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Spatial prioritisation of environmental service payments for biodiversity protection

In collaboration with
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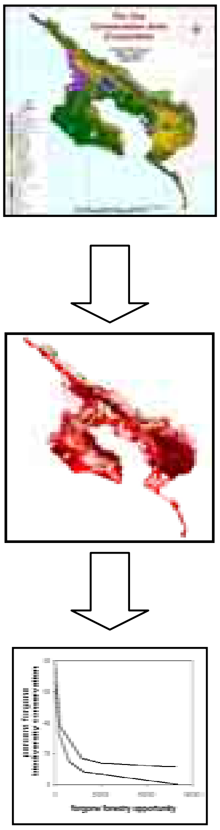

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Sammendrag

Kostnadseffektivitet av ulike allokeringer av miljøinsentiver til vern av biologisk mangfold på privat eiendom vurderes med modellen TARGET. Data for alternative indikatorer for biologisk mangfold og alternativekostnadene ved tapte jord- og skogbruksinntekter som brukes i modellen er hentet fra Costa Rica’s ACOSA verneområde. Resultatene fra modellen kan brukes til bedre prioritering av miljøtjeneste-betalinger (environmental service payments) for vern av biologisk mangfold utenfor statlige vernområder.

Fire norske emneord	Fire engelske emneord
1. biomangfoldsindikatorer	1. biodiversity complementarity indicators
2. TARGET kostnadseffektivitetsanalyse	2. TARGET cost-efficiency analysis
3. miljøtjenestebetaling	3. environmental service payments
4. Costa Rica	4. Costa Rica

Prosjektleder	Forskningsleder	Forskningsdirektør
David N. Barton		

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Bioindicators Project

Spatial prioritisation of environmental service payments for biodiversity protection

Decision-making models for evaluating cost-effectiveness of conservation priorities using alternative biodiversity indicators

Photo: D.N.Barton, 2002

Corcovado National Park, Costa Rica

Foreword

The Project ”Decision-making models for evaluating cost-effectiveness of conservation priorities using alternative biodiversity indicators” (Short title: Bioindicators Project) has been supported by a grant from the Norwegian Research Council. We are grateful for their support of such and inter-disciplinary and international undertaking.

Collecting and analysing georeferenced biodiversity and economic land use data for this study could not have been possible without the efforts of researchers from several different fields within the Bioindicators Project, and previous work conducted by other researchers and institutions in Costa Rica. Dan P. Faith (Australian Museum) made the TARGET software available to the project and provided invaluable assistance in running the model; Marco Castro and Alvaro Herrera (Instituto Nacional de Biodiversidad, INBio) provided and assessed GIS data from INBio’s *ECOMAPAS* project and biodiversity inventory *Atta ;* Mauricio and Edwin Vega (Instituto de Politicas para la Sostenibilidad, IPS) conducted studies of agricultural and forestry opportunity costs in ACOSA; Bodil Wilman (NINA) provided assistance in formatting GIS data to Access and TARGET input files. Conservation area managers from the Area de Conservación Osa (ACOSA) and the Sistema Nacional de Areas Protegidas (SINAC) participated in workshops and interviews to discuss the results and possible applications of TARGET trade-offs analysis. We would like to thank NORAD for supporting the participation of conservation area managers from other Central American countries at these workshops and to thank INBio for organisation and hosting.

Oslo, 1. December 2003

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Summary

Title: Spatial prioritisation of environmental service payments for biodiversity protection
Year: 2003
Authors: David N. Barton[1] (NIVA), Dan Faith (Australian Museum), Graciela Rusch and Jan Ove Gjershaug (NINA), Marco Castro (INBio), Mauricio and Edwin Vega (IPS)

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This paper demonstrates the use of TARGET trade-offs analysis for prioritising environmental service payments (so-called *PSA* or '*Pagos por Servicios Ambientales*' in Spanish[2]) to private land-owners in the Osa Conservation Area (ACOSA), Costa Rica. The paper answers a number of research questions of direct management relevance in ACOSA and general relevance to biodiversity conservation planning in the region. What is the incremental opportunity cost of extending environmental service payments to areas outside established protected areas? What have been the incremental costs and biodiversity complementarity of existing allocation of economic incentives to private conservation relative to a cost-efficient allocation as calculated using TARGET? How might ACOSA authorities and the National Forestry Fund (FONAFIFO) in charge of PSA prioritise between future competing applications for incentives from land-owners in the Osa Conservation Area? What data collection challenges must be overcome in order to implement TARGET as a prioritisation tool for PSAs at the national level in Costa Rica?

Our analyses for the ACOSA area conclude that the current selection of areas to receive environmental service payments for forest protection , forest management, and reforestation has not been cost-efficient, in the sense of maximising biodiversity protection on private land outside existing national parks, while also minimising the opportunity costs to agriculture and commercial forestry. The paper goes on to show how TARGET methodology may be used to rank PSA canididate areas by their cost-efficiency in representing complementary biodiversity at lowest cost at regional level (ACOSA). Current limitations of the analysis include sufficient resolution to evaluate PSA candidate areas smaller than 100 hectares. The paper discusses the possibility of application of methodology at national level provided improved processing capacity of the TARGET software, and improved national coverage of GIS for environmental attributes that are used as biodiversity surrogates.

Other reports in the Bioindicators Project

(Barrantes, E.Vega et al. 2002; Vega and Vega 2002; Vega 2002)

Barrantes, G., E.Vega, et al. (2002). Determinación de los costos de manejo y protección en ACOSA (Bioindicators Project: NOTAT N-03/014). San Jose, Instituto para Politicas de Sostenibilidad**:** 26.

Vega, E. and M. Vega (2002). Determinación del costo de oportunidad y clasificación por clases de capacidad de uso (Bioindicators Project: NOTAT N-03/012), Instituto de Políticas para la Sostenibilidad**:** 34.

Vega, M. (2002). Determinación del rendimiento forestal en el Area de Conservación Osa (Bioindicators project: NOTAT N-03/013), Instituto de Políticas para la Sostenibilidad (IPS)**:** 24.

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[1] Corresponding author: David.barton@niva.no, Norwegian Institute for Water Research (NIVA).
[2] We stick to the original Spanish abbreviation throughout the paper as Costa Rica has been one of the pioneers in the use of these economic incentives in forestry conservation.

1. Introduction

Until recently the designation of protected areas in Costa Rica – both on private and public land - had not been evaluated for its effectiveness in protecting known biodiversity in the country. One of the first efforts of prioritising conservation areas at a regional level, while integrating biodiversity and economic concerns, was the evaluation of the cost of a minimum set of areas to conserve pristine ecosystems and endemic and rare species (Vreugdenhill 1992). The minimum set was evaluated using a scoring system for the attractiveness of potential protected areas based on a spreadsheet model with costs calculated as average land purchase and management costs per protected area. The GRUAS study was the first national level planning effort to employ GIS based data (Garcia V. 1996), identifying potential biological corridors and re-classifying existing protected areas in order to assure representation of a minimum set of interconnected vegetation macrotypes. The study took into account the local potential for land use conflict through local consultations, as well as a qualitative evaluation of the potential for other environmental services, particularly water supply.

The GRUAS study became a “benchmark” for declaration of protected areas and corridors since 1996. Because it used only a simple surrogate for biodiversity importance (macrotype vegetation) , its lack of a quanitative priority-setting methodology, and its political impact it has led to a considerable research effort in the country on how to improve the criteria for selecting new public protected areas. A number of formal approaches to formal priority-setting in the environmental economics literature have been proposed; including ‘scoring’, ‘iterative’, ‘linear programming’ and ‘hazard’ based approaches(Pfaff and Sanchez 2003, in press).

Although the detail of information varies (Vreugdenhill 1992; Garcia V. 1996) are based on *scoring* of areas based on their contribution to an objective of representing a minimum set of biodiversity surrogate attributes. These scoring based apporaches have not considered the costs of conservation in a spatially explicit manner, partly for lack of appropriate GIS data. GIS based GAP analyses have more recently been used to identify land cover, vegetation and selected wildlife habitat that was not represented with the network of protected areas (Powell, Barborak et al. 2000). Although GIS-based GAP analyses have used a greater number of , and more detailed spatial information regarding surrogate attributes of biodiversity, gap identification has not been concerned with the economic consequences of protected area priority-setting.

The other main vain of priority setting approaches applied in Costa Rica by economists since the GRUAS study have been ’hazard’ based. The probability of a forest habitat vanishing over time is modelled as a regression function of a series of pressure and constraint variables, including population density, ease of access, land suitability for agriculture and presence of protected areas (Rosero-Bixby, Maldonado-Ulloa et al. 2002; Pfaff and Sanchez 2003, in press). A multi-period dynamic model using similar spatially explicit land use drivers to predict forest cover was developed by (Cornell 2000). The different authors use the resulting regression functions to calculate deforestation hazard at a future date based on e.g. projected population growth by area. Pfaff and Sanchez argue that an index of deforestation hazard should be one of the main criteria for prioritising new areas for protection (in addition to the benefits and costs of protected areas, and protected area effectivness in reducing deforestation hazard). All these studies have in common a probabilistic approach to priority-setting, as well as using several explanatory variables which are closely correlated with – but do not explicitely account for - opportunity cost of conservation.

Although these studies are from Costa Rica, they provide a good timeline of the state of the art in priority-setting methods of the past decade internationally. Given Costa Rica's relative advantages to other tropical developing countries in the avaiability of georeferenced biophysical and socio-demographic data, it has provided a testing ground for new approaches to conservation planning. The above review of the literature indicates that the iterative and programming approaches have not been applied previously to protected area planning in Costa Rica, and probably not in Central America.

The present study is an example of an "iterative" approach, where priority-setting is based on marginal gains in biodiversity of adding successive areas to the existing set of protected biodiversity relative to an established conservation target, and weighed against the opportunity costs of conservation. To our knowledge the approach is new in the context of Central America for; (i) quantification of the marginal benefits of protecting additional areas using a surrogate indicator of biodiversity complementarity, (ii) iterative trade-off analysis of biodiversity complementarity versus opportunity costs , (iii) using trade-offs analysis to evaluate priority-setting of conservation on *private* land through environmental service payments.

The paper is laid out as follows. Section 2 presents the TARGET methodology used for evaluation of biodiversity-cost trade-offs and priority-setting. Section 3 presents the Costa Rican system of environmental service payments and their application to the Osa Conservation Area (ACOSA) where our analyses are conducted. Section 4 presents results from the evaluation of cost-efficiency of the present allocation of environmental service payments in ACOSA. Section 5 demonstrates an approach to priority setting of environmental service payment contracts to individual private land owners. Section 6 and 7 offer a discussion of the results and conclusions. Appendix 1 offer the reader further documentation of the TARGET methodology and applications in other sites. Appendix 2-3 provide further documentation of the surrogate biodiversity indicator and the calculation of agricultural and forestry opportunity costs.

