The role of trade-offs in biodiversity conservation planning: linking local management, regional planning and global conservation efforts

DANIEL P FAITH† and P A WALKER*

Australian Museum, 6 College St., Sydney, New South Wales 2010, Australia
**CSIRO, Sustainable Ecosystems, Canberra, ACT 2601, Australia*

†*Corresponding author (Fax, 61-0293206050; Email, danf@austmus.gov.au)*

Biodiversity conservation planning requires trade-offs, given the realities of limited resources and the competing demands of society. If net benefits for society are important, biodiversity assessment cannot occur without other sectoral factors "on the table". In trade-offs approaches, the biodiversity value of a given area is expressed in terms of the species or other components of biodiversity that it has that are additional to the components protected elsewhere. That "marginal gain" is called the *complementarity* value of the area. A recent whole-country planning study for Papua New Guinea illustrates the importance of complementarity-based trade-offs in determining priority areas for biodiversity conservation, and for designing economic instruments such as biodiversity levies and offsets. Two international biodiversity programs provide important new opportunities for biodiversity trade-offs taking complementarity into account. Both the Millennium Ecosystem Assessment and the Critical Ecosystems or "hotspots" programs can benefit from an explicit framework that incorporates trade-offs, in which a balance is achieved not only by land-use allocation among areas, but also by the crediting of partial protection of biodiversity provided by sympathetic management within areas. For both international programs, our trade-offs framework can provide a natural linkage between local, regional and global planning levels.

[Faith D P and Walker P A 2002 The role of trade-offs in biodiversity conservation planning: linking local management, regional planning and global conservation efforts; *J. Biosci.* **27** (*Suppl. 2*) 393–407]

1. Introduction

A reality of biodiversity conservation planning is that it requires taking into account many things other than biodiversity. Biodiversity assessment is a form of risk analysis (e.g. Faith and Walker 1996a,b) in that it involves decision-making based on quantifying the unknown or partly known. There is consequently an element of open-endedness to processes such as selection of protected areas; any additional area protected will always increase estimated overall biodiversity protection to some degree. Trade-offs are required, given the realities of limited resources and the competing demands of society. Consequently, not only biodiversity information but also information about other needs of society must be considered. While such trade-offs have been considered at the level of species priorities (Weitzman 1992), in this paper, we are concerned with land management and land-use allocation: for example, determining which areas in a region are priorities for protection of biodiversity.

Trade-offs generally may rely on cost-benefit analysis or, alternatively, more general multi-criteria analyses that escape the need for economic/dollar valuations of biodiversity. Trade-offs that are concerned with the biodiversity of different areas pose special problems (Faith *et al* 1994; Faith 1995, 1997a) because the biodiversity value of an area changes with the changing status of other areas. The biodiversity value of a given area is typically

Keywords. Biodiversity; hotspots; millennium assessment; opportunity cost; planning; trade-offs

Abbreviations used: CE, Critical ecosystems; MA, millennium ecosystem assessment; PNG, Papua New Guinea.

expressed in terms of the components (e.g. species) of biodiversity that it has that are additional to the components protected elsewhere. That "marginal gain", to use the economists' term, is called the *complementarity* value of the area (e.g. Vane-Wright *et al* 1991; Pressey *et al* 1993).

Regional biodiversity planning can take advantage of complementarity in a way that promotes "regional sustainability" (Faith 1995, 1997a) – a balance between competing needs of society. Areas selected for biodiversity protection should have a high enough complementarity value to compensate for any corresponding "opportunity cost" of conservation (the cost to society implied by forgoing some other land use in favour of biodiversity protection). Effective comparison of complementarity and costs depends on the weight given to the costs; solutions (land allocations) for different weightings fall along a trade-offs curve (figure 1a). Examples of such curves will be discussed in this paper. Using trade-offs curves, a set of areas can be identified that achieves a given level of biodiversity representation/protection, with minimum opportunity costs (Faith 1995). Trade-offs space also can be used to explore scenarios – for example, whether a fixed allocation of areas to one land use means that the best trade-offs curve for the region is now much worse.

Clearly, if net benefits for society are important, biodiversity assessment cannot occur without other sectoral factors "on the table". Decision-making about land allocations that ignores such factors not only implies lower net benefits at that time, but also may imply that it is no longer possible to achieve high net benefits in the future. Such constraints might arise through previous land use decisions or through impacts such as climate change. Constraints also may be a consequence of loss of degraded land to both biodiversity protection and other land use opportunities, fixed protected areas with high opportunity cost but low biodiversity representation, or fixed production areas with high biodiversity loss but low production opportunity. With such constraints, the new trade-offs curve of best-possible solutions moves away from the optimum (implying lower net benefits; figure 1a),

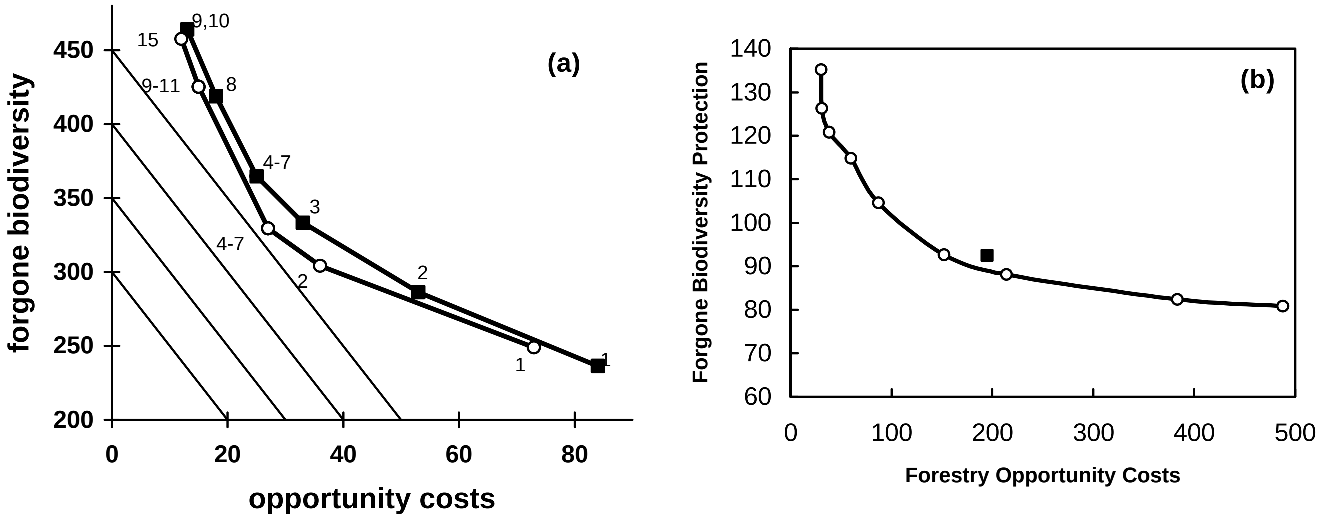

Figure 1. (**a**) A figure re-drawn from Faith (1995) showing two trade-offs curves in a trade-offs space. Any allocation of land uses to all areas in the region defines a point in this space. The horizontal axis indicates total opportunity costs of biodiversity conservation and the vertical axis indicates total amount of biodiversity protection "forgone" – not protected by the given land use allocation. A desirable allocation would correspond to a point near the lower left-hand corner of the space. In practice, no allocation of land uses to areas in the region will be able to simultaneously achieve all opportunities for biodiversity protection and other uses. The best-possible allocations sit along a trade-offs curve, whose exact position depends on the overall degree of conflict between biodiversity and other uses, and on the constraints on allocations. For any curve, the preferred allocation depends on the relative "importance" weight given to the two axes. In this example, the upper curve is the trade-offs curve under constraints, such as previous land use outcomes/decisions that restrict the capacity to achieve the degree of balance previously possible. The line segments are equal-balance or equal net-benefits contours for a weighting of 5·0 on opportunity costs (more generally, these segments may be curvilinear in the space). The point of intersection of the trade-offs curve with the lowest possible segment (having greatest net benefits) defines the best solution for that weight. Numbers along the trade-offs curves are weights that would lead to selecting those points along the trade-offs curve as the best land allocations. (**b**) A re-drawing of the trade-offs space from a study in NSW, Australia. The dark square is that allocation of land that meets the biodiversity target, but without taking costs into account. The curve shows optimal allocations for varying weights on costs. Although the dark square allocation appears close to an optimal allocation along the curve, there is low overlap in the actual set of areas assigned to biodiversity protection.

and there is a reduction in "regional sustainability" – the degree to which the region has achieved its capacity for finding a balance among competing needs of society.

