure that properly incorporates biodiversity into forms of multi-criteria analysis. A case study integrating biodiversity and forestry production is presented here, in which suitabilities for forestry are estimated using a decsion-support package, LUPIS. We have linked LUPIS to the DIVERSITY package (Faith and Walker, 1993) in order to combine exploration of weights with complementarity estimates based on ED. In this study, simplified suitabilities for forestry were estimated using LUPIS and these forestry "opportunity values" were input to DIVERSITY where a nominated weight, *w*, converted these to effective amounts of biodiversity, E. Because an area's contribution to total biodiversity (its complementarity value, C) can be more or less than E depending on which other areas are also protected, we used an iterative strategy (Faith and Walker, submitted-b) for selecting protected areas.

## Introduction

Our research on integrating conservation and development in south-east forests of Australia forms one of the regional case studies in CSIRO's multi-divisional program (MDP) on biodiversity. A range of different mechanisms for integrating conservation and production are to be developed and applied as part of this study. Here, we report results from a study carried out within one south-east forests region, that highlight two aspects of effective regional integration:

1) making best-possible use of available data as a surrogate for biodiversity values.
2) searching for combinations of land-use allocations that best avoid conflict between biodiversity and production.

Strategies are needed for reconciling competing demands at the regional level when areas are to be selected for protection of biodiversity and there are associated "costs", possibly equivalent to foregone development/production opportunities. An earlier study (Cocks et al., in press) used the LUPIS decision support package to explore allocations in the Bateman's Bay region. LUPIS allows the exploration of land-use assignments using a simple procedure in which an area is assigned the land-use for which it has highest suitability; these relative suitabilities depend on nominated weights assigned to user-defined guidelines. One limitation of that study was that complementarity was not taken into account - the suitability of an area for protection of regional biodiversity should depend not just on the weights but also on which other areas are protected.

## Biodiversity surrogates

The ecological continuum model underlying ED links representation of the environmental space to representation at the species level; the number of species represented by a set of areas will be large to the extent that, on average, the distance from any point in the space to its nearest protected area is small. The expected complementarity value, "C", of an area (the relative number of additional species it contributes) is indicated by the extent to which addition of the area to a partial-set reduces the sum of these distances. This criterion is a special case of a general "p-median" criterion (Faith, 1994; Faith and Walker, 1993, in press a).

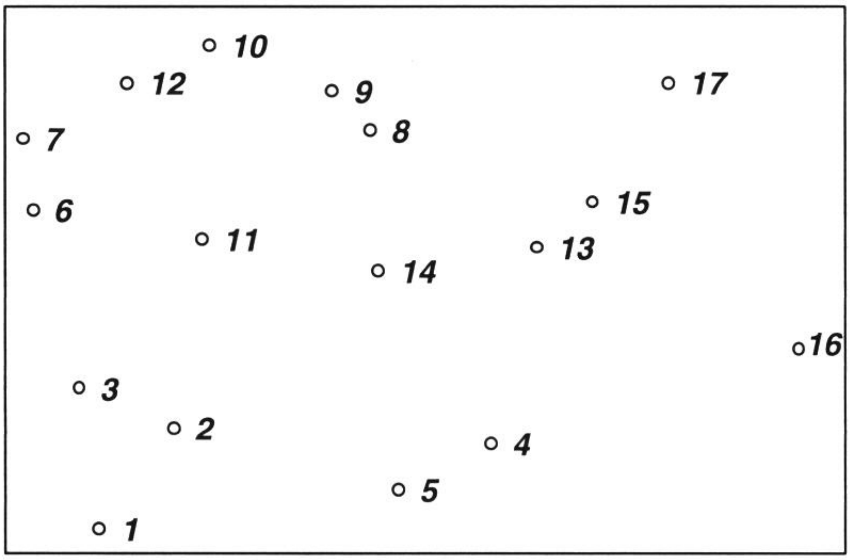


Figure 1.
a) A two-dimensional environmental space for 17 areas.

If only three areas could be chosen for protection, then a good set of three will be one that best spans this space (for example areas 22, 12, and 15).

**Biodiversity and trade-offs**

The DIVERSITY software package (Walker and Faith, 1994) can be used to find, for any weighting, that allocation of areas to protection that maximises total net benefit (Faith and Walker, in press b); this is equivalent to minimising the sum of (weighted) forgone biodiversity and (weighted) costs. Each area selected for protection makes a weighted contribution to biodiversity that exceeds its weighted cost.