2. Trade-off analysis methodology using TARGET

Introduction

This section provides background for the land-use / biodiversity conservation methods used in our study. We used methods implemented in the software package, TARGET. TARGET is one module of the DIVERSITY software package (Faith and Walker 1995) and is also a software module described within the BioRap toolbox (Faith and Walker 1996). The biodiversity trade-offs strategies used in TARGET are described in (Faith and Walker 1996; Faith, Walker et al. 1996). Extensive applications of TARGET are reported in the set of publications following the World Bank funded "BioRap" planning study in Papua New Guinea (Faith, Margules et al. 2001; Faith, Margules et al. 2001; Faith, Margules et al. 2001; Faith, Nix et al. 2001; Faith, Walker et al. 2001)

TARGET uses information on the biodiversity attributes (environmental data, vegetation types, species, etc) contained in different geographic areas (polygons, grid cells, properties, etc) within a region to search for sets of areas that represent the biodiversity of the region. At the same time, the sets may be required to satisfy one or more constraints and/or have minimum cost. Further, TARGET may evaluate scenarios - for example, the biodiversity gains/losses if an area is added/deleted from a set of protected areas. Fundamental to all TARGET analyses are estimates of complementarity - the marginal contribution in biodiversity representation provided by an area in the context of a set of protected areas; in other words, how much the selection of an additional area will contribute to the representation of overall biodiversity already protected. Because such marginal gains depend on context (an area's attributes may or may not be represented already by a given set), TARGET algorithms operate by iteratively re-calculating such values in the course of selecting sets of areas.

TARGET assumes that the areas in a region are described as containing one or more different biodiversity "attributes". The attributes must be spatially explicit (be related to an area) and should have a known or estimated value for all areas to be compared in the analysis. At the coarsest level of resolution might be physical (environmental) attributes that are related to the spatial distribution of living organisms, biotopes, habitat types, vegetation types, etc. The attributes might be species or other biotic units. 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.

TARGET focuses on regional biodiversity "targets". TARGET typically searches 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 other competing land uses. Thus, costs vary among areas and so can influence the selection of sets of areas that are to balance biodiversity conservation with other needs of society (or achieve conservation within a budget).

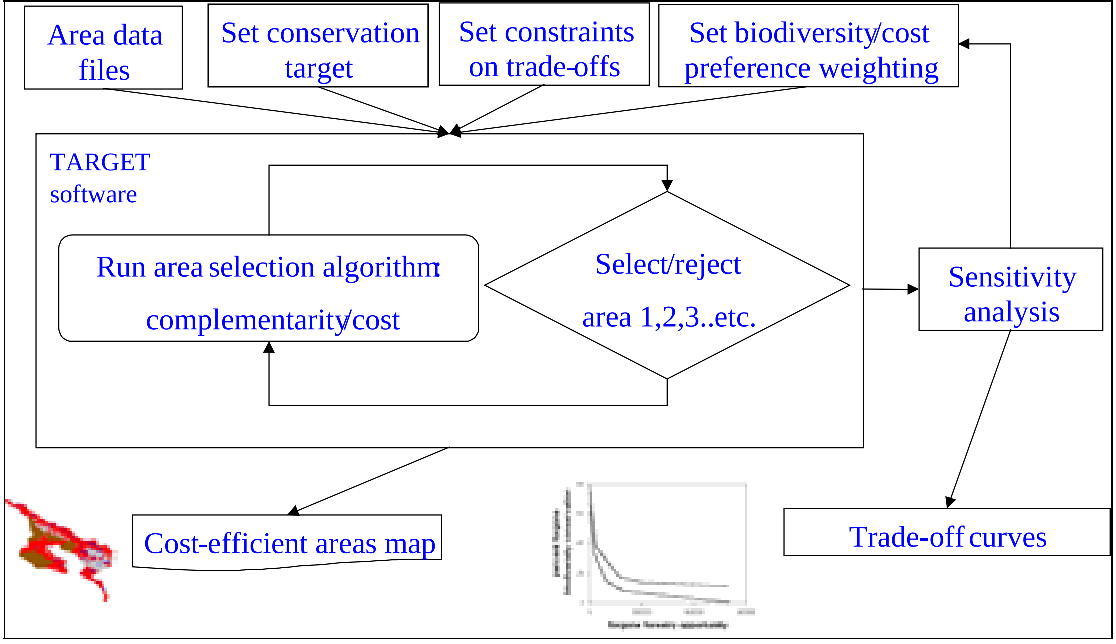
When costs are taken into account, the relative "importance" or weight given to these costs, relative to biodiversity representation, will influence the outcome of the allocation procedure. An area is justified for protection if and only if its "complementarity" value (its marginal contribution to overall biodiversity representation) exceeds its weighted cost. In other words, if the area has biodiversity which is under-represented elsewhere in protected areas, it will be selected provided the opportunity costs are comparatively low. This marginal contribution of a given area simply reflects how much additional contribution it makes to the overall regional achievement of a nominated conservation target.

Within TARGET, the nominated weight is multiplied by the cost for each area, providing a value that is compared to the area's current complementarity value. A selected area must have a complementarity value that exceeds its weighted cost. As TARGET iteratively selects areas, a previously selected area will be deleted by TARGET if its complementarity has been reduced (as a consequence of other selections) and no longer exceeds weighted cost.

The first step in using TARGET involves setting a target level for representation for all biodiversity attributes. For any given area, the software calculates the number of so-far-under-represented attributes that the area could contribute to the list of protected areas. This indicates how well the area complements the existing ones in the context of the target. We call this a complementarity-based biodiversity value. TARGET iteratively adds and deletes areas from a list of nominated protected areas (the “select list”) so as to approach the nominated target levels of representation. Normally, the area that is next added to the set is the one that has the greatest complementarity-based biodiversity value – it is the area that adds the most biodiversity to the set. This means that the final complementarity values for a set of areas (corresponding to how much biodiversity would be lost if the area were removed from the set) may not correspond at all to the complementarity values observed at the time that the area was selected.

When cost trade-offs are used, TARGET attempts to balance this contribution against the specified costs of protection. The area which is added to the “select list”, at any stage, is the one which has the greatest difference between complementarity and (weighted) cost. **Figure 1** below shows a schematic representation of TARGET analyses.

Figure 1. Schematic representation of TARGET input data , algorithm and output

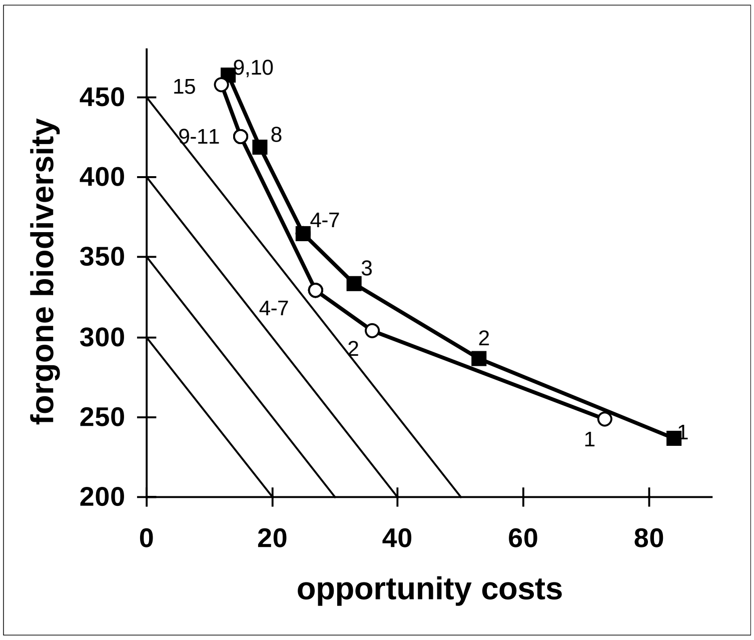


Note: ‘area data files’ contain biodiversity attributes, opportunity cost and other characteristics (e.g. protected area status); ‘conservation targets’ can be specified as (i) representation of a percentage of biodiversity attribute occurences in the study area or as (ii) probabilities of persistence of each biodiversity attribute across the whole study area; ‘constraints on trade-offs’ include pre-selection of adequately protected areas (e.g national parks) or exclusion from the analysis of areas permanently destined for non-conservation land uses (e.g. non-forest areas, monocultures etc.); each TARGET run produces a set of cost-efficient areas which may be output to a map; sensitivity to different user-defined ‘biodiversity/cost preference weights’ can be explored in trade-off curves.

Trade-offs space

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 are explored when a range of weights on costs are nominated over successive analyses - each weighting provides a set with some degree of biodiversity representation and some total cost. **Figure 2** (re-drawn from Faith 1995) shows 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, where both foregone biodiversity and opportunity cost are low.

Figure 2. Biodiversity – opportunity cost trade-off curves



Note: the horizontal axis shows total opportunity cost of a praticular land use allocation to biodiversity conservation (in monetary units); the vertical axis shows the total biodiversity foregone - not protected - relative to the nominated conservation target (in units of biodiversity complementarity, as here, or as % achievement of the target, as in the rest of the paper)

In this example, the upper curve is the trade-offs curve under constraints, such as previous land use decisions (e.g. a national park) that may restrict the capacity to protect areas with the highest biodiversity and lowest cost. The line segments are equal net-benefits contours are those for a nominated weighting of – in this case - 5.0 on opportunity costs. The point of intersection of the trade-offs curve with the lowest possible segment – i.e. having greatest net benefits in terms of biodiversity minus weighted costs - defines the best solution for that nominated 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. For example, a *low* weight of 1.0 on cost corresponds to a point with *high* cost to the right of the curve.

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 future land use allocations (e.g. existing protected areas in high opportunity cost, low biodiversity areas). For any curve, the preferred allocation depends on the relative ‘importance’ weight given to the two axes.

A low weight implies a high valuation of biodiversity relative to other land uses - i.e. a preferende for allocating highly productive agricultural and/or forestry land to conservation purposes. Given that foregone land use opportunities are valued in monetary terms the weight can be given an interpretation as the ‘inverse price’ (1/p) of a marginal gain in biodiversity protection. No judgement is made in TARGET analysis of what is the ‘correct’ or ‘market clearing’ weight /price ; sensitivity analysis of different weights as summed up in the trade-off curve is used to illustrate the implicit cost of different conservation targets. In economic terms the trade-off curve is similar to an isoquant in a ‘production function’ where the marginal rate of subsitution between foregone biodiversity and foregone alternative land use opportunities is the weight discussed above and denoted by the straight lines in the graph. The trade-off curve can also be used to derive elasticities of substitution between conservation and alternative land uses at different stages of a protected areas expansion.

Trade-offs space can also be used to explore scenarios – for example, the impacts on the trade-offs curve of a fixed allocation of areas to a particular land use (a constraint), versus unconstrained optimisation. 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; see figure above), 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.

Probabilities of persistence and partial protection

Biodiversity planning is not just about selecting formal protected areas at lowest opportunity cost. Regional sustainability – achieving a balance between conservation and other needs of society - also depends on identifying the contributions to biodiversity conservation made by areas having both conservation and "production" (agricultural, forestry, mining etc.). Thus, allocation of different areas to competing land uses so as to maximize net benefits is one aspect of finding a balance between competing needs of society. The search for net benefits also recognizes cases where two or more “services” are complementary and can be met in a single area. Net benefits to society, a better balance between potentially conflicting goals, therefore can be achieved on occasions when it is found that the different land uses are not so much in conflict. Eco-forestry might be an example of such mixed use. In Costa Rica, sympathetic management of private lands as a consequence of so-called environmental service payments (PSA) is a case in point. We refer to such areas as offering “partial protection” of biodiversity, and can use TARGET to take these into account as part of regional planning.

“Partial protection” of biodiversity – assigning land uses to areas that provide at least partial protection of biodiversity while not (entirely) forgoing other land use opportunities – may lead to a trade-offs curve providing greater net benefits. In contrast, higher curves in trade-offs space (offering lower net benefits as in the upper curve in **Figure 2** above) 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. Conservation payments to private land owners, for example, may provide at least partial protection of biodiversity. When we take into account those contributions, clearly there is 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 those areas where most is gained by providing payments that help ensure partial protection.