Allocation of different areas to different land uses so as to maximize net benefits is only one key to finding a balance between competing needs of society. The search for net benefits also recognizes cases where two or more "services" can be met in a single area. Net benefits to society, a better balance between potentially conflicting goals, can therefore be achieved on occasions when it is found that the different land uses are not so much in conflict. "Partial protection" of biodiversity – assigning land uses to areas that provide at least partial protection of biodiversity while not forgoing other land use opportunities – leads to a trade-offs curve providing greater net benefits (Faith 1995). In contrast, higher curves in trade-offs space (offering lower net benefits; figure 1a) arise when there are fewer opportunities for such partial protection.

When partial protection of biodiversity is credited to other land uses, it can be taken into account in calculating complementarity values for regional planning (Faith and Walker 1996b). Eco-forestry (see e.g. Faith *et al* 2001a), for example, may provide at least partial protection of biodiversity. When we take into account those contributions, clearly there is then reduced pressure on other areas to contribute to biodiversity goals, and so there is greater opportunity for other land use opportunities. In regional planning, we can identify specific areas where most is gained by implementing a form of development that achieves partial protection. Economic incentives for such sympathetic management then may be applied to those areas. Such analyses are currently being explored in our study applying trade-offs in regional tourism planning in Douglas Shire, North Queensland, Australia.

1.1 *Biodiversity trade-offs studies in Australia and Papua New Guinea*

We have been working on cross-sectoral trade-offs approaches, incorporating biodiversity and opportunity costs, since our early case study in New South Wales, Australia (Faith *et al* 1994, 1996). That study demonstrated advantages of trading-off biodiversity and other sectoral needs of society at the regional level (figure 1b). While not knowing any "correct" weighting for various costs, sensitivity analysis revealed which areas were selected for protection no matter what the weight assigned to opportunity costs – and which areas were never selected (Faith *et al* 1994). That study also highlighted another important aspect of trade-offs. The optimal solution had low overlap with one that would have achieved the same biodiversity target ignoring costs (figure 1b), suggesting that consideration of costs cannot simply be an add-on consideration to refine land allocations. The New South Wales study represented the first integration of general opportunity costs into conservation priority-setting algorithms, and the same basic approach has now been adopted elsewhere (for discussion, see Faith *et al* 2001a).

Our more recent trade-offs project (Faith *et al* 2001b; see also Nix *et al* 2000) identified candidate areas for biodiversity protection in Papua New Guinea (PNG), providing an ongoing evaluation framework for moving towards a country-wide conservation goal, while at the same time providing opportunities to alter the priority area set in the light of new knowledge, changes in land use, and/or changes in economic and social conditions.

We applied a new approach to percentage-based conservation targets in PNG, based on trade-offs. The maximum diversity that could be protected by an unconstrained 10% of total area became the working biodiversity target. Reaching that same biodiversity target then required more than 10% of the total area, because of trade-offs involving constraints (e.g. existing reserves) and opportunity costs. The subsequent satisfaction of the 10%-based target in a low-cost proposed protected set covering 16·8% of PNG (Faith *et al* 2001b) corresponded to relatively high net benefits (figure 2).

Achieving a biodiversity protection target with minimum opportunity cost was an important outcome in PNG, given that biodiversity values overlap with forestry production values, and high forgone forestry opportunities would mean significant losses to land owners and the government. In the PNG study, the same level of biodiversity representation conceivably could have corresponded to a small or large overlap with the desirable areas for forestry production. Clearly, achieving net benefits means that evaluations and planning cannot be carried out without taking into account such factors as timber production, agriculture, population centres, carbon sequestration, and the economics of government levies, incentives and subsidies. The PNG study demonstrated that complementarity is not just about selecting a set of priority protected areas, but about a new 'biodiversity economics' relating to offsets, levies, subsidies, incentives and other economic instruments. Future scenario development in PNG therefore will focus on biodiversity targets, land use constraints, timber plans, population issues, scope for levies, offsets markets, and subsidies (Faith *et al* 2001a).

Regional sustainability was addressed at two interacting levels in the PNG study. First, the planning approach minimized forgone timber opportunities for a given biodiversity protection level. Second, the analysis framework addressed the potential for eco-forestry as potentially replacing intensive logging, so that areas producing logging income could contribute to biodiversity protection. The PNG study, however, did not credit allocations of partial protection of biodiversity towards achieving the target. Future trade-offs may be achieved even more effectively when production lands are credited in the allocation process to at least partial protection of biodiversity (when they do actually make such a contribution). Our current approach to integration of such credits uses probabilistic strategies for expressing biodiversity persistence in a planning framework (Faith 1995; Faith and Walker 1996b,c, 1997).

Because the PNG study (in focussing on achieving a nominated target at least cost) did not incorporate partial protection allocations and, overall, did not capture the full breadth of trade-offs space and scenarios analysis, we will present an hypothetical example to illustrate important aspects of trade-offs. We will present example analyses, using our trade-offs software, TARGET, to highlight the role of biodiversity trade-offs in providing a framework for sustainability, both across sectors and across spatial scales.

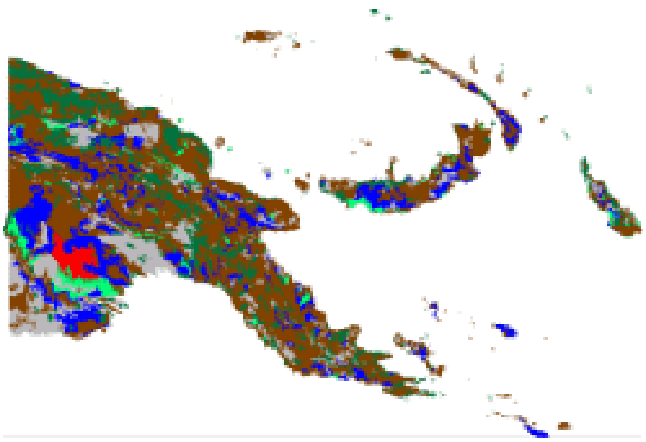

Figure 2. A proposed priority set of areas for biodiversity protection in PNG (gray areas). This set satisfies a 10%-based biodiversity representation target while minimizing conflict with forestry production, agricultural potential, population centres, and high land use intensity areas. The areas shown in colours have complementarity values based on a higher 15%-based biodiversity target, which would require protection of more attributes. The calculation of complementarity values assumes a regional 0·999 probability of persistence goal for all biodiversity attributes, with 0·10 baseline probability of persistence and assuming a 0·90 probability of persistence for areas (and their attributes) within the proposed protected set (gray areas). An area will have high complementarity if changing its persitence probability from 0·10 to 0·90 would make a large step towards a 0·999 probability of persistence for all attributes. Low to high values are indicated by dark green, brown, blue, red, lighter-green. These complementarity values may determine degree of carbon or biodiversity credits, attractiveness for eco-forestry programs, or the size of environmental levies to be charged for production use of the area. For full details, see Faith *et al* (1999) and Faith *et al* (2001a).

Those examples then set the stage for our consideration of the role of such trade-offs in several new international initiatives. In this paper, we will examine two of these, the millennium ecosystem assessment (MA; see Ayensu *et al* 1999; Reid 2000; http://www.ma-secretariat.org; http://www.millenniumassessment.org/) and the critical ecosystems (CE) or "hotspots" program (Mittermeier *et al* 1999; Myers *et al* 2000; http://www.defyingnaturesend.org/about/CABSconferencewrapup.pdf and http://www.cepf.net/). The need to move beyond single sector assessments is a central rationale for the MA, which is concerned with trade-offs among "ecosystem services" that include such things as water quality, food production, and conservation of biodiversity option values. The CE has a focus on conserving the key biodiversity hotspot areas of the world, with a prioritization strategy that takes into account the need to minimize opportunity costs. Both the MA and CE so far appear to have no explicit framework that incorporates the sorts of trade-offs used in our case studies, where balance is achieved by allocation among areas and crediting partial protection. For both programs, we will argue that our trade-offs framework can provide a natural linkage between local, regional and global planning levels. A balance within individual areas feeds into the assessment of trade-offs at the regional level – and the potential of that region for trade-offs may make it more deserving of high global priority for conservation efforts.

2. Example trade-offs analyses using TARGET

TARGET is one module of the DIVERSITY software package (Faith and Walker 1994, 1996c; Walker and Faith 1998). It is also part of the BioRap toolbox (see Nix *et al* 2000), and was used in the PNG trade-offs analyses. The biodiversity trade-offs strategies used in TARGET were originally developed in one of the other DIVERSITY modules (ED; Faith and Walker 1994). TARGET not only provides for analyses, as in the PNG study, that seek to achieve a biodiversity protection target at least cost, but also provides procedures to explore scenarios in trade-offs spaces (figure 1a).