Fig. 2 shows a set of six protected areas, having a forgone biodiversity of 365 and forgone forestry of 27 units. If forestry is given a weight of 5, then this allocation of areas to protection, with the remainder being forested, is optimal in providing maximum possible total net benefit.

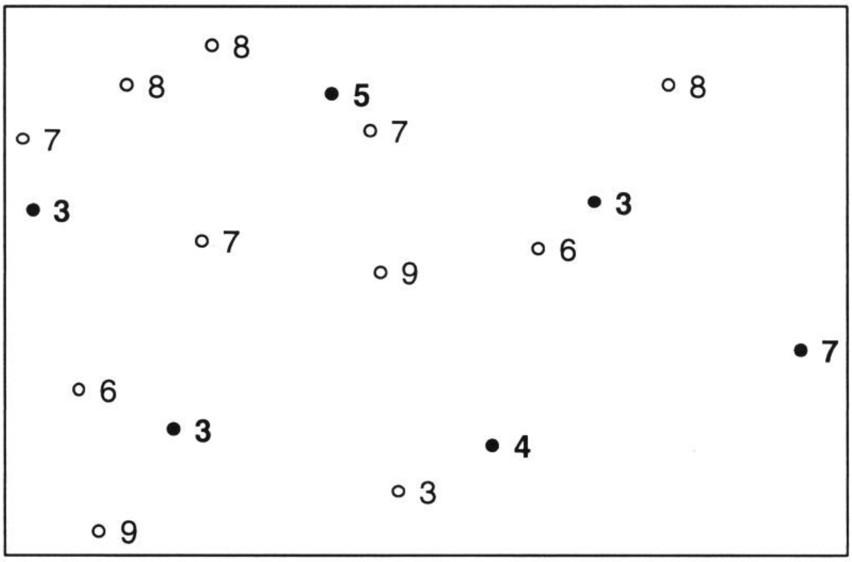


Figure 2. A set of six protected areas, having a forgone biodiversity of 365 and forgone forestry of 27 units. If forestry is given a weight of 5, then this allocation of areas to protection, with the remainder being forested, is optimal in providing maximum possible total net benefit.

**Table** 2.

| area | contribution | cost | weighted cost |
|---|---|---|---|
| 2 | 75 | 3 | 15 |
| 4 | 55 | 4 | 20 |
| 6 | 55 | 3 | 15 |
| 9 | 45 | 5 | 25 |
| 15 | 57 | 3 | 15 |
| 16 | 54 | 7 | 35 |
| *14* | *19* | *9* | *45* |

Note that area 16 is protected even though it comes at a high cost of 7 units; because it fills a gap in the environmental space, without possible substitute areas that might be cheaper, the area makes a contribution to ED of 54 units that exceeds this weighted cost.

If another area were to be added to these, one candidate might be area 14, filling a gap at the centre of the space; however, its contribution to ED given the 6 area already protected, is just 19 units, and this will not exceed its weighted cost of 45 units.

The costs using the above strategy could be any estimates of forgone opportunities when a given area is allocated to biodiversity protection. In the next sections, DIVERSITY will be linked to a land-use planning approach, LUPIS, and demonstrated using competing land use suitabilities reflecting the degree to which an area satisfies guidelines about how land-use options relate to properties of areas.

## LUPIS and previous Bateman's Bay applications

The Batemans Bay area on the South coast of New South Wales has been the site of substantial research effort to devise and demonstrate land use planning techniques. SIRO-PLAN (Cocks et. al