One way in which TARGET addresses partial protection is through the use of probabilities of persistence (P). We can think of three kinds of probabilities. First, the target for any given attribute can be seen as some overall target probability of persistence over the region– or conversely a probability of extinction (1-P). If individual areas are assumed to be more or less independent, then overall probability of a given attribute going extinct everywhere at once is a product of probabilities of extinction for individual areas where that attribute is present. A second probability then is one that makes some assumption about the probability of persistence/extinction of a member attribute if that area is selected for protection by TARGET (e.g. for formal protection, or as an PSA area). Lastly, a probability can be assumed for each attribute in areas that are not already in nor selected for protection - this forms an assumption of a "background" probability of persistence without protection.

Consider a single attribute and suppose we have assigned it a regional target of 0.9999 probability of persistence - or a 0.0001 probability of extinction. Recall that individual areas/places are thought of as independent, so that the overall probability of extinction is the product of the probabilities of the individual places.

Suppose for simplicity that there is no "baseline" or "do-nothing" probability of persistence - that is, the probability of extinction is 1 for those places having the attribute of interest, but not selected for protection. If selected, the probability of persistence is (say) 0.9 – or probability of extinction of 0.1

Then if N places having the attribute are selected, the overall probability of extinction is $(0.1)^N$. Given the target, we know that we need N to be at least 4. This implies a percent needed out of the total number of occurrences of the attribute in the region. It also implies a "distance" at the start that we are away from the target - expressed as the total amount of the attribute that is needed (or still needed after some areas are selected). The initial distance in this simple example is 4. The total distance over all attributes is the sum of these distance values.

When there is a baseline probability of persistence value, the target amount needed is adjusted accordingly. Note that for general probabilities of the regional target, the baseline and for protected areas the distance may be expressed in decimals, something like 14.5 - as if half an area attribute is needed in order to reach the target precisely - in practice of course a whole attribute must be sought.

So, the complementarity value as expressed by TARGET is just the reduction in distance offered by the area if selected at any point. Note the complementarity does not directly express any incremental change in probability of persistence, because it is counting up how much of the attribute is represented.

For the PSA analyses, we nominated a target probability of .999 for each attribute across the whole region, i.e. an 0.1 % chance of extinction. We assumed a probability of persistence in any area that was selected for environmental service payments to be either 0.2 or 0.75 (senstivity analysis), while attributes in areas already within national parks were assumed to have an 0.9 probability of persistence.

Once these probabilities were assigned within an analysis, TARGET proceeded in the normal way in iteratively selecting and deleting areas to build up a set, taking weighted costs into account. In these analyses, complementarity becomes a marginal gain in overall probability of persistence of all attributes.

3. Environmental service payments in Costa Rica and Osa Conservation Area

The history of environmental service payments (PSA, or “pagos por servicios ambientales”in Spanish) in Costa Rica can be traced back to the first sustainable forestry incentives under the 1969 Forestry Law (No. 4465). Its present form is due to Forestry Law 7575 (1996) which mandates the payment of forest conservation or reforestation incentives to four environmental services:

- Mitigation of greenhouse gases
- Protection of water sources for urban, rural and hydrolectric purposes
- Protection of biodiversity
- Protection of ecosystems, life forms and scenic beauty for tourism and scientific purposes

The 1996 National Forestry Law prohibits land-use conversion from forest to agriculture, but in practice managed forests are often thinned and then converted to agriculture over a period of several years. Despite the ambitious aims laid out by the Forestry Law, incentives are not differentiated geographically by environmental service, nor according to differences in opportunity costs to forestry and agricultural activities. Current incentives are approximately based on national averages for opportunity costs of foregone cattle pasture (Vega and Vega 2002), historically the immediate competitive land-use to forestry, and the direct financial costs of the different forestry activities which are promoted (Table 1).

Table 1. Environmental service payments (PSA as of 2001)

Type of land use and PSA contract	**Total amount payable over 5 yrs. (US$/ha)**	**Annual payments years 1-5 US$/ha (%)**					**Period of contractual obligations (yrs.)**
		1	2	3	4	5	
Reforestation	565	283 50%	113 20%	85 15%	57 10%	28 5%	15
Forest Management	344	172 50%	69 20%	34 10%	34 10%	34 10%	10
Forest Protection	221	44 20%	44 20%	44 20%	44 20%	44 20%	5

Source: FONAFIFO (2002)(Camacho and Reyes 2002). The incentive amounts are changed on an annual basis. As of 2003 the incentive category of Forest Management was discontinued, with incentives for Reforestation and Protection PSAs remaining approximately the same.

The National Forestry Fund (FONAFIFO) which administers the PSA system has strong transaction cost arguments against implementing a more differentiated payments to private land owners[3]. Barring the use of differentiated payments to attract the 'right' land owners, better targeting of payments to areas with low opportunity costs requires improving the administrators' knowledge of opportunity costs.

FONAFIFO's ability to promote the supply of environmental services under the Forestry Law has also been severely limited by funding, due to limitations on the earmarking of general taxes (Pagiola, Bishop et al. 2002). From 2001, under a new modality, 3.5% of gasoline tax is destined to FONAFIFO for PSAs. PSA applications are formally selected by FONAFIFO in consultation with the National System of Conservation Areas (SINAC), based on selection criteria laid down every year by presidential decree. Decree selection criteria are largerly qualitative and vary from area to area and by type of PSA. For forest protection PSAs criteria typically include broad qualitative criteria such as[4]:

- protecting water sources
- protecting flora and fauna of scientific interest
- in land use capacity classes VI-VIII (slopes of up to 60%, shallow soils)
- in forest succession with carbon sequestration potential
- exposed to forest fires
- of archeological interest
- scenic beauty
- high density high forest industry potential

A significant portion of funding for PSAs is also tied to the geographical priorities of international donations, such as the World Bank and GEF Ecomarkets Project (World_Bank 2000) which promoting certain biological corridors - two of which are in the ACOSA study area[5]. Only 13% the total PSA budget in 2001 was available for new PSA areas (Camacho and Reyes 2002). Priority is also given to areas within the Mesoamerican Biological Corridor. PSA allocation has been criticised because applications are based on such a large number of empirical and often inconsistent criteria. In the absence of a consistent priority setting approach within conservation areas , PSA allocations depend more on first-come-first-serve rationing as well as the lobbying power of the NGO or land owners promoting the application (Miranda 2003).

Successful efforts to prioritise PSAs based on marginal contributions to environmental services have been limited to carbon sequestration (Pfaff and Sanchez 2003, in press). Several authors have called for alternative proxy measures to consistently assess progress towards biodiversity conservation when clearly defined 'units' of biological diversity are not available (Pagiola, Bishop et al. 2002). In their review of the effectiveness of PSAs to combat deforestation Nasi et al. (2002) call for approaches to identifying in spatial terms areas where PSAs could "tip the balance", i.e. where degradataion and deforestation currently are marginally more profitable options than conserving forests (Nasi, Wunder et al. 2002).

Accepting FONAFIFOs transaction cost argument against further differentiation of environmental service payments, a second best approach would be to prioritise PSA allocation based on centralised data and modelling of cost-efficiency. Here we demonstrate how surrogate biodiversity indicators and quantification of opportunity cost of forest protection can be used to achieve a more economically cost-efficient allocation of PSAs towards biodiversity conservation at the regional (sub-national level). The TARGET approach demonstrated would be relevant for the regional FONAFIFO offices and their regional SINAC counterparts such as the Osa Conservation Area (ACOSA).

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[3] pers. com. Oscar Sanchez, Director FONAFIFO.

[4] Criteria translated from Decreto ejecutivo No 30090-MINAE,2002

[5] Paso de Danta and Corcovado-Piedras Blancas biological corridors

In practice, the lithmus test of a new system of allocating public funds to forest conservation in the present political climate in Costa Rica (and many other countries we can think of) is achieving better targeting of environmental services at the same or lower implementation costs than the existing system. The information/transaction cost properties of the centralised model-based allocation mechanism we propose, versus proposals for marginal benefit pricing or auction-based allocation is evaluated elsewhere (Faith, Carter et al. 2003). Here we will concentrate on demonstrating the principles of the TARGET approach used to prioritise between PSAs.

The box below outlines the approach to applying TARGET to the problem of selection of sets of areas for conservation payments.

Box 1. Proposal for a cost-efficient method of allocating PSAs to biodiversity conservation

Based on the methodological framework of TARGET we propose the following general steps for prioritising the spatial allocation of PSAs. It is based on the principle of a fixed financial budget for PSAs and the objective of providing maximum biodiversity complementarity at lowest opportunity cost to forestry and agriculture in the area:

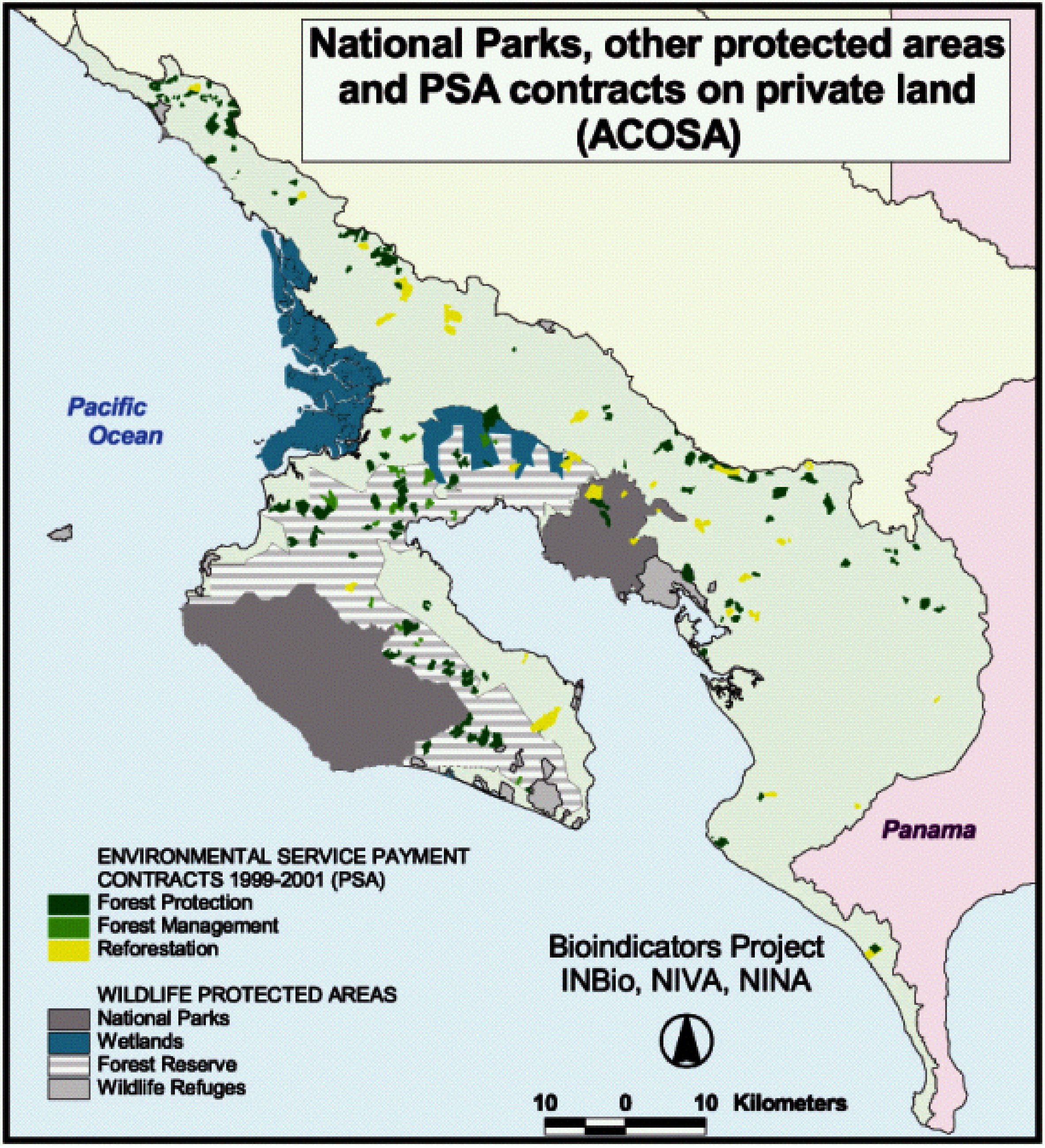
1. Establish the available financial budget for PSAs in the present selection round
2. Establish the geographical coordinates of the candidate PSA areas
3. Assign opportunity cost and biodiversity attributes toi candidate PSA areas based on GIS land use capacity, physical, topographical, environmental and biologal data
4. Convert polygon locations to grid code locations appropriate for analysis in TARGET
5. Pre-select existing protected areas which are assumed to have 100% protection and/or are unavailable for PSAs (national parks, mangrove wetlands and existing PSA areas).
6. Exclude all non-candidate areas from the trade-offs analysis
7. Run the trade-offs analysis in TARGET setting a ”low” biodiversity target, and conduct a sensitivity analysis of the weight on costs varying it from low to high to establish the trade-offs curve
8. Follow the trade-offs curve from low to high opportunity cost selecting areas until the available budget for PSAs has been expended .