TARGET processes locationally referenced data and links to spatial mapping software. TARGET assumes that the areas in a region are described as containing one or more different biodiversity "attributes". Attributes may be species or other surrogate information for biodiversity. For example, the attributes at the coarsest level of resolution might be forest types, with further definition of finer-resolution attributes describing variation within forest types. The finer-resolution attributes might correspond to different species, or might be other abiotic descriptions, such as soil types. Within each area, each attribute also has some quantitative value associated with it – this value might, for example, correspond to the total number of hectares of that forest type within that area.

Input to TARGET consists of this list of geographic areas, each containing a set of attributes found in the area, with some quantitative value associated with each. Also, a nominated degree of representation (a target) for each attribute is provided as input. The first step in using TARGET involves setting that target level for representation for all biodiversity attributes. These target levels may be derived from consideration of standard regional biodiversity "targets". For example, the Caracas Action Plan, which is linked to the protected-areas elements of the Convention on Biological Diversity, proposed as a broad target that 10% of each biome be represented in a protected areas system. TARGET implements one strategy for applying 10% (or similar) targets so that they can more effectively be used as comparative performance indicators among countries or regions. A benchmark analysis may be carried out, as in the PNG study (Faith *et al* 2001c) to determine how much heterogeneity (how many attributes) could be sampled (perhaps to some predefined viability level) under an assumption that any 10% of the region can be selected. This level of heterogeneity becomes the new effective biodiversity target. The target amount for each attribute then may be set, as it was in the PNG study, to a single viable representation of each attribute. Subsequent analyses ask how this target can be reached in the face of real constraints (such as existing disturbed areas or an existing reserve system) and opportunity costs.

Basic TARGET analyses search for a set of candidate protected areas that achieves nominated target levels of representation of all the attributes, but with a minimum opportunity cost. These opportunity costs of biodiversity protection often will correspond to estimates of the suitability of the areas for forestry production or other land uses. When costs are taken into account, the relative weight given to these costs, relative to biodiversity representation, will influence the outcome of the allocation procedure. An area is justified for protection if and only if its complementarity value exceeds its weighted cost.

TARGET iteratively adds and deletes areas from its list of priority protected areas so as to approach the nominated target levels of representation. During the course of analyses, the software repeatedly calculates a new complementarity value for any given area, reflecting changes in the degree of additional attribute representation/protection that the area can contribute to the list of protected areas.

When trade-offs are used, TARGET attempts to balance this complementarity contribution against the specified costs of protection. The area which is added to the selected priority set, at any stage, is the one which has the greatest difference between complementarity and (weighted) cost. The user can take advantage of TARGET capabilities to extend and modify the simple search provided by the basic algorithm. One approach can use alternative random starts. Another approach can begin with a high weighting on costs, such that targets are not met, and the reading in of this partial result into a subsequent analysis with lower weight on costs. This strategy can be applied iteratively until the target is met. Similar iterative approaches might initially mask out some areas, giving preference to others until later iterations. In practice, we have found these strategies useful in identifying optimal solutions. We note that the basic step-wise trade-offs algorithm (Faith and Walker 1996a,c) contrasting costs and complementarity has now been implemented in other software (e.g. "WorldMap"), but the limited search options means that least-cost solutions are less likely to be identified (Faith 2002).

When costs are given high weight in TARGET analyses, some initial biodiversity targets are not reached. A land cover type, for example, may have a lower level of representation (not all attributes within that type are represented) because protection of that type generally implies higher opportunity costs. Land cover types that are more heterogeneous (have a greater number of different attributes describing variation within the type) may justify greater representation, particularly in the presence of competing land use demands.

In addition to costs, the other factor that properly should influence the amount of area needed for representation/protection of an attribute is the degree to which areas of that type are likely to persist in the absence of formal protection. Quite extensive attributes (e.g. extensive vegetation types) may require a relatively small per centage of their total area in formal protection, because the extent of coverage helps ensure overall regional persistence of that type. Each biodiversity attribute in a given area may have some assumed degree of persistence in the absence of any new land-use allocation for the area, and some different degree of persistence if the area is allocated to a particular land use (e.g. formal protection or sympathetic management). Examples of degrees of persistence values, based on probabilities, are shown in the PNG example (figure 2; see also Faith *et al* 2001a).

TARGET uses one simple strategy (Faith and Walker 1996b,c, 1997) in which partial protection in the absence of action/re-allocation can be taken into account through modification of targets, and there is some further partial-protection or persistence value assignable for each attribute if the given area is allocated to protection. The usual quantitative values in the input data files, associated with each attribute in each area, are interpreted as indicating the degree of persistence of the attribute (e.g. persistence of a particular species) if that area were allocated to protection. The gain in total regional degree of persistence for a given attribute is a function of that attribute's individual persistence values in the set of protected areas. When the values for all areas are negative log transforms of probabilities of extinction, then summing these values provides a (negative log transform) of the overall regional probability of extinction of the attribute (e.g. of a species). The associated regional target for the attribute may be a 0·999 probability of persistence, equivalent to a 0·001 probability of extinction (a negative $\log_{10}$ transform value of 3).

2.1 *Trade-offs analysis examples*

The map shown in figure 3 is for a hypothetical region having 30 areas. The input file shown in table 1 lists the biodiversity attributes present in each area. For each area, the first line gives the area sequence number, the number of attributes present in the area and an area descriptor (here just the sequence number). The attributes are then listed with a quantitative value for each, corresponding, let us say, to number of hectares coverage. For example, area 1 has 3 attributes, numbers 1, 2, and 3, and each attribute has a quantitative value of 1 unit. Other input files to TARGET contain information concerning costs, constraints and any information for diagnosis of results.

We will first discuss example analyses that attempt to achieve a biodiversity representation target, similar to the analysis of PNG, and then will examine the corresponding trade-offs curves. The target for these analyses is one representation of each of the 30 attributes (here we used a simple approximation to that target by setting the target for each attribute to be just 0·01 of its total extent of appearance in the region; e.g. the target for attribute 1, which overall has 3 units of occurrence, is 0·03 units). As in the PNG study, the nominated total number of attributes (here, 30) may be indicated by the total number that can be represented in a set of areas totaling a nominated percentage area of the region, with no constraints on selection (see Faith *et al* 2001c).

The opportunity costs of biodiversity protection are shown on the first map (figure 4a). These might correspond to forgone forestry production opportunities. For any nominated weight on costs, the selection of priority protected areas stops when there is no possible additional area whose complementarity value exceeds its weighted cost. In these examples, TARGET runs proceeded from an initial high weight, to a series of lower weights, until the target was achieved. A first analysis, with a weight of 0·1, did not meet the target. A run with a weight of 0·01 did reach the target, with ten areas selected in order to reach the representation target at least cost (the selected areas are shown in blue in the second map, figure 4b). The total cost was 424 units. For each area selected for biodiversity protection, its final biodiversity complementarity value exceeded its weighted opportunity cost. The relative complementarity values are shown on the next map (figure 4c). Areas 6 and 7 are the two most costly areas in the region (figure 4a), but were nevertheless selected, as their complementarity (figure 4c; table 2) exceeded their weighted cost (but see below). The low weight of 0·01 given to forestry production opportunity costs was not enough to out-weigh the contribution of these two areas to biodiversity representation.

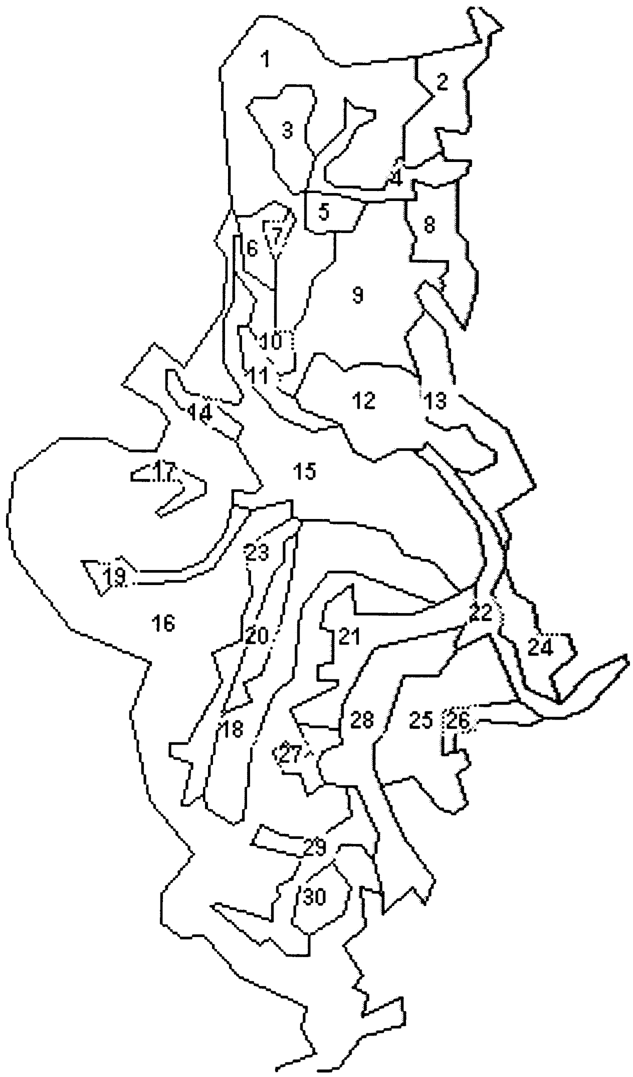

Figure 3. A map for a hypothetical region, showing 30 numbered areas.