1982)is an issue driven method for land use planning in which plans are evaluated in terms of the extent that guidelines expressing the attitudes of interest groups towards the major issues are achieved. LUPIS is a special purpose spatial decision support package (Ive and Cocks, 1982, 198?) developed to assist in the implementation of the SIRO-PLAN method. A major opportunity to review and extend the capabilities of came in 1990 with the undertaking of a further demonstration exercise in the Batemans Bay area (Cocks et. al in press)- an area which includes substantial proportion of mixed native eucalypt forests which have to varying degrees been logged for over a hundred years. Consistent with national polarisation of the debate over the use of Australia's remaining native hardwood forests the area had increasingly come under pressure from conservationists and foresters. To demonstrate the approach the exercise was formulated around the two central issues at the centre of conflict over land use in the forested areas of the study area. Firstly conservationists were concerned that those parts of the forest with particular value for biological conservation, recreation and aesthetic appreciation were in need of protection from logging operations. Secondly, the timber industry sought on-going access to the forest resources of the area for sawlogs and pulpwood. From these central issues ten land uses were recognised as necessary to accommodate the diverse interests- four involving protective-oriented use of the forest resource and four involving production-oriented use. The two remaining uses involved cleared land adjacent to the forested area. The method relies upon the development of guidelines to direct the plan development process. Guidelines (Cocks et. al 1986) may be either imperative (commit or exclude uses subject to conditions) or indicative (prefer or avoid uses subject to conditions). In all some 180 guidelines were formulated to drive the inventorying, evaluation and allocation phases of the exercise (Cocks et. al in press). In addition to proposing actions to assist in resolution of land use conflicts the guidelines engender the data required to operationalise the guidelines. Prior to commencing data collection the study the area was divided into 3439 grid cells (or portions thereof) of 0.1 deg. lat. by 0.1 deg. long. It is against each of these grid cells that data was collected and a land use allocation proposed. data items were assembled for each mapping unit to permit guideline satisfaction ratings to be generated. The guideline satisfaction ratings quantify the attractiveness of each mapping unit from the perspective of the guideline. The LUPIS package offers the land use receiving the highest suitability score as the preferred use on each mapping unit. The suitability score for each land use is defined as:

$$\text{Sum } r_{ijk}.w_k$$

where $r_{ijk}$ is the guideline satisfaction rating for guideline k reflecting the relative attractiveness of implementing land use j on mapping unit i from the perspective of the guideline k and $w_k$ is the guideline importance weight. The suitability score reflects the relative value placed upon implementing the preferred use.

Having created a first plan the normal procedure would be to enter an iterative process of adjusting the value of the weights on individual guidelines to achieve a more acceptable guideline achievement profile and plan that the current plan. Because there is no way of knowing beforehand what is possible relative to the current position this stage must of necessity be one of exploration. Furthermore the numerical value of the weights do not in themselves have any significance, rather it is the result that the weights engender in terms of guideline achievement that is important. Therefore the weights are the vehicle used to arrive at an acceptable plan.

## A limitation of LUPIS in incorporating biodiversity

Note that the mapping units are treated independently in the allocations by LUPIS. This raises difficulties for exploring solutions that efficiently (i.e. in a small number of low-cost areas)

represent regional biodiversity in a resultant set of areas (mapping units) allocated to biodiversity protection.
The Bateman's Bay case studies referred to above used clusters or "types" as the surrogate for biodiversity. The problem then is related to a well-formulated problem of reserve selection called the minimum set problem (for review, see Pressey, et al., 199); a minimum number of areas is sought such that each type is represented a nominated number of times. There are two limitations to this approach when incorporated into LUPIS. One is the problem common to all applications using "types" as surrogate information; a continuum is arbitrarily divided into pieces, and an arbitrary target of replication of each type is nominated. Variation both among and within types is lost; this loss of useful complementarity information must seriously limit the efficiency with which areas can be selected to represent regional biodiversity (for discussion, see Faith and Walker, 1993, 1994, in press a,b,c).
The second problem, more specifically related to LUPIS, is that, even when an arbitrary target for a given type is nominated, it may be impossible to achieve it using only the usual weights. For example, suppose that type x in Table 2 occurs in 10 areas, with raw (unweighted) suitability values as shown. There is no possible weighting that will achieve a 20% representation.

Table 2.

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| area's presence of type x | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| raw competing suitability | 1 | 2 | 2 | 2 | 2 | 3 | 3 | 4 | 5 | 6 |

This same difficulty appears when a continuous environmental space is used, but without ED as an estimator of complementarity. Returning to the example of Fig. 1, suppose for example that the point in environmental space represented by area 16 now also was represented by many other areas. In the LUPIS context, all these areas would have the same biodiversity value, so that if the given weighting implied the allocation of area 16 to protection, it would also imply (unless costs varied among these areas) that all the other areas would be assigned to protection as well.

This problem parallels the misuse of species richness as an indicator of conservation value. When areas are individually chosen based on their species richness in an attempt to form a set of representative areas (e.g. Prendergast, et al. ), there is no guarantee that the final set is rich as a set and not just a sampling of areas containing much the same subset of species.