Application to the Osa Conservation Area

The approach is illustrated using data on biodiversity surrogates and opportunity costs of agriculture and forestry from the Osa Conservation Area (ACOSA), one of 11 conservation areas dividing the whole territory of Costa Rica and constituting the National System of Conservation Areas (SINAC). ACOSA has a total land area of some 430,437 hectares, including two terrestrial national parks (Corcovado, Piedras Blancas), a marine national park (Ballenas), the Térraba-Sierpe National Wetlands RAMSAR site, the Golfo Dulce Forest Reserve, and a number of Wildlife Reserves. In principle only national parks and mangrove wetlands are 100% state property. In the rest of the protected area system land is largely privately owned and PSAs are used to promote forest conservation.

Figure 3 shows the distribution of protected areas and PSAs from 1999-2001. The map shows that the majority of existing PSAs are within protected areas. However, the large minority outside protected areas, and their seemingly random geographical distribution begs the question asked earier regarding allocation criteria. Have the criteria used thus far provided a cost-efficient allocation of PSA to areas providing the highest biodiversity complementarity value at the lowest opportunity cost to agriculture and forestry? To answer that question we now turn to the framework for quantifying and comparing biodiversity complementarity and opportunity cost.

Figure 3. National parks, other protected areas and PSA contracts



4. Data

Biophysical data as surrogates for biodiversity

A set of biophysical attributes characterised the land units in terms of their contribution to represent the natural environments in ACOSA. Since complete maps of the biota of ACOSA do not exist, these attributes were used as an assessment of biodiversity, by making most use of available information. Topography, climate and substrate are fundamental determinants of biological activity and their spatial distributions can play a primary role in explaining the spatial distribution of plant and animal species (Faith et al. 2001a). Maps of natural resources provide an important basis for nature conservation and can often be used as surrogates for more definitive biodiversity data (Austin 1991) because of the difficulty of obtaining comprehensive data on species relative to that of producing resource maps (Pressey and Bedward 1991).

Our approach relied largely on biophysical spatial data retrieved from cartography and aimed at developing a database with all existing significant data that gave complete coverage of ACOSA at the highest possible spatial resolution. Based on previous work in ACOSA (Madrigal and Rojas 1980; Herrera 1986; Austin 1991; Pressey and Bedward 1991; Gomez and Herrera 1993; Tournon and Alvarado 1997; Ardon and Garcia 1998; Kappele, M.Castro et al. 2003), the major environmental variables influencing the distribution of forest types were assumed to be climate, soil, lithology, topography (elevation) and landform. In total there were 685 different surrogate biodiveresity attributes. In order to make a more refined use of available data we additionally included major vegetation formations and the set of endemic vascular plants for ACOSA in selected TARGET runs. Appendix II gives a detailed account of the data sources and the criteria used to construct the biodiversity attributes.

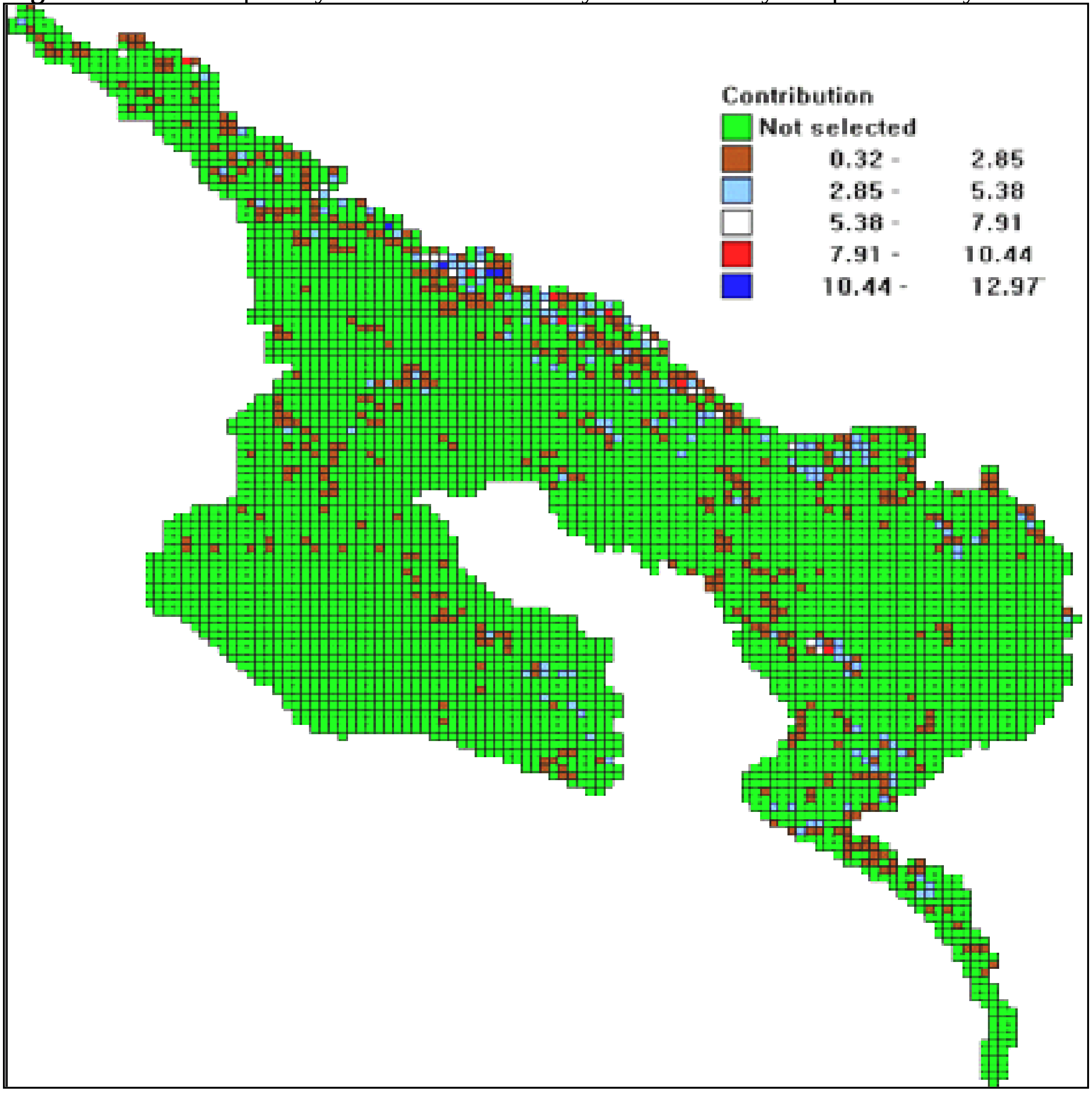
The retrieval of cartographic data was conducted by the Institute of Biodiversity in Costa Rica (INBio) in collaboration with the ECOMAPAS project (Kapelle et al. 2003). The endemic species list was obtained from INBio’s inventory data base, *Atta*. The compilation of the environmental and biological data base, and the generation of the biodiversity attributes was conducted by the Norwegian Institute for Nature Research (NINA).

Cartographic data was associated with land-use capacity polygons in the whole study area and converted to 25 ha grid cells (raster), and then 1x1 km mapping units for purposes of analysis in TARGET. Although biodiversity attribute data are available at 25 ha resolution, using a 1 km^2 in the trade-off analysis was a restriction set by the processing capacity of TARGET.

The data on presence of endemic species in ACOSA was excluded from TARGET analysis in first instance because it was thought that available distributions had been biased by intensive sampling in threatened and easily accessible areas. Although, endemic species are generally a conservation priority when declaring protected areas, we were interested in evaluating priority setting using only biodiversity surrogates. Endemic species are prioritised by the TARGET algorithm if they are not already in the protected set of areas. Given the sensitivity of results to the presence of endemics and the sampling doubts regarding true endemicity, this is an issue to which we will return in future work.

Figure 4 illustrates a map of complementarity values calculated using the surrogate biodiversity indicator described above and in more detail in Appendix 2. Areas with the highest complementarity are given in blue, next highest complementarity in red and so on. The particular values in **Figure 4** are the complementarity values of areas in relation to diversity already represented in national parks Corcovado and Piedras Blancas (not shown here, see **Figure 3**). The areas selected are the optimal set for this particular scenario, i.e. adding further areas will not represent new unprotected biodiversity nor contribute further to reaching the established biodiversity protection target.

Figure 4. TARGET priority set of areas based only on biodiveristy complementarity



Note: TARGET scenario used: national parks were pre-selected; no areas excluded from the analysis (masks); opportunity cost of all areas set to zero; regional probability of persistence target (PP)=0.999; protected area PP=0.9; un-protected area PP=0.

Opportunity cost of protection

Opportunity costs of protection were generated based on the general assumption that areas selected for conservation by the TARGET model would be unavailable for agricultural and forestry exploitation. The present analysis therefore excludes evaluation of partial protection alternatives with for example sustainable forestry activities. While the evaluation of 'forest protection' PSAs is less data demanding, it is currently the most important type of incentive: in 2001 82.5% of all PSA contracts were for 'forest protection', while 10.2% were for sustainable forestry management and the remaining % for reforestation/plantations. In 2003 only PSAs for forest protection and reforestation are being allocated, although this may change again.

The scope of opportunity costs illustrated in this paper is limited to productive activities and does not attempt to value other environmental services from forests. Spatially explicit local recreational and global carbon storage values have recently been included in GIS based benefit-cost analysis of woodland management in the UK (Bateman, Lovett et al. 2003). While we have not been able to conduct local travel-cost studies of forest recreation demand in ACOSA, the consideration of carbon storage values will be considered in future based on the available land cover data in ECOMAPAS.