Table 1. The input file to TARGET software for the example based on 30 areas. First row (left half of table) refers to area 1 as having 3 attributes. The area number is repeated at the end of this row. The next three rows list the attributes (in this case 1, 2, and 3) followed in each case by an amount (here 1 unit in each case). Later rows are in right half of table.

1	3	1	16	3	16
1	1		6	1	
2	1		11	1	
3	1		14	1	
2	3	2	17	3	17
2	1		21	1	
4	1		23	1	
6	1		26	1	
3	3	3	18	2	18
5	1		22	1	
6	1		24	1	
7	1		19	2	19
4	2	4	7	1	
28	1		11	1	
29	1		20	2	20
5	2	5	8	1	
6	1		18	1	
10	1		21	1	21
6	5	6	12	1	
22	1		22	2	22
24	1		12	1	
26	1		20	1	
28	1		23	3	23
30	1		5	1	
7	5	7	8	1	
21	1		16	1	
23	1		24	1	24
25	1		12	1	
27	1		25	2	25
29	1		10	1	
8	2	8	11	1	
11	1		26	3	26
16	1		27	1	
9	4	9	30	1	
15	1		17	1	
16	1		27	4	27
18	1		11	1	
20	1		12	1	
10	1	10	13	1	
12	1		14	1	
11	1	11	28	2	28
13	1		13	1	
12	2	12	19	1	
1	1		29	1	29
14	1		15	1	
13	2	13	30	6	30
4	1		1	1	
17	1		2	1	
14	1	14	7	1	
25	1		9	1	
15	3	15	12	1	
2	1		19	1	
14	1				
19	1				

We next examined the effect of having an existing protected set of areas, constrained to be part of any new priority set. In the PNG study, such an existing set significantly boosted the total area and opportunity cost needed to reach the biodiversity target. The analysis began with the existing protected areas, 16, 17, and 18, and searched for the best areas to add to the protected set of areas, while minimizing costs. Even with this constraint, we found a lower-cost solution (387 cost units; figure 4d) that reached the target. This illustrates that the simple default search in TARGET was not effective in the previous analysis – highlighting the need to use the package's multiple random starts and other options for an effective search. In this new lower cost solution, all the pre-existing protected areas contributed to reaching the target (table 2).

In the next analysis, we considered other kinds of land-use constraints without existing protected areas imposed. Suppose that areas 2, 3, 4, and 5 are permanently cleared for agriculture (therefore biodiversity protection is forgone and 81 units of forestry production opportunity are forgone). Also, area 30 is committed to intensive forestry production, precluding any biodiversity protection in that area. In the TARGET analysis, these areas were masked out, with 81 units of opportunity cost imposed at the start of the analysis. The best-possible result (figure 4e) was not quite able to reach the target (one attribute is found only in a masked out area) and the cost was now higher, at 539 units, including the 81 units forgone from the start. In this allocation, areas 6 and 7 were allocated to protection, having high complementarity values (table 2).

Next, these land use constraints are combined with the imposition of the set of existing protected areas. In the resulting allocation (figure 4f), the target again was not met because of attribute 1 being lost through areas masked out. The total cost was quite high at 630 units. Existing protected areas, 17 and 18, did not make any unique contribution to biodiversity representation (their complementarity values were 0; table 2). High cost areas, 6 and 7, again were allocated to protection, having high complementarity values (table 2). We return to a discussion of the interactions among the various land use constraints, in discussing the trade-offs curves, below.

The final analysis considered partial protection of biodiversity. Suppose that high opportunity cost areas 6 and 7 are taken to provide forestry opportunities in a way that allows partial protection of some biodiversity attributes present in these areas. Suppose that all attributes in these areas except 21–24 (table 1) are protected under this hypothetical "eco-forestry" management. The TARGET analysis then allows these two areas to be allocated to this partial protection, with no implied opportunity cost. The resulting allocation (figure 4f) turned out to be the same as in the previous analysis. Attributes not available

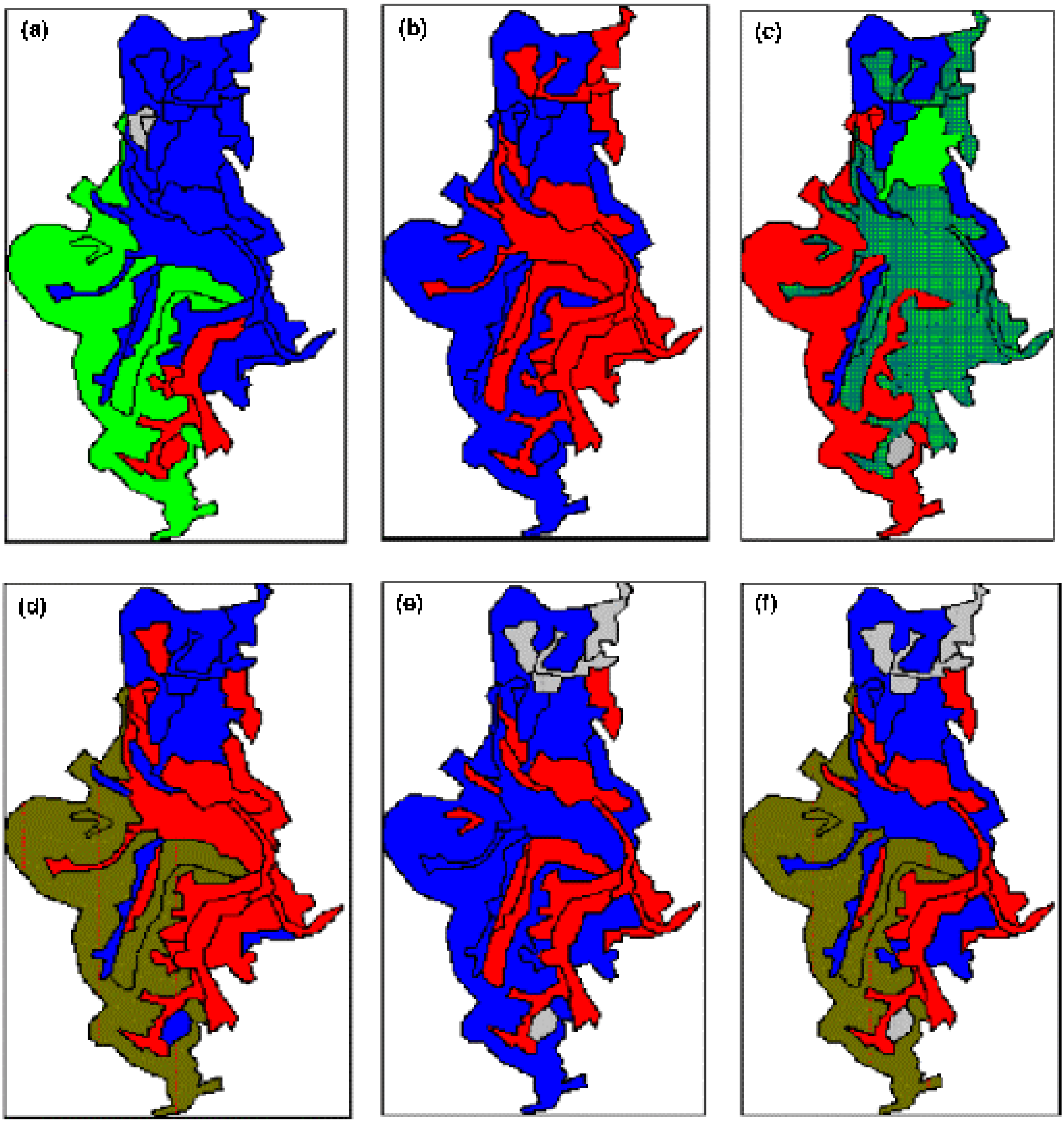

Figure 4. (**a**) Opportunity costs (see also table 2) of conservation for each of 30 areas, equal to forestry production forgone if an area is allocated to biodiversity protection. Low to high values correspond to blue, red, green, gray. (**b**) A priority set of proposed protected areas (blue) reaching the biodiversity target and minimizing costs, without any other constraints on land allocation. (**c**) The final complementarity values for the selected priority areas from (**b**). Dark green corresponds to areas not selected. Low to high complementarity values correspond to blue, green, red, gray. (**d**) A priority set (blue) found that reaches the biodiversity target, minimizing costs, and also taking into account the set of three areas given as existing protected areas (brown). (**e**) A priority set (blue) found that reaches the biodiversity target, minimizing costs, and also taking into account the unavailability of three areas cleared for agriculture, plus one degraded area (gray areas). (**f**) A selected priority set (blue) found that reaches the biodiversity target, minimizing costs, and also taking into account the unavailability of three areas cleared for agriculture, one degraded area (gray areas), and the set of three areas given as existing protected areas (brown). This same allocation occurs when areas 6 and 7 are assigned eco-forestry, providing partial biodiversity protection with no opportunity cost.