The solution is to think of the biodiversity value of a given area as its complementary contribution in the context of the other areas that are protected. This is achieved here by linking DIVERSITY and LUPIS.

## Linking DIVERSITY and LUPIS

The suitability score for the biodiversity-protection land use has the same general form, Sum $r_{ijk}.w_k$, as defined above, where $r_{ijk}$ now is the guideline satisfaction rating for a single guideline, k, reflecting the relative attractiveness of implementing land use j (biodiversity protection) on mapping unit i from the perspective of the guideline k and $w_k$ is the guideline weight.

The single biodiversity guideline states that an area that would make a contribution to the overall biodiversity represented by the set of all protected areas, should itself be protected.

In practice, for a given assignment of weights on all other criteria or guidelines, the maximum suitability (excluding biodiversity protection) can be calculated for each area, as in a conventional LUPIS analysis. These values then can be used in DIVERSITY as the costs of protection, as illustrated in the example of Fig. 1. The weight assigned to biodiversity may be defined prior to DIVERSITY analysis, or a range of weights maybe used over several runs of the algorithm.

In the simplest case, for a single nominated weighting on biodiversity, an iteration is completed after DIVERSITY has allocated to protection those areas whose final biodiversity contribution exceeds its cost. The result of this iteration has not changed in form from a conventional LUPIS analysis; each area for the nominated weightings is assigned the land use for which it has highest suitability.

## An example based on the Bateman's Bay Region

### *Data and guidelines*

The Bateman's Bay region of N.S.W. is divided into 3439 0.1°x0.1° grid cells, forming part of a CSIRO data base (Austin et al., unpublished data). In this preliminary study, these cells were used as the area-units for allocations. Attention is restricted to the 2914 grid cells deemed to be within the forest province (Cocks et. al in press). Of these grid cells in the forest province 304 have cleared in part for other activities e.g. agriculture. The remaining 525 grid cells are outside the forest province and have been cleared of forest cover and subject to various development activity and therefore are not serious candidates for conservation or forestry.
The four production oriented uses applicable to the forested areas were consolidated into one mega forestry (Forestry) use. The value of any mapping unit for Forestry was taken as being the highest suitability score of the four production-oriented land uses. This recast exercise was set up as a very basic LUPIS formulation focusing on two land uses (Conservation and Forestry) and one preference guideline of the form: “as far as possible give preference to Forestry on mapping units with high value for forestry.” For completeness two exclusion guidelines were included of the form: “exclude Conservation (Forestry) from unforested areas.

### *Deriving an environmental space*

Available environmental descriptions of the areas, relating to aspects of solar radiation, temperature, rainfall, and nutrient status, were used as surrogate information for biodiversity assessments. A set of temperature, precipitation, solar radiation and edaphic variables were derived to provide the ‘environmental envelope’. Estimates of mean monthly temperature, precipitation and solar radiation values for the centre points the 3439 grid cells were estimated by interrogation of climatic surfaces, given latitude, longitude and elevation and the program ESOCLIM (Hutchinson, 1984, 1989). The resulting mean monthly climatic estimates were amalgamated into fifteen ‘bio-climatic’ parameters that were better thought to relate to biological process (Nix, 1986; Busby, 1986a,b). Two edaphic factors were also added; an estimate of the nutrient status of the cell was derived from geochemistry, and terrain roughness index. The 17 variables used in this study are shown in Table 2.

**Table 2**. environmental variables used to derive an environmental space.

1. Temperature:
    - Mean annual
    - Mean maximum of hottest month
    - Mean minimum of coldest month

    - Mean annual range
    - Seasonality (coefficient of variation)
2. Precipitation:
    - Annual precipitation
    - Seasonality (coefficient of variation)
    - Driest quarter mean
    - Hottest quarter mean
    - Coldest quarter mean
3. Radiation
    - Mean annual
    - Mean of maximum month
    - Mean of minimum month
    - Mean annual range
    - Seasonality (coefficient of variation)
4. Nutrient Index (1-5)
5. Terrain roughness (1-5)

Ordination was then used to generate an ‘environmental envelope’. The first step in this process is the estimation of association or resemblance between the 3439 grid cells on the basis of the 17 environmental variables. One problem here is the degree of correlation (co-linearity) between a number of the temperature variables. If this was ignored, the weighting of the temperature variables would be expected to increase against the others. To circumvent this, the environmental variables were grouped into five equally weighted classes, one each for temperature, precipitation, solar radiation, nutrient and terrain roughness. Using a program GASO (Belbin 1994), each group contributed equal weight to the pair-wise cell association.