Appendix 3 gives a detailed account of data sources, processing methodology and sources of error in the calculation of opportunity cost indicators .

Agriculture

Agricultural opportunity cost was based on the geographical distribution of 8 standard land-use capacity classes (LCC) (MAG-MIRENEM 1995); from land with no restrictions on agricultural production (class I) to land with severe restrictions on agricultural and forestry activities (class VIII). Land-use capacity data was compiled in GIS from several historical sources each partially covering the ACOSA study area (Vega and Vega 2002). For each LCC a list of crops grown in the Brunca region of which ACOSA is a part was compiled. Net equivalent annual return[6] based on market good and factor prices from national agricultural statistics was furthermore compiled. For each LCC average per hectare return for that class was calculated weighted by the relative area of each crop for that class in the study region. Agricultural opportunity cost therefore represents foregone net annual returns at first point of sale, dominated by the most prevalent crop type for that land-use capacity class.

Opportunity cost data was associated with land-use capacity polygons in the whole study area and converted to 25 ha grid cells (raster), and then 1x1 km mapping units for purposes of analysis in TARGET. Although biodiversity and opportunity cost attribute data are available at 25 ha resolution, using a 1 km^2 in the trade-off analysis was a restriction set by the processing capacity of TARGET. For each mapping unit agricultural return was weighted by the relative area of each land-use capacity class within that mapping unit.

Forestry

Forestry opportunity costs were calculated based on the distribution of 5 major forest ecosystem types in ACOSA identified by the ECOMAPAS project of Costa Rica's National Biodiversity Institute (INBio). The only available forestry inventory information for these forest types come from forest management plans approved by the ACOSA administration. All management plans with information on species composition (28 in all) were examined to classify the proportion of timber volume by species falling into 6 different price categories by composition of soft and hardwoods. Extracted timber volume in each category was assumed to represent relative species distribution of standing timber volume by price category.

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[6] using a discount rate of 11% and a 15 year planning horizon. 15 years was chosen because it is the maximum period for contractual obligations under environmental service payments in Costa Rica. It is also the minimum period for forest rotations regulated by ACOSA.

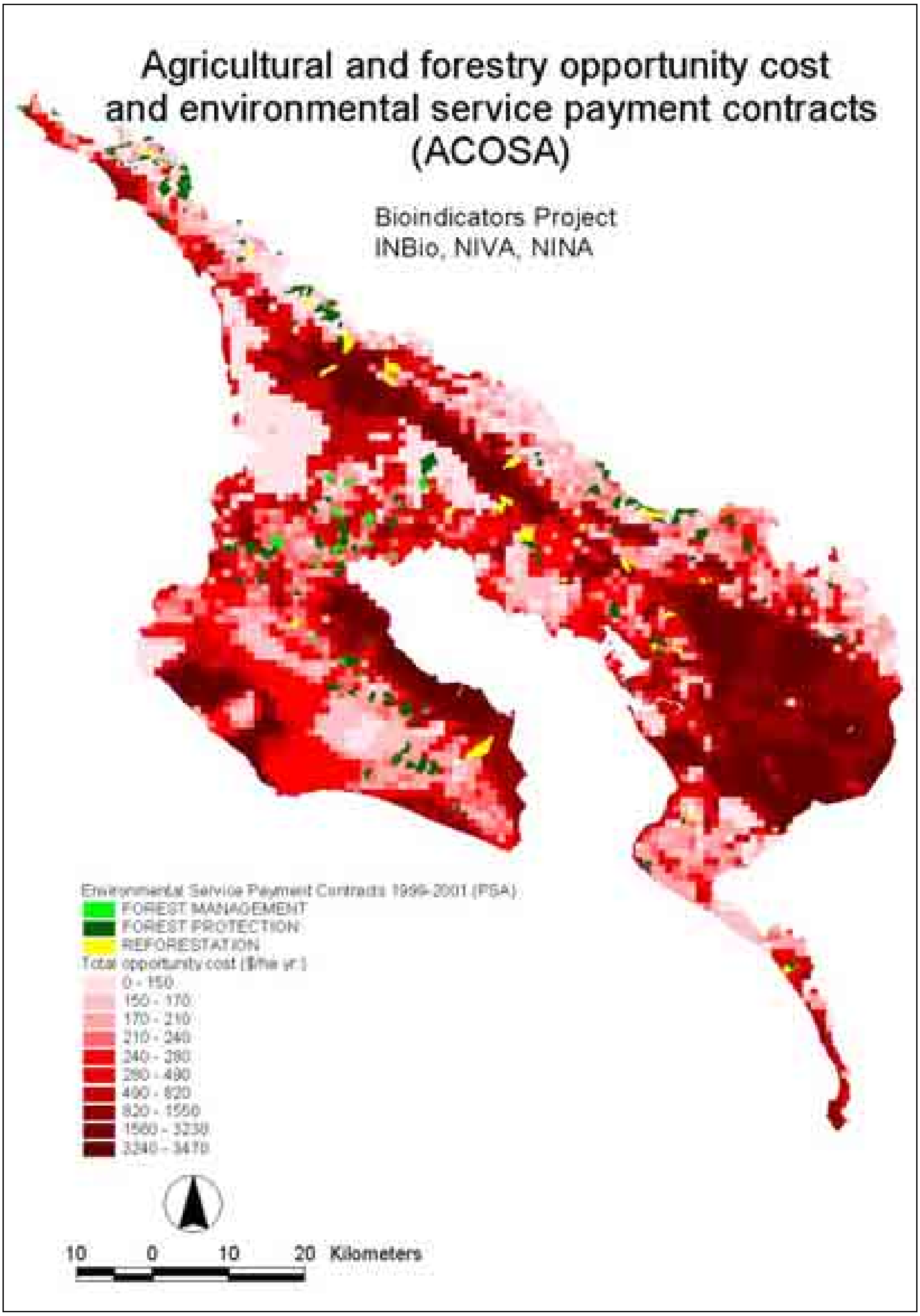
Annualised forest returns were calculated based on the assumption that the volumes extracted under the forest management plans are equivalent to total standing commercial volume . Annual forestry returns per hectare were calculated by multiplying the estimated clear-cut yield above with the average timber price paid at sawmill. For each mapping unit average forest return is weighted by the proportion of the grid cell covered by a given forest type. Forestry opportunity cost therefore represents foregone average annualised timber yield weighted by relative forest type cover for each cell.

Land currently under forest which is passed into conservation must forego both returns from logging as land is cleared and then agriculture as land use changes. Under Costa Rica’s forestry legislation clear-cutting and land-use change is prohibtied. In practice in ACOSA, as in Costa Rica at large, such prohibitions are often circumvented through successive forest management plans, and so the most common situation is ‘creeping’ deforestation (Rosero-Bixby, Maldonado-Ulloa et al. 2002). In our approach, annual forestry and agricultural opportunity costs are simply added by grid cell to arrive at aggregate opportunity cost. This assumes that land may pass completely from forest to agriculture in the first year. This represents an overvaluation of opportunity costs in forested areas, with the bias being greatest for primary forest (which would take longer to clear). Improvements in the methodology might weight forest and agricultural returns in any one spatial unit, based on past marginal rates of deforestation. Forest opportunity costs are generally small relative to agricultural opportunity costs – limiting the effect of this bias on the ranking of areas based on *relative* costs.

Figure 5 summarises the spatial distribution of total agricultural and forestry opportunity costs in ACOSA. Past environmental services payment (PSA) constracts (1999-2001) are superimposed to give the reader a feel for the data. It is immediately clear that most PSAs have been in relatively low opportunity cost areas, with the few exceptions being reforestation PSAs which also recieve the highest incentive payments (see Table 1). It is also clear that calculated average opportunity costs are considerably higher than past incentive payments. While there may be several reasons for this difference in absolute values, as discussed above and in appendix 3, relative opportunity costs seem to explain the spatial distribution of existing PSA contracts quite well.

In summary, the cost data is deemed to be reliable for relative comparisons and priority-setting between areas, but less reliable for natural resource accounting purposes should these be undertaken in ACOSA in future based on our data.

Figure 5. Agricultural and forestry opportunity costs and environmental service payment contracts



5. Evaluating the cost-efficiency of current environmental service payments

In this section we use TARGET analysis to analyse the cost efficiency of the selection PSAs (1999-2001) relative to an objective of maximising biodiversity complementarity within the areas receiving PSAs. We establish several hypotheses for the TARGET analyses:

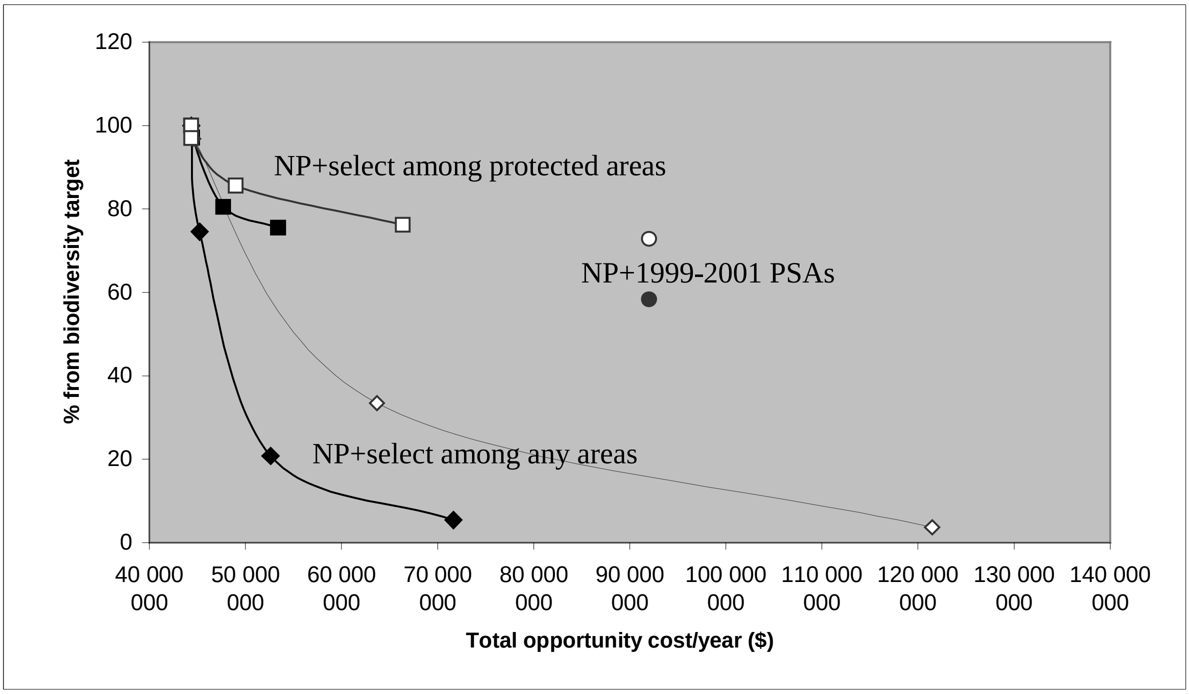
H1: only a relatively small decrease in the distance to the biodiversity conservation target is achieved by adding the1999-2001 PSA contracts to already protected national parks while costs increase substantially

H2: Using the software TARGET to make an optimal selection of areas within existing protected areas, but outside national parks, improves cost-efficiency measured as incremental cost per unit of biodiversity complementarity .