for representation in areas 6 and 7 were represented by areas 17 and 18. These two areas now show a unique contribution to biodiversity representation (table 2, under the column labeled “partial”). The important consequence of crediting partial protection is that the same level of biodiversity representation now was achieved much more cheaply (cost = only 440 units, avoiding the previous opportunity cost of 190 units for areas 6 and 7).

2.2 *The trade-offs curves*

While the above analyses focussed on achieving the biodiversity target, we now turn to the full set of analyses that provide various trade-offs curves, depending on the constraints and other assumptions of the analyses.

Table 2. Complementarity values and costs for the 30 areas. Complementarity values are raw values times 100. Analyses 4a–4f refers to allocations shown in those corresponding figures. The term “Partial” refers to the allocation (figure 4f) assuming partial protection of biodiversity in areas 6 and 7 when assigned to sympathetic forestry management.

	TARGET analysis					Opportunity cost of conservation
Area	4b	4d	4e	4f	Partial	
1	1	1	4	4	4	26
1	1	1	4	4	4	26
2	0	2	0	0	0	20
3	0	0	0	0	0	19
4	0	4	0	0	0	21
5	2	2	0	0	0	21
6	10	0	10	4	4	92
7	10	0	10	6	6	98
8	0	0	0	0	0	30
9	6	6	6	6	6	30
10	0	0	0	0	0	10
11	3	3	0	0	0	10
12	0	0	0	0	0	21
13	4	0	4	4	4	22
14	0	2	0	0	0	11
15	0	0	3	3	3	23
16	9	9	4	4	4	33
17	0	6	0	0	4	40
18	0	4	0	0	4	51
19	0	0	3	3	3	24
20	0	0	0	0	0	23
21	0	0	0	0	0	10
22	0	0	0	0	0	21
23	4	4	4	4	4	28
24	0	0	0	0	0	30
25	0	0	2	2	2	22
26	0	6	0	0	0	32
27	0	0	9	9	9	60
28	0	0	0	0	0	61
29	0	0	0	0	0	65
30	13	13	0	0	0	64

The lower curve with solid circles in figure 5a is the trade-offs curve taking into account costs, but no other constraining factors. As in figure 1, net benefits are greatest for solutions close to the lower left hand corner of the trade-offs space; “higher” curves in the space imply reduced net benefits. The solution along this curve where forgone biodiversity equals 0 corresponds to that shown in figure 4b,c. Areas 16, 17, and 18 next were constrained as fixed, existing, protected areas to produce a range of new best-possible solutions (allocations) falling along the upper trade-offs curve in figure 5a. That higher curve suggests that the best possible allocation, when high weight is to be given to forestry, now cannot provide the net benefits previously possible.

In figure 5b, the lower curve is the unconstrained curve, while the upper curve reflects allocations where areas 2–5 are permanently cleared for agriculture, and so are unavailable for biodiversity protection and forestry. Further, area 30 is committed to forestry production with no biodiversity protection. The solution along this upper curve where forgone biodiversity equals 0 corresponds to that shown in figure 4e. In this case, the best-possible biodiversity representation now achievable was reduced by one attribute (though in general this loss could be more).

If forestry production (as the opportunity cost of conservation) is given high weight (solutions found along the left-most portions of the curves in figure 5b), the loss in net benefits (the gap between the two curves) reflects largely the loss of 81 units of forestry opportunity from areas 2–5 which were permanently cleared for agriculture. However, if the biodiversity target is to be met, the loss in possible ways to achieve that target implies an additional loss of approximately twice those 81 units – 160 more units of forgone forestry opportunity would be required, as indicated by the position of the two solutions along the horizontal axis. Alternatively, if society had been willing to forgo, at most, the original 387 units of forestry, then the upper trade-offs curve would mean that the corresponding biodiversity forgone now is at least 12 units (figure 5b). Thus, land clearance implies more than simply the direct loss in biodiversity protected in those areas – the loss in possible balanced solutions is even more dramatic.

We see that a scenario where land is unavailable for a land use (for biodiversity protection, for production, or even for both) has implications best revealed in trade-offs space. In other words, the implications of scenarios are revealed less by individual variables than by the level of the trade-offs among them. Thus, synergistic effects of different factors are not necessarily related to processes but are expressed through loss of flexibility in finding a balanced solution.

In figure 5c, the lower curve again is that for no constraints, and the upper curve is for allocations for the