Principal co-ordinate analysis (Gower, 1966) was then run on the association matrix to produce a reduced-dimensional environmental space; for the present analysis, the first four dimensions of this space were used.

Alternative sets of protected areas (candidate areas were limited to those 2914 cells that were forested) then were evaluated using the ED criterion ("environmental diversity"; Faith and Walker, 1993; submitted-a).

## DIVERSITY *analyses*

For a given weighting, an area was in the final protected set if and only if its final C value was greater than its E value. The above search strategy was repeated for a range of nominated weightings, producing a curve tracing alternative solutions (sets of protected areas; see Figure).

In this study, scope for compromise is demonstrated by the comparison of results for low versus high weighting of forestry, for a given total number of protected areas. When forestry was given high weight, it was possible to not only match the total biodiversity protected (as indexed by ED) found when forestry was given low weight, but also achieve this with a markedly smaller amount of foregone forestry opportunity. For the higher weight, the procedure effectively found substitute-areas for protection so that apparent conflict with forestry requirements was reduced.

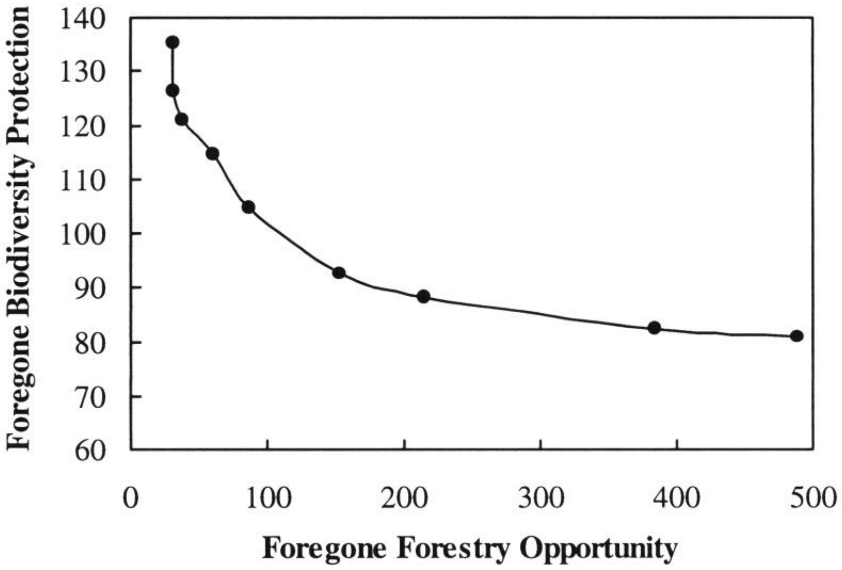


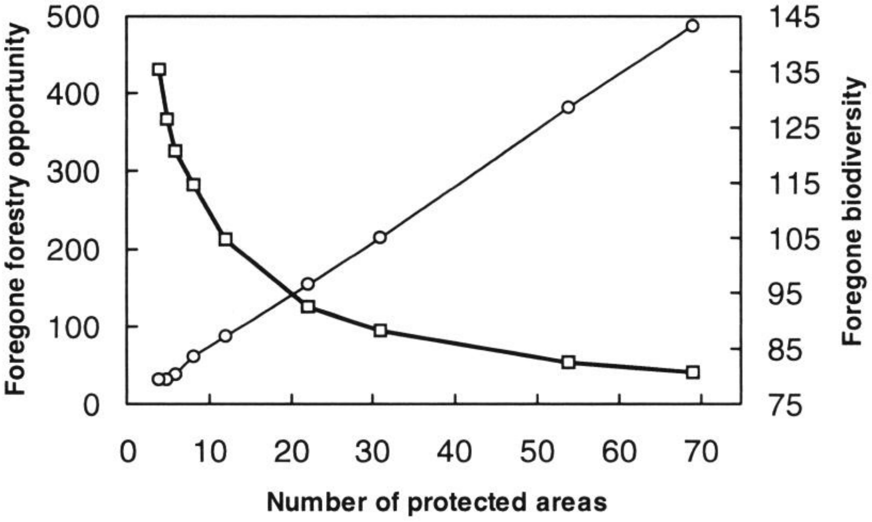
**Figure**. The points from left to right represent solutions for weights, *w*, of 1.0, 0.8, 0.7, 0.5, 0.25, 0.1, 0.06, 0.02, and 0.01. For each area, its forestry opportunity value was multiplied by *w* to convert it to effective-biodiversity units.