H3: Choosing areas for protection freely among all areas outside national parks reduces the distance to target further, but at a higher cost per unit of target than under H2.

For the trade-off analyses using TARGET we assume that additional biodiversity protection comes in the form of "forest protection PSA" incentives (see Table 1) to private land owners both inside and outside non-public protected areas

Figure 6. Biodiversity-cost trade-offs in ACOSA and cost-efficiency of PSAs



Note: *Squares*: areas selected only from existing protected areas and with national parks pre-selected; *Diamonds*: areas selected from both inside and outside protected areas, and with national parks pre-selected; *Circles*: PSAs awarded in 1999-2001 and national parks; *Open and filled symbols*: probability of persistence in PSA areas 20% and 75% respectively;

Figure 6 shows the "optimal set" trade-off curves for protection of new areas in addition to existing national parks (NP), when (i) new areas only come from non-public protected areas (square data points) and (ii) when areas for protection can be selected from anywhere both within and outside existing protected areas (diamond data points). Two sets of trade-off curves represent assumptions about the probability of persistence of biodiversity within areas receiving “protection PSAs”, either (i) probability of persistence equals 0.2 (open data points) or (ii) probability of persistence equals 0.75 (filled data points). By comparison our conservation target probability of persistence is set to 0.999, while biodiversity represented within publicly owned national parks is assumed to have a 0.9 probability of persistence.

All scenarios have pre-selected existing national parks for protection (Corcovado and Piedras Blancas) which is why the horisontal. We see that the existing national parks have an opportunity cost of about $ 44 million per year, calculated as the cost of not being able to use the area for agriculture and forestry.

The set of areas under national parks including PSAs allocated in 1999-2001 is represented by the round point in the upper right hand part of **Figure 6**. Relative to the optimal trade-off curves to the left we see that the set of PSAs was not cost efficient with a distance to the biodiversity target of 60-80% and an opportunity cost of around $ 90 million /year. The opportunity cost is roughly twice as large– for the same amount of additional biodiversity protection achieved – as on the optimal trade-off curve (about $45 million/year).

If FONAFIFO could have selected candidate PSAs among any land within non-public protected areas in ACOSA, opportunity costs could be reduced, but with slightly lower biodiversity target achievement (“NP+select among protected areas”).

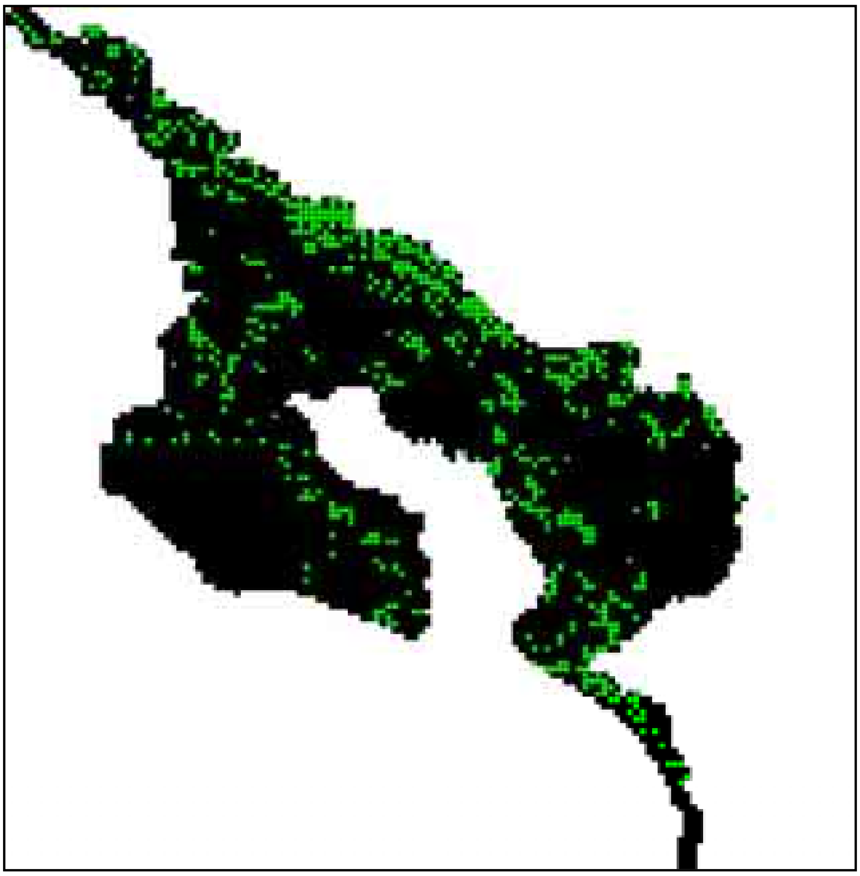
If PSA could have been selected from any area, the same biodiversity target could be achieved at approximately half the opportunity cost (NP+select among any areas), relative to the set of areas currently within national parks and the PSA programme (‘NP+1999-2001 PSAs’).

Finally, we observe that an increased probability of persistence within existing PSA areas (from 0.2 to 0.75) leads to a reduction in the % distance to the biodiversity target of less than 55%. Such a gain in conservation terms depends on how constrained FONAFIFOs choice of PSA areas is. Larger gains are achievable when PSAs can be selected from anywhere within ACOSA (except the national parks).

Figure 7 (map) illustrates the set of areas that are selected by TARGET as priorities for protection when any area outside national parks can be selected. Some interesting aspects of the selected set include:

1. High complemtarity , low cost areas are somewhat fragmented, and largely concentrated in forested areas (for comparison see figure A3.4).
2. The selection of areas show that those of high complementarity to already protected areas are concentrated in the highlands (national parks in ACOSA cover almost entirely lowland areas).
3. To a large extend this complementarity is ‘hidden’ if only current forest type classifications are used to represent biodiversity and becomes evident in our study because of the use of more detailed environmental data (geology, topography, etc).
4. The analysis shows a concentration of areas boundering with the Area de Conservación La Amistad, Piedras Blancas and Guaycará, as well in the Pavón area. These contain attributes that are poorly represented in the existing national parks. It is also interesting to note that there are some localities surrounding the Corcovado National Park that are of interest.
5. It is important to note that the biodiversity complementarity value of the areas bordering La Amistado (to the north-east of the study area) , would most likely decrease in a broader regional analysis, which would include other ‘áreas de conservación’ .

Figure 7. TARGET selected cost-efficient set of areas from anywhere within ACOSA outside national parks



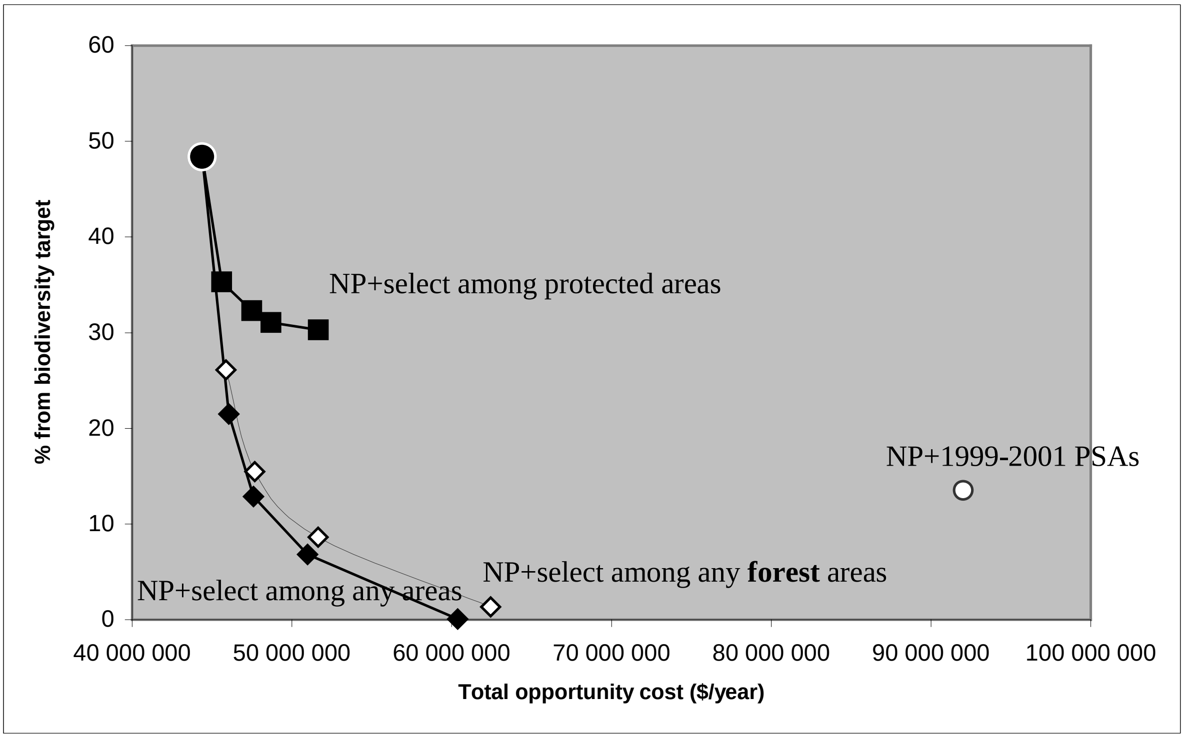
Note: national parks have been preselected and are not illustrated.
Probability of persistence in PSA areas = 0.75.

An objection that was raised to the trade-off curves in **Figure 6** was that the surrogate biodiversity indicator is dominated by environmental characteristics, rather than actual species presence/ absence data. Obviously, not all areas outside national parks are of equal conservation interest, although the surrogate biodiversity indicator we are using can give that impression -it represents "potential" species diversity using the diversity of environmental characteristics as a surrogate indicator.

On the other hand the use of environmental data is a very strong surrogate with a regional coverage because relevant environmental data have a direct bearing on the distribution of organims and they permit us to compare all areas simultaneously and under the same premises. It can be argued that good environmental data with good coverage are stronger than coarse categories / poorly maped vegetation types. In many instances vegetation maps are drawn quite subjectively and are also based on some judgement of the distribution of environmental variables (often also subjective). The most serious problem with the environmetal data is that they are as good as we can get, but they are still coarse. The second is that we may not have used the most relevant environmental data. However at the regional scale, we are quite confident that the ones we have available are those that matter most. It is also positive to be able to represent the 'potential' biodiversity and not the actual biodiversity - if the site has not been severely intervened (e.g. by a hydropower dam) it will recover its biodiversity value, at least to a large extent. A selection of sites based on the actual species composition will be misleading at a regional scale and with a long term planning perspective. Of course it should be clear in any incentives program that the landowner should let the orginal vegetation recover. A measure of biodiversity potential would also be interesting for the CO_2 offsets system where it would be possible to offer incentives to recover natural forest from cropland, for example.

In **Figure 8** we have therefore excluded from the analysis any areas with no standing forest (as of 1996) . Forested areas should be those where potential and current biodiversity are more closely related, although the analysis can still be criticised because partially logged forests may lead to lower probability of persistence of species there than "virgin" forest. The issue of partial degradation and lower probabilities of persistence is an avenue for future work.