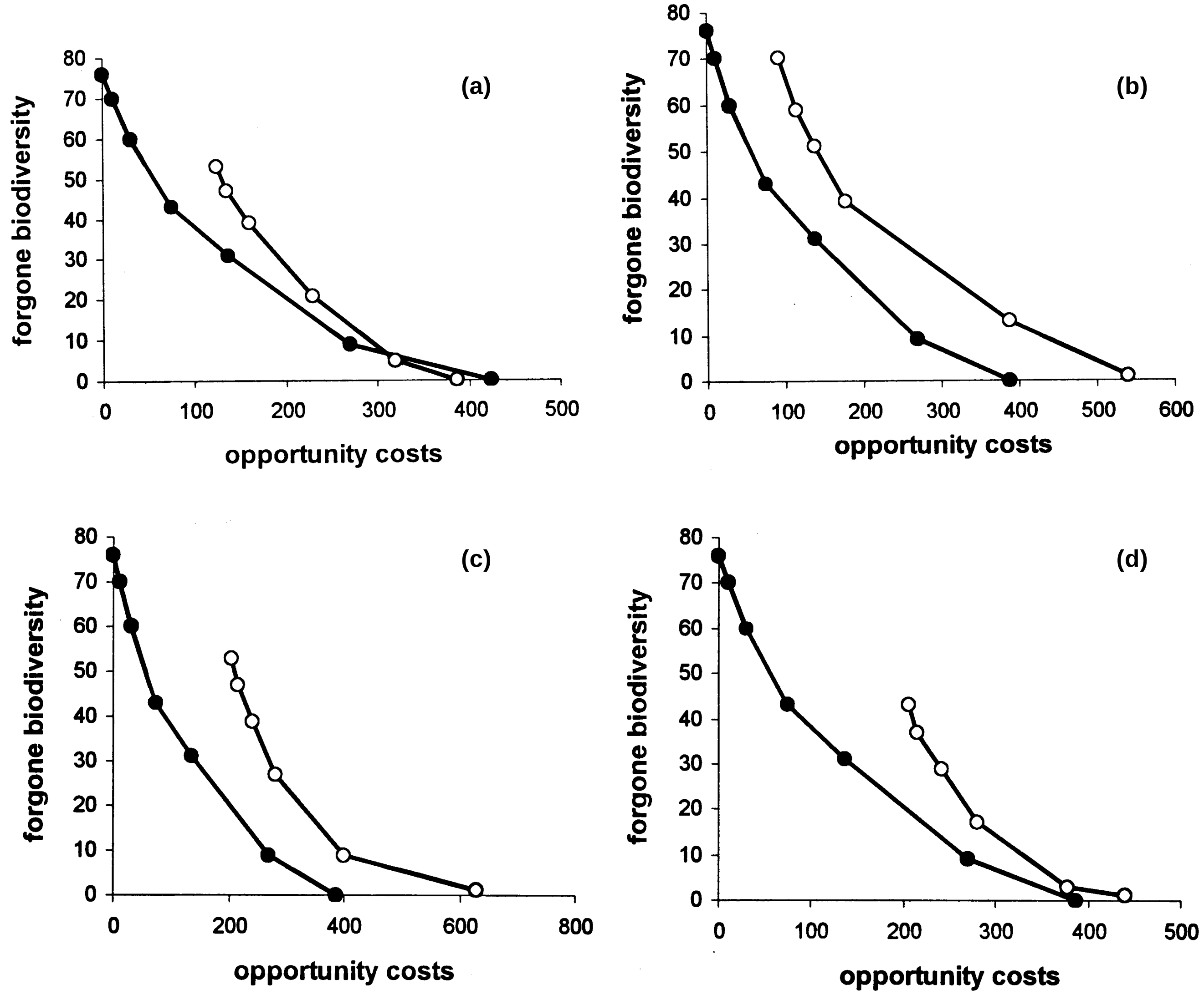

Figure 5. Trade-offs curves for the TARGET examples. For general description of the trade-offs space and curves, see the legend to figure 1. (**a**) The lower curve with solid circles is the trade-offs curve taking into account costs but no other constraining factors. The upper trade-offs curve results when areas 16, 17, and 18 are fixed, existing, protected areas. The solution (land allocation) along this curve where forgone biodiversity equals 0 corresponds to that shown in figure 4d. Note that this solution also provides a lower cost solution for the unconstrained case (see text for further explanation). **b–d** consequently show the modified unconstrained curve with the cost, at zero forgone biodiversity, set to 387 not 424 units, reflecting this improved result for the unconstrained case. (**b**) The lower curve is the unconstrained curve, while the upper curve reflects allocations where areas 2–5 are permanently cleared for agriculture, and area 30 is committed to forestry production, with no biodiversity protection. These constraints result in a significant loss in possible balanced solutions. (**c**) The lower curve is the unconstrained curve, while the upper curve reflects allocations for the combination of a fixed existing reserve set (areas 16, 17, and 18) and the constrained land uses for areas 2–5 and 30. The loss in possible balanced solutions is increased by having all the constraints in combination. (**d**) The lower curve is the unconstrained curve, while the upper curve reflects having areas, 6 and 7 allocated to a sympathetic management regime that also provides protection to at least some components of biodiversity.

combination of a fixed existing reserve set and the constrained land uses for areas 2–5 and 30. The solution along this curve where forgone biodiversity equals 0 corresponds to that shown in figure 4f. While the committed protected areas originally (figure 5a) had no effect on the cost of reaching the target, now, when other constraints exist as well, the existing protected areas imply a large increase in cost to achieve the target. The suitability of areas 2–5 for agriculture, combined with the committed protected set, implied a large increase in forgone forestry opportunities – exceeding the simple summing of the two factors taken separately. Thus, there is a synergy among the factors. A decision concerning whether to protect those existing protected areas ideally would have been made taking scenarios relating to other factors into account.

When we assume, as described earlier, that the two areas, 6 and 7, most valued for forestry production, can be allocated to a sympathetic management regime ("eco-forestry") that also provides protection to at least some components of biodiversity, a different upper curve results (figure 5d). The allocation of priority protected areas for the near-zero forgone biodiversity is the same as in figure 5c (but areas 6 and 7 now have only partial protection). The cost, as noted earlier, is much less. The combination of within-area and within region balance is powerful in ensuring scope for achieving net benefits even in the presence of other constraints Thus, a management scenario of "eco-forestry" over different candidate areas could be explored effectively in trade-offs space.

A final point concerning this partial protection is that allocation of areas 6 and 7 to eco-forestry had no opportunity cost in the analysis. But the original forestry costs (figure 4a) might have been viewed as attractiveness ratings ("negative costs") for eco-forestry, if there were a choice to made among areas. Faith *et al* (2001a) discuss such scenarios further, in the context of PNG.

The PNG study and the example TARGET analyses demonstrate the link between balanced land use allocations *among* areas and balanced use *within* areas. A unified calculus takes both into account in assessing regional sustainability – the degree to which a region has achieved its capacity for balancing society's needs. We now examine how this framework can serve the MA and CE programs. In both programs, there is scope for a stronger role for trade-offs, based on biodiversity complementarity. In the case of the MA, trade-offs already form the central program rationale. However, species richness is the main biodiversity focus, suggesting that biodiversity complementarity can play a greater role. In the case of the CE, complementarity (as estimated by endemism) of different regions is central to priority setting for conservation, but trade-offs within regions could play a strong role.

3. Trade-offs and the Millennium Assessment

The MA is a new international program of ecosystem assessments, organized and supported by UNEP, IUCN, World Bank, WRI, and others (see http://www.ma-secretariat.org; http://www.millenniumassessment.org/; see also Ayensu *et al* 1999; Kaiser 2000; Reid 2000) with the "goal of improving management of ecosystems (at all scales) by providing information to decision-makers about the condition or "health of ecosystems, consequences of ecosystem change, and options for response (policy, legislative, technological, etc.)". Health here is seen as the capacity to supply goods and services to society. Daily (1997) refers to these "ecosystem services" as "the conditions and processes through which natural ecosystems, and the species that make them up, sustain and fulfill human life". The MA identifies trade-offs among services as a key issue, arguing that "the challenge of meeting the human needs for ecosystem goods and services is so great that trade-offs have become the rule" and that "it remains to be seen whether the capacity of the system to provide the combination of the services is optimized". The challenge therefore is to learn as much as possible about interlinkages among services. Further, "only be looking at the entire array of goods and services provided by ecosystems can wise decisions be made that address the interlinkages among them". "The MA is thus concerned with examining how changes in ecosystems affect access to basic needs such as food, fuel, fiber, water; how they affect local climate and risks associated with droughts, storms, floods; how they affect human health and human economies; and how they affect less tangible cultural, moral, aesthetic, and ethical concerns". (Quotes above are from the MA web pages, http://www.ma-secretariat.org.)

3.1 *Biodiversity conservation versus other services*

The conservation of biodiversity is recognized as a key ecosystem service (Daily 1999). However, given the wide range of different services competing for attention in the MA, it is natural to ask whether biodiversity conservation will be ignored in practice. While the argument can be made that protecting other services protects biodiversity, actions to maintain specific species – the "biospecifics" (sensu Faith 1997b) associated with specific services – does not necessarily maintain overall biodiversity as well. Biodiversity conservation must be given some explicit weight relative to other services for effective trade-offs to be achieved.

The process of trading-off services in the market-based economic framework of the MA also may lead to a neglect of biodiversity and its option values (for discussion of option values, see e.g. Faith *et al* 2001a). In the context of the MA, Ayensu *et al* (1999) call for new information on the economic value of "non-marketed" goods and services produced by ecosystems, noting that economic values "may be significant to management decisions". Because the ecosystem services approach looks for economic values, the option values of biodiversity may be hard to quantify as part of the same assessments.

Conserving the option value of biodiversity may be an acknowledged ecosystem service, but there is a danger that it will be left out of assessments as too hard to quantify in terms of economic value (see e.g. Kremen *et al* 2000).

In spite of these concerns, the focus on trade-offs in the MA is potentially quite compatible with non-economic valuations as well. For example, Daily (1997) states, "this forecasting exercise will illuminate the trade-offs among different ecosystem variables, and therefore among different mixtures of ecosystem goods and services (which may be measured in contrasting units such as mass of carbon or diversity of species)". In accord with this, we suggest that a land-use allocation trade-offs space, with emphasis on complementarity among areas, can play an important role in the MA. As the PNG study illustrates, there can be a mix of markets (as in carbon offsets markets) together with "top-down" imposed trade-offs that set biodiversity targets based on quantification of biodiversity option values (Faith *et al* 2001a).

3.2 *The importance of complementarity*

In exploring scenarios of human-induced change on ecosystems and consequent impacts on trade-offs among services, it is important to consider changes in biodiversity complementarity values. We have seen that interdependencies among different constraints/factors, as in the TARGET examples, account for changes in complementarity values. For example, areas 17 and 18 had non-zero complementarity only when partial protection in areas 6 and 7 was incorporated into the regional plan for biodiversity protection (table 2). In the PNG study, changes of complementarity value under different scenarios affected expectations about carbon offsets, levies and other services.

The key role of biodiversity complementarity in trade-offs among services needs to be considered in the context of the MA's stated perspectives on biodiversity. The MA planning documents (http://www.ma-secretariat.org; http://www.millenniumassessment.org) describe biodiversity information largely as species-richness or total diversity. For example, references are made to the need for richness maps for different regions and ecosystems. However, regional trade-offs must compare an area's "marginal", context-dependent, biodiversity contribution to other services.