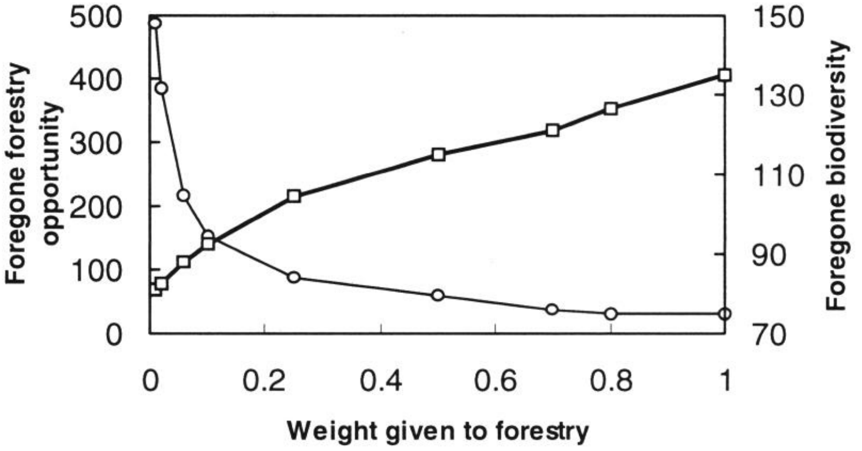
The search for solutions used a simple heuristic; results for 1.0 and 0.5 are not global optima.

The number of areas chosen for protection for each solution-point (from left to right) are 4, 5, 6, 8, 12, 22, 31, 54, and 69.

If forestry suitabilities were ignored and 22 areas were selected solely based on maximising represented biodiversity, the solution shown by the x in Fig.4 is found. This solution does well at representing biodiversity, but there is enough flexibility in the region that many other sets of 22 areas could be found with about the same biodiversity representation. Indeed, the point along the trade-off curve for 22 areas demonstrates that it is possible to find 22 areas that are just as representative but also avoid conflict with competing land-use requirements.

Choosing a set of protected areas prior to considering competing land uses may consequently lead to sub-optimal solutions. Further, because about one-third of the areas differ between the two solutions, it is not a simple matter to identify and transform the initial solution into the optimal one. Thus, opportunities are foreclosed.





As the number of protected areas increases forgone biodiversity naturally decreases but at a slower rate (Fig. 2b). This shape arises because the solutions for smaller numbers of protected areas are efficient representations of the environmental space (within the constraints imposed by the weighting on forestry), so that solutions for higher numbers of protected areas can only match these efficient representations and add areas filling in smaller "gaps" in the space. On the other hand, the costs continue to increase in this example approximately linearly.

The lower plot (Fig. 2c) shows the corresponding changes in forgone biodiversity and cost with changes in the weight given to forestry. There is a rapid fall in the forgone forestry, and relatively small increase in forgone biodiversity, as the weight given to forestry increases from zero; this highlights the dramatic difference between choosing protected areas without regard to costs versus giving these costs some weight.

Sensitivity analysis provided guidelines for prioritising areas by identifying those areas that 1) were assigned protection even when high weight was given to forestry relative to biodiversity, or 2) were not assigned protection even when low weight was given to forestry.

For example, areas 60 and 2156 occurred in all solutions over weights up to 0.80. Area 2634 appeared in allocations when the weight given to forestry was greater than 0.10.

## Discussion

Future work on this case study will incorporate other important aspects of integration not considered here. Most important of these will be the incorporation into regional assessments of mechanisms (Faith and Walker, submitted-c) for taking into account the contribution of production land to biodiversity protection.

The procedure discussed here also can incorporate conservation guidelines or criteria other than biodiversity. In the procedure described above, each area was represented by the highest suitability for a non-protection land-use. Given other protection criteria, each area would be represented by the highest suitability difference between non-protection and protection, calculated for a given area as maximum suitability for a non-protection land-use minus the non-biodiversity protection suitability.

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