Figure 8. Sensitity of biodiversity-cost trade-offs to conservation interest in non-forest areas



Note: *Squares*: areas selected only from existing protected areas and with national parks pre-selected; *Open diamonds*: selection from any forested areas, and with national parks pre-selected; *Filled diamonds:* selection among any areas, and with national parks pre-selected *Circles*: PSAs awarded in 1999-2001 and national parks;

Figure 8 illustrates the consequences for the analysis of excluding non-forest areas from the TARGET appraisal. The curve "NP+select among any forest areas" (white diamonds in the figure) shows that any given target achievement is slightly more expensive than when any area is available for selection. The difference is marginal. As a comparison of figures A3.2 and A3.4 show, forested areas generally coinicide with low agricultural opportunity cost areas. The one exception is the Corcovado National Park on the eastern side of the Osa Peninsula (see **Figure 3**). This area has however been pre-selected in the TARGET scenario as "not available for trade-off" as it is a public protected area. Low opportunity cost – high biodiversity areas are the ones which are first selected by the TARGET algorithm, even when any area is open for selection. This is the reason for the two trade-off curves to the lower left being very similar in **Figure 8**. The story would be quite different in an area of a moving agricultural frontier, where forested areas would also be on land with high agricultural opportunity cost.

6. Using TARGET to rank environmental service payments candidates

Every year the Costa Rican National Forestry Fund (FONAFIFO) faces the problem of how to “buy” the most environmental services - including biodiversity protection - at least cost. The previous section demonstrated that the current system of allocating environmental service payments is not cost-efficient when agricultural and forestry opportunity costs are considered. FONAFIFO currently has no consistent way of evaluating the “importance” of biodiversity within PSA candidate areas and the economic trade-offs involved in prioritising between candidates. The following analysis illustrates the use of TARGET as a tool for prioritising allocation of PSAs areas by their biodiversity complementarity and oppportunity cost.

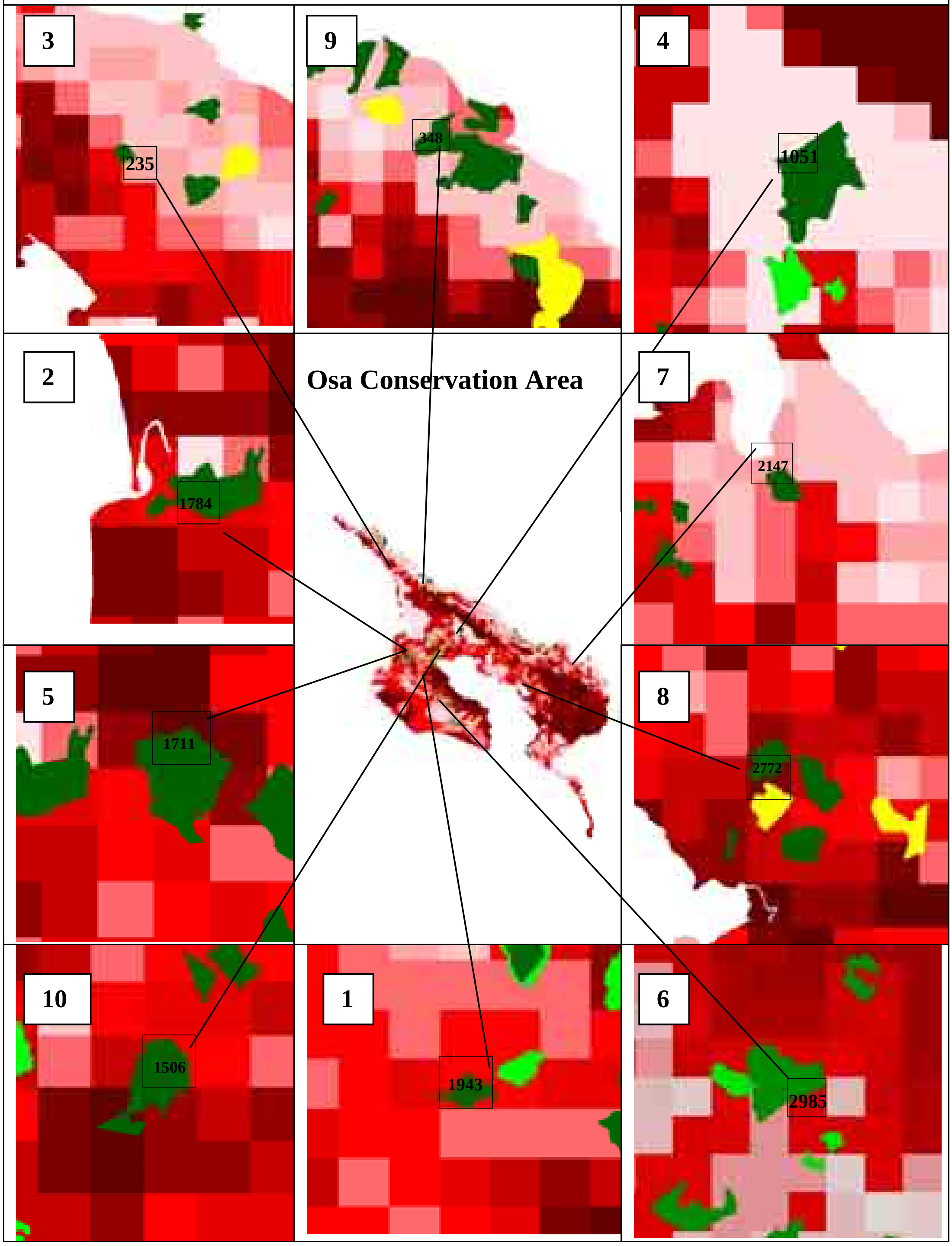
Using the approach outlined in box 1, we test the following hypothesis:

H4: TARGET can provide an unambiguous ranking of sets of PSA candidate areas based on distance to biodiversity conservation target and opportunity cost.
By unambiguous we will mean that given a list of candidate areas their ranking does not depend on variations in the biodiversity target or probability of persistence of PSA areas versus fully protected areas (NP). However, see H5.

H5: Ranking and selection of PSA candidate areas based on cost-efficiency may be sensitive to the order in which areas are evaluated by the authorities (here FONAFIFO).
This hypothesis is of interest because “path dependency” inherent in the calculation of complementarity values means that the order in which candidates are evaluated may affect their cost-efficiency ranking.

For the analyses we selected 10 mapping units to represent hypothetical PSA candidates for a particular year in which FONAFIFO must allocate its budget for environmental service payments in ACOSA. **Figure 9** shows the selected areas from around the ACOSA study area. The selected mapping units actually intersect with farm polygons (in dark green) currently receiving environmental service payments for forest protection (1999-2001).

Figure 9. Evaluation of 10 hypothetical PSA candidate areas (single 1 km^2 cells)



Note: PSA candidate areas numbered 1-10. Area identity # as used by TARGET in black. Map scale: each quadrant 1 km^2. Polygons: dark green areas = 1999-2001 "protection PSAs"; light green areas = 1999-2001 "forest management PSAs", yellow areas = 1999-2001 "forest plantation PSAs".

Table 2 provides a summary of some of the characteristics of the 10 areas. For clarity of presentation we have illustrated the selection algorithm for individual mapping units (100 ha), rather than the whole farm polygon. The size of the properties that actually received PSAs in 1999-2001 vary between 23-407 hectares in our example. The number of surrogate biodiversity attributes in each area varies between 3-11. The opportunity cost per hectare varies between $47-2032.

Table 2. Characteristics of hypothetical candidates for environmental service payments (PSA)

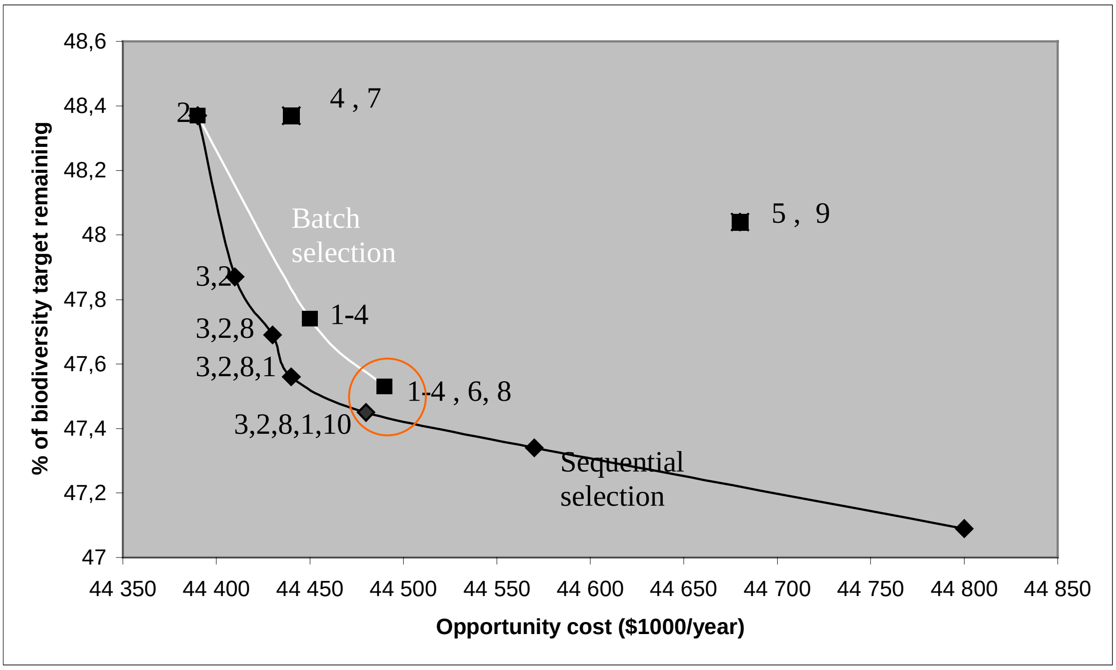
Hypothetical PSA candidate area (100 ha each)	**TARGET analysis unit #**	**Total area of actual* PSA polygon (ha)**	**# of different biodiversity surrogate attributes present**	**Opportunity cost of area ($ ha^{-1} yr^{-1})**	**Complementarity value (D) ****
Area 1	1943	42	4	224	0
Area 2	1784	201	5	266	2 500
Area 3	235	23	6	169	11 500
Area 4	1051	407	4	47	20 000
Area 5	1711	207	11	2032	20 110
Area 6	2985	242	7	337	9 870
Area 7	2147	49	5	175	16 400
Area 8	2772	64	3	910	10 000
Area 9	348	392	10	125	25 300
Area 10	1506	139	4	237	0

Note: * actual PSA are 1999-2001 contracts. ** complementarity values when all 10 areas + national parks are pre-selected. Biodiversity complementarity values do not necessarily correspond to those underlying **Figure 10** as the order of selection to the protected set is different.

In the table we have also included each areas calculated biodiversity complementarity value (D) given that all 10 areas are selected and that existing national parks are pre-selected for protection. The values in the last column are specific to this particular scenario. As **Figure 10** below shows, this complementarity value depends on the order in which areas are added to the existing set of protected areas.

The lowest trade-off curve in **Figure 10** illustrates in what order candidate PSA areas would be chosen if they were evaluated and selected sequentially. As we move from the upper left of the curve down towards the right the points represent separate TARGET selection of successively less cost-efficient candidate areas. In the first TARGET run, area 2 is the most cost-efficient addition to the existing set of protected areas in addition to the national parks. In the second TARGET run, area 2 is pre-selected along with national parks and area 3 is shown to be the most cost-efficient of the nine remaining areas, and so on.

Figure 10. Sequential and batch-wise selection of candidate PSA areas.



Note: horisontal axis starts at $ 44 million because national park are assumed pre-selected before candidate PSA areas are evaluated.