Similarly, the MA asks: "Where is the condition of the ecosystem to maintain biodiversity in good condition and where is it declining? What do we know about the impact of habitat change on species diversity and how does this differ in different regions and taxonomic groups? What do we know about the impact of fragmentation on species diversity?" (http://www.ma-secretariat.org). We argue that impacts on complementarity values are perhaps more critical to trade-offs.

The MA's focus on diversity or total richness is revealed also in the call for "an additional analysis of the state of our scientific understanding of whether or not patterns of species richness in known taxonomic groups match patterns in poorly known groups". The trade-offs framework, in contrast, focuses on a quite different form of prediction, asking whether the complementarity value for one taxonomic group predicts the complementarity of other groups (Faith *et al* 2001c).

Other discussions of the MA have given less emphasis to total diversity. Daily's (1997, 1999) proposed framework for trading-off ecosystem services highlights marginal gains: "The evaluation of the tradeoffs currently facing society, however, requires estimating the marginal value of ecosystem services (the value yielded by an additional unit of service, all else held constant) to determine the costs of losing-or benefits of preserving – a given amount or quality of service" (Daily 1997). We endorse this perspective as compatible with the role of complementarity in trade-offs, but with one caveat. In our biodiversity trade-offs framework (Faith 1995), the quantities being traded-offs are more general than ecosystem services. Often the opportunity costs are not a good or service: in PNG a cost of biodiversity protection is the "transaction" cost, equal, for example, to costs of administration.

In the discussion above, we have emphasized complementarity in trade-offs (among areas) within a region. But within-area issues are important too. The MA's emphasis on total species diversity (rather than complementarity) is partly a natural consequence of seeing diversity as a driving factor influencing other services (e.g. see McGrady-Steed *et al* 1997; Naeem and Li 1997; but see Huston *et al* 2000). In considering impacts of changes in biodiversity, the MA asks: "How does change in species diversity affect the biological productivity of ecosystems and in particular the production of fish, food, fiber and other products directly consumed by people?" (http://www.ma-secretariat.org). A "balance" among services within an area is achieved if such an interdependency exists – maintaining biodiversity implies maintenance of those other services as well. More generally, those considerations raise issues of partial protection, where biodiversity conservation and maintenance of other services go hand-in-hand (not necessarily through any functional dependence, but through any kind of management compatibility).

The broad scope of the problem of balancing various services within and among areas suggests to us that the general property of our trade-offs framework that is of most potential use for the MA is its unified view of trade-offs over different scales. "Partial protection" of biodiversity within an area feeds into "regional sustainability" assessment at higher scales, as illustrated in the examples discussed above. The MA, which has a strong focus already on finding a balance among "ecosystem services" *within* areas, will benefit also from trade-offs *among* areas as part of its scenarios analyses.

4. Trade-offs and critical ecosystems

The CE program (Mittermeier *et al* 1999, 2000; Myers *et al* 2000; http://www.conservation.org/hotspots/) is based in part on Conservation International's programs identifying 25 global hotspots, based on places having high estimated levels of endemicity (see Mittermeier *et al* 1999; Myers *et al* 2000). The CE hotspots approach excludes trading-off biodiversity with opportunity costs as a strategy for prioritizing among regions: "We should also emphasize here that the biological criteria are always the first cut, the first layer of analysis, in determining the priority status of a particular region. We believe that it is dangerous and misleading to mix threat and biological criteria in the first step of analysis, and even more confusing when social, economic, and even political feasibility criteria are mixed into this first level. It is important always to keep in mind that a biodiversity priority-setting exercise must focus first and foremost on the biological, and that other criteria such as threat, social and economic factors, political will, feasibility, and the like should be introduced in subsequent layers of analysis. Indeed, we believe that these are most useful in the project design phase, when such factors become particularly relevant" (see http://www.conservation.org/hotspots/).

While we strongly advocate trade-offs for priority setting, we do agree, in part, with this position. At the level of prioritizing among regions, endemicity is useful as a key factor. First, endemism contributions to complementarity values can determine the "must-have" areas in any trade-offs analysis that is to represent all taxa (Faith *et al* 2001c). Those areas are given priority no matter what the cost. Further, the suggested application of the socio-economic factors only at the "project design" phase can be interpreted to encompass trade-offs to determine which areas *within* the region are to be protected for biodiversity conservation.

The hotspots approach recently has been justified as the most cost effective way to protect biodiversity (Myers *et al* 2000). Mace *et al* (2000) argued that the claim of cost-efficiency was suspect without application of trade-offs and other approaches to priority setting. However, simple application of trade-offs selection procedures at the *among-regions* level does not capture the proper role for trade-offs in priority setting (see also Faith *et al* 2001a). Trade-offs, given their key role *within regions*, may influence priorities *among* regions simply because we want to know where they are most urgently needed (or where the potential to achieve good trade-offs is judged most under threat, according to scenarios such as those in our earlier examples).

The CE program, in spite of the biology-only criteria quoted above, acknowledges such a consideration: "The three major wilderness areas of the Congo, the Amazon, and New Guinea and associated forests in insular Southeast Asia not only contain a very large fraction of the world's species, but they are among the very places where natural process unfold on something like their natural scale. Their protection has to be a major priority. These areas suffer from a variety of threats that include logging, mining, the extraction of oil and gas, and the conversion to monoculture agriculture, such as soybeans" (Pimm 2000). Thus, the CE program appears compatible with trade-offs (such as those applied in the PNG study) within a region, possibly with some higher-level priority given to those regions where the trade-offs within are most needed.

It is interesting that the CE recommendations regarding hotspots might be read to imply that *all* (undisturbed) areas within these areas are to be protected: "An estimate of a few billion dollars would ensure conservation on all 11% of remaining habitat in the hotspots. . . . The typically high population densities, small size of habitat patches available for conservation and high opportunity costs associated with protection mean that effective conservation of biodiversity in the hotspots, while essential, is also relatively expensive" (see http://www.defyingnaturesend.org/about/CABSconferencewrapup.pdf).

This idealized view also can be reconciled in practice with trade-offs. The trade-offs framework may play an important role in either (i) justifying why all the remaining intact habitat must be protected, or alternatively (ii) showing how some areas can be allocated to other uses so as to reduce overall costs to society in terms of forgone opportunities. In the first case, a 10% (or other) conservation target may be applied as it was in the PNG study (see Faith *et al* 2001c). Meeting the target means protecting biodiversity within the region to the extent that it could have been accomplished with an unconstrained 10% of the area. If land clearance/disturbance is extensive, then all remaining areas may require protection to meet that biodiversity target. In the second case, some trade-offs are still possible in achieving the conservation target, and opportunity costs therefore can be minimized through a combination of land allocation and partial protection, where multiple ecosystem services are accommodated within the same region and sometimes even within the same area.

Simply assuming all undisturbed areas within a hotspot deserve protection could imply an unduly great opportunity cost of conservation. When trade-offs are possible, there can be a large penalty to society to ignore them (see figure 1a). In the PNG study, hypothetical analyses based on biodiversity protection without regard to costs created unnecessarily low net benefits (Faith *et al* 2001b).

Given that PNG is part of the CE priority tropical wilderness areas for conservation, it is interesting also that PNG is regarded as having low costs: "Whereas the hotspots consist of heavily exploited and often highly fragmented ecosystems greatly reduced in original extent (usually between 4% and 25% remaining), the major tropical wilderness areas are still largely intact (over 75% of original vegetation cover remaining) and have very low human population density (less than 5 people/km^2). Myers (1988) had touched on a concept of this kind in his first hotspots paper, briefly referring to what he called "good news areas". Further, "since they are still under far less human pressure than the threatened hotspots (although the pressures on them are increasing rapidly), the "opportunity cost" of conservation is much lower in these areas, i.e. large-scale conservation set-asides can be achieved at far lower financial cost than in the areas where little remains (Rice and Bowles, personal communication)" (http://www.conservation.org/hotspots/).

Thus, low population density and large areas "intact" are seen as implying low opportunity costs of conservation. We see PNG as indeed not devastated, but not a "good news" area either. In truth, PNG can imply low realized opportunity costs or quite high realized opportunity costs, depending on whether a balance is found through biodiversity planning based on trade-offs (see also Faith *et al* 2001b). PNG is a good example of a worthy priority region, because the potential net benefits for society may be needlessly foreclosed through poor planning that does not address conflict among various needs of society (see also Faith 2001). The risk of losing those potential net benefits is the strong argument for investment in PNG. In one of our earlier examples, we argued, "land clearance implies more than simply the direct loss in biodiversity protected in those areas – the loss in possible balanced solutions is even more dramatic".

5. Discussion

We have discussed the MA and CE programs separately, but have argued in each case that trade-offs among areas at the regional scale will play a key role. In the CE, global conservation priorities have been proposed, with much fanfare. But conceivably every country or region could benefit from implementing some trade-offs planning, in order to prioritize within regions and explore scenarios. In the PNG study, the total planning and scenarios cost was on the order of US$ 500,000 (see Nix *et al* 2000), suggesting that every country could be a "priority" for regional planning. It is an open question as to whether the greatest gains per unit investment can be made by initiating some good trade-offs everywhere versus intensive conservation work in selected places.

In the MA, the idea that the biodiversity in a given area provides a range of services whose valuation may mean that biodiversity is valued as well, has been promoted, again with much fanfare. But conceivably a big step towards a balance among all these services can be achieved by implementing trade-offs among areas within regions. That process allows for cases where biodiversity protection remains in direct conflict with favoured services, within individual areas. It is an open question as to whether the greatest gains per unit investment can be made by initiating better trade-offs among areas versus finding a better balance within areas by linking biodiversity protection to provision of other services. The trade-offs framework explored here can contribute to exploring such alternative strategies.

References

Ayensu E D, Claasen V, Collins M, Dearing A, Fresco L, Gadgil M, Gitay H, Glaser G C, Lohn L, Krebs J, Lenton R, Lubchenco L, McNeely J A, Mooney H A, Pinstrup-Andersen P, Ramos M, Raven P, Reid W V, Samper C, Sarukhan J, Schei P, Tundisi J G, Watson R T, Xu G H and Zakri A H 1999 Ecology – International ecosystem assessment; *Science* **286** 685–686

Daily G C 1997 *Nature's services: Societal dependence on natural ecosystems* (Washington: Island Press)

Daily G C 1999 Developing a Scientific Basis for Managing Earth's Life Support Systems; *Conserv. Ecol.* **3** 14 [online URL: http//www.consecolorg/vol3/iss2/art14]

Faith D P 1995 *Biodiversity and regional sustainability analysis* (Canberra: CSIRO)

Faith D P 1997a Biodiversity assessment and opportunity costs; in *Investing in biodiversity* (Paris: OECD) pp 87–103

Faith D P 1997b Biodiversity biospecifics and ecological services; *Trends Ecol. Evol.* **12** 66

Faith D P 2001 Cost-effective biodiversity planning; *Science* **293** [online] 2 November. http://www.sciencemag.org/cgi/eletters/293/5538/2207#356

Faith D P 2002 Those Complementarity Analyses Do Not Reveal Extent of Conservation Conflict in Africa; *Science* [online] 10 January. http://www.sciencemag.org/cgi/eletters/293/5535/1591#381

Faith D P, Margules C R, Walker P A, Hutchinson M and Nix H A 1999 Biodiversity conservation planning and implementation in Papua New Guinea: from targets and trade-offs to environmental levies and carbon-offsets; in *Pacific Science Congress* (Sydney: University of New South Wales) pp 133

Faith D P and Walker P A 1994 *DIVERSITY: a software package for sampling phylogenetic and environmental diversity Reference and user's guide v. 2·1* (Canberra: CSIRO)

Faith D P and Walker P A 1996a Integrating conservation and development effective trade-offs between biodiversity and cost in the selection of protected areas; *Biodiver. Conserv.* **5** 417–429

Faith D P and Walker P A 1996b Integrating conservation and development incorporating vulnerability into biodiversity-assessment of areas; *Biodiver. Conserv.* **5** 431–446

Faith D P and Walker P A 1996c DIVERSITY – TD; in *BioRap rapid assessment of biodiversity. Vol. 3: Tools for assessing biodiversity priority areas* (eds) D P Faith and A O Nicholls (Canberra: CSIRO) pp 63–74

Faith D P and Walker P A 1997 Regional sustainability and protected areas biodiversity protection as part of regional integration of conservation and production; in *National parks and protected areas: selection delimitation and management* (eds) J Pigram and R C Sundell (Armidale: University of New England Press) pp 297–314

Faith D P, Walker P A, Ive J R and Belbin L 1994 Integrating conservation and forestry production effective trade-offs between biodiversity and production in regional land-use assessment; in *Conserving biological diversity in temperate forest ecosystems – towards sustainable management* (Canberra: Australian National University) pp 74–75

Faith D P, Walker P A, Ive J and Belbin L 1996 Integrating conservation and forestry production exploring trade-offs between biodiversity and production in regional land-use assessment; *For. Ecol. Manage.* **85** 251–260

Faith D P, Walker P A and Margules C R 2001a Some future prospects for systematic biodiversity planning in Papua New Guinea – and for biodiversity planning in general; *Pac. Conserv. Biol.* **6** 325–343

Faith D P, Margules C R and Walker P A 2001b A biodiversity conservation plan for Papua New Guinea based on biodiversity trade-offs analysis; *Pac. Conserv. Biol.* **6** 304–324

Faith D P, Margules C R, Walker P A, Stein J and Natera G 2001c Practical application of biodiversity surrogates and per centage targets for conservation in Papua New Guinea; *Pac. Conserv. Biol.* **6** 289–303

Huston M A, Aarssen L W, Austin M P, Cade B S, Fridley J D, Garnier E, Grime J P, Hodgson J, Lauenroth W K, Thompson K, Vandermeer J H, Wardle D A, Hector A, Schmid B, Beierkuhnlein C, Caldeira M C, Diemer M, Dimitrakopoulos P, Finn G J A, Freitas H, Giller P S, Good J, Harris R, Högberg P, Huss-Danell K, Joshi J, Jumpponen A, Körner C, Leadley P W, Loreau M, Minns A, Mulder C P H, O'Donovan G, Otway S J, Pereira J S, Prinz A, Read D J, Scherer-Lorenzen M, Schulze E-D, Siamantziouras A-S D, Spehn E, Terry A C, Troumbis A Y, Woodward F I, Yachi S and Lawton J H 2000 No consistent effect of plant diversity on productivity; *Science* **289** 1255

Kaiser J 2000 Ecologists Hope to Avoid the Mistakes of Previous Assessment; *Science* **289** 1677

Kremen C, Niles J, Dalton M, Daily G, Ehrich P, Fay J, Grewel D and Guillery R P 2000 Economic incentives for rain forest conservation across scales; *Science* **288** 1828–1829

Mace G M, Balmford A, Boitani L, Cowlishaw G, Dobson A P, Faith D P, Gaston K J, Humphries C J, Lawton J H, Margules C R, May R M, Nicholls A O, Possingham H P, Rahbek C, van Jaarsveld A S, Vane-Wright R I and Williams P H 2000 It's time to work together and stop duplicating conservation efforts; *Nature* (*London*) **405** 393

McGrady-Steed J, Harris P M and Morin P J 1997 Biodiversity regulates ecosystem predictability; *Nature* (*London*) **390** 162–165

Mittermeier R, Myers N and Mittermeier C G 1999 *Hotspots: Earth's biologically richest and most threatened ecoregions* (Mexico City, Washington DC: CEMEX)

Mittermeier R, Myers N, Gil P and Mittermeier C G 2000 *Hotspots*; http://www.conservation.org/hotspots/

Myers N 1988 Threatened biotas: "hotspots" in tropical forests; *Environmentalist* **8** 1–20

Myers N, Mittermeier R A, Mittermeier C G, da Fonseca G A B and Kent J 2000 Biodiversity hotspots for conservation priorities; *Nature* (*London*) **403** 853–858

Naeem S and Li S 1997 Biodiversity enhances ecosystem reliability; *Nature* (*London*) **390** 507–509

Nix H A, Faith D P, Hutchinson M F, Margules C R, West J, Allison A, Kesteven J L, Natera G, Slater W, Stein J L and Walker P A 2000 *The BioRap toolbox: A national study of biodiversity assessment and planning for Papua New Guinea* (Canberra: CSIRO Press)

Pimm S 2000 *Preliminary report for the conference "Defying Nature's End' – A practical agenda for saving life on the planet*"; (http//www.defyingnaturesend.org/about/CABSconferencewrapuppdf)

Pressey R L, Humphries C J, Margules C R, Vane-Wright R I and Williams P H 1993 Beyond opportunism key principles for systematic reserve selection; *Trends Ecol. Evol.* **8** 124–128

Reid W V 2000 Ecosystem data to guide hard choices; *Iss. Sci. Tech.* **16** 37–44

Vane-Wright R I, Humphries C J and Williams P H 1991 What to protect? – Systematics and the agony of choice; *Biol. Conserv.* **55** 235–254

Walker P A and Faith D P 1998 *TARGET: Software for priority area setting* (Canberra: CSIRO)

Weitzman M L 1992 On diversity; *Q. J. Econ.* **58** 157–183