This evaluation is iterated until FONAFIFOs budget for PSA allocation is spent. In the figure this could be the point at which areas 3,2,8,1 and 10 have been selected. These five areas represent 500 hectares receiving PSAs at $283/ha (in 2001), or an equivalent $ 141 500 spent by FONAFIFO. If FONAFIFOs annual budget was say $150 000, these would be the only applicants to receive PSAs that round. On the vertical axis we see that areas 3,2,8,1 and 10 reduce the distance to the overall biodiversity target by about 1 %. On the horizontal axis we see that the opportunity cost to agriculture and forestry of protecting these areas is around $ 100 000/year.

The curve labeled "batch selection" illustrates a different story – it makes a difference in what year PSA applications are presented for whether they are selected or not – the so-called "path dependency" issue. If FONAFIFO had a year 1 budget limited to making payments to say 400 has, and only areas 1-5 were PSA applicants that year, TARGET would select areas 1-4 for protection. If in the second year the budget is reduced to say an equivalent of 200 hectares of PSAs and only areas 6-10 are candidates, the most cost-efficient areas to add are 6 and 8. The "batch" trade-off curve lies to the right of the "sequential" trade-off curve illustrating that the fewer PSA candidates that are presented per evaluation period the less cost-efficient is the set of areas selected over time. This is true even when the same set of areas is evaluated in the two approaches.

In **Figure 10** we also show how cost-inefficient a random choice of areas can be. The sets of areas 4, 7 and 5 , 9 lead to very little % reduction in the distance from the biodiversity target, but have relatively high opportunity costs.

A quick comparison of table 5.1 and figure 5.3 will make the reader ask why area 7 and 9 weren't selected instead of area 8 and why area 4 wasn't selected before area 2. How can the solution be so unstable even if the calculation of complementarity is correct?

The answer is that areas 7 and 9 would not be preferred over 8 because they are too expensive *relative* to their complementarity value. Area 4 is not selected before 2 because, althought he complementairy value for 4 is larger when all areas are in the set, at the time of consideration in the algorithm area 2 has higher complementarity relative to its cost than area 4. The complentarity values depend on the context of the choise, and this is why TARGET sometimes will not select an area that seemingly has low cost and a large number of attributes represented. The context dependency of PSA rankings due to complementarity, although conceptually sound, represents perhaps the greatest pedagogical challenge for its implementation in practice.

Given that FONAFIFO's role is to maximise the provision of environmental services within its given budget for PSAs , opportunity cost to forestry and agriculture have not been one of the main constraints in selecting areas. Because the environmental service payment to forest protection is constant per hectare this is equivalent to running a TARGET analysis where areas are selected purely on their complementarity value. AS we have seen this would not provide a cost-effective selection of areas.

7. Discussion

Cost-efficiency of current environmental service payments

The TARGET trade-offs analysis in **Figure 8** and **Figure 10** above illustrate the simple point that the "current" allocation of PSAs has not been as cost-efficient as it could be. Possible reasons for this are discussed below. While reviewing results it is important to keep in mind the assumptions behind the analysis:

The surrogate biodiversity indicator and the TARGET input data make only a crude distinction between the degree of human intervention in natural habitats – they are either forested or not forested. No value-judgements are made as to whether natural or agricultural vegetation and their associated environmental attributes are preferred.

Forestry Law No.7575 sets out four types of environmental service which may be the object of environmental service payments. This analysis deals with only one of them, protection of biodiversity. The biodiversity evaluated here does not include ecological/habitat functions (see appendix 1). For example, prioritisation of PSAs to areas deemed biological corridors is a priority issue for e.g. the World Bank Ecomarkets project. This includes the land between the Corvocado and Piedras Blancas national parks (see figure 2.1). In the TARGET every area is evaluated solely for its biodiversity complementarity, and no distinction is made regarding possible ecological funcionality.

However, prioritisation done using TARGET can provide an evaluation of these functions by performing the selection through a hierarchical prioritisation procedure, e.g. the biodiversity complementarity vs opportunity cost trade-off can be constrained in first instance to corridor areas. Such analysis makes evident the compromise of conservation priorities between unconstrained maximum representation of biodiversity and the maintenance of corridors or large size areas to maintain habitat connectivity and population survival. This is the thrust of the analysis in **Figure 6**, where we compare complementarity-cost trade-offs when any area can be selected versus a selection of areas constrained to existing protected areas (the Forest Reserve, Wetlands and Wildlife Refuges linking the peninsular Corcovado and mainland Piedras Blancas National Parks, **Figure 3**). Whether these areas are in fact viable biological corridors or not, **Figure 6** shows that prioritising corridors means foregoing the representation of much biodiversity which is complementary to the present system of protected areas – illustrated as approximately a 70% distance from target achievement, versus about a 30% target achievement when any area can be selected.

The evaluation of other environmental services than biodiversity conservation in the TARGET trade-off analysis (e.g CO2 sequestration, hydrological services, scenic beauty/tourism) can follow two strategies: (i) including spatially distributed physical indicators as attributes within the surrogate biodiversity indicator, or (ii) valuing the incremental benefits of these services in forested areas and deducting this from the agricultural and forestry opportunity costs of forest protection. Both approaches raise difficult methodological and political questions which cannot be evaluated satisfactorily within the context of this paper.

Figure 10 illustrates that the National Parks (Corcovado and Piedras Blancas) have an agricultural opportunity cost of around $ 44 million/year. When NPs are pre-selected, any trade-offs have a minimum cost equal to this minimum set of protected areas. The cost estimates seem intuitively very large to park managers and researchers working in the Osa

Conservation Area (ACOSA). The opportunity cost calculations in TARGET are based on historical market prices and do not consider the potential effects on future prices of e.g. large increases in local supply of crops. A drop in local crop prices may be the case where cultivation is started in what is today national parks or forested land with good agricultural potential.

Absolute values for opportunity costs are generally more valid for TARGET analyses when evaluating small land use changes (rather than large land allocation decisions). This includes scenarios in which current land use constraints by pre-selecting national parks; where all non-forest areas are excluded from the trade-off analysis; and where the weighting of costs is low and many of the existing forested areas are selected for (continued) conservation. In TARGET scenarios where non- incremental land use changes are considered, opportunity costs should be viewed as indicative of “relative” costs of different conservation options - still a valid tool for priority setting - but not very accurate estimates of the absolute cost to society of these options. In conclusion, due to price effects of large land conversions opportunity costs are also context dependent and are not ideal as a method of biodiversity valuation.

Ranking PSA candidates using TARGET

The policy conclusions for FONAFIFO of our TARGET analysis in **Figure 10** would be that it is more cost-efficient to evaluate as large a number of candidate areas as possible within one evaluation period. This suggests the need for incentives that will make farmers reveal and formulate PSA applications as soon as possible in an evaluation round. Once the universe of candidates have been identified, the most cost-efficient approach to evaluation is sequentially – one area at a time – until the budget is exhausted. Sequential selection should be with replacement to be as cost-efficient as possible, i.e. candidates which are rejected in one period should be kept in the set to be evaluated for the next period. The results raise the question - not pursued here – of whether annual evaluations by FONAFIFO is an optimal strategy.

Note that the ”sequential” selection approach is an adaptation of the optimal selection algorithm used by TARGET which requires that biodiversity complementarity values are recomputed every time a new area is added to the protected set. Using this algorithm the ranking of areas given by the trade-off curve may change every time a new area is added to the protected set. This ”path-dependence” of the optimal set is illustrated in figure 5.2. In practice candidate PSAs are evaluated in annual ”lumps” or ”batches”, rather than all at once, and such sequencing effects are unavoidable. Given that FONAFIFO is interested in unambiguous selection criteria when explaining their priorities to land owners, TARGET offers a way of explaining and evaluating how important path dependecy is. Gaining full knowledge of the universe of PSA candidates is of course costly from an administrative point of view. (Faith, Carter et al. in press) discuss incentive mechanisms for revealing land owners’ opportunity costs of forest conservation and their interest in putting up land for environmental service payments.

In the present analysis we used a grid based area analysis instead of property based, because property maps are not available for the entire area of ACOSA. The hypothetical 1 km^2 PSA candidates is a simplification of how the types of PSA applications that would be evaluated in practice. As **Figure 9** illustrates, PSA candidates come in all shapes and sizes. The question arises of how to evaluate polygons partially covering several analysis units within TARGET. With accurate GIS data TARGET opens the possibility of evaluating candidate polygons in parts. This raises the problem of the accuracy and resolution of GIS data, and administrative costs of carrying out the analyses that TARGET makes possible:

- In the current analysis biodiversity complementarity and opportunity cost only have a 1 km^2 resolution because of processing limitations in TARGET. Ground truthing and the underlying data and has been carried out by ECOMAPAS with resolution at 16-25 hectare level. This is still not detailed enough to deal with the smallest PSA candidate areas, which can be as small as 2 hectares. Until mapping resolution and ground truthing is improved it seems that implementing the TARGET selection procedure illustrated in this paper, would require TARGET to deal with PSA candidate polygons as "batches" which are ranked in the same way as in **Figure 10**. Computationally, each "batch" would be evaluated separately for its total biodiversity complementarity and opportunity cost in addition to existing protected areas. Resulting total cost and complementarity per polygon[7] would give the ranking of each candidate PSA polygon for that year.

- The cost of increasing GIS resolution must be weighed against the gains in cost-efficiency. Being able to evaluate and prioritise between parts of a candidate polygon would lead to a more cost-efficient set of areas for protection, but would be more costly to monitor. This is a problem often faced by FONAFIFO when land owners put up only part of their property as PSA candidate - property boundaries are more readily available in national catasters, while any sub-area must be ground-truthed in detail.

Costs have two distinct interpretations in our analysis which initially may lead to confusion about what is meant by "optimal set " of areas ; the "cost-effectiveness" approach of FONAFIFO to maximise biodiversity protection within a fixed budget for PSA incentives; and the "cost-efficiency" approach of a "central social planner" (possibly SINAC managers) of maximising biodiversity protection at a minimum opportunity cost to agriculture and forestry. The procedure illustrated in **Figure 10** shows us how both definitions can be operative decision criteria; the selected set of areas achieves the highest biodiversity complementarity within a financial budget constraint (cost-effectiveness), while it is also the set of areas which achieves lowest economic opportunity cost for a given value of biodiversity complementarity (cost-efficiency).

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[7] This is currently not an output of TARGET and must be calculated by hand.

8. Conclusions

Costa Rica's 1996 Forestry Law mandates the compensation of land owners for the provision of four environmental services, including carbon sequestration, preservation of scenic beauty, water supply and hydropower services, and conservation of biodiversity. As such, the legislation is pioneering in its intention to use economic incentives to directly promomte "supply" of services provided by forest conservation. The National Forestry Fund (FONAFIFO) charged with allocating spending has to date had no consistent way of prioritising between candidates areas as a function of the environmental services provided by a specific area. Nor have there been systematic consideration of the opportunity costs to agriculture and forestry of setting aside private land for protection – the assumption has been that the opportunity costs would be lower than the level of PSAs on offer and that this would lead to an efficient set of PSA contracts (Pagiola, Bishop et al. 2002).

Availability of spatially explicit ecological and economic data in ACOSA is an obvious limitation to the application of the TARGET approach. With the exception of vascular plants[8], the species distribution data from ACOSA in INBio's Atta species inventory - although rich for plants and insects relative to other conservation areas in Costa Rica - was still insufficiently georeferenced to be used in the surrogate biodiversity indicator in this study. A concurrent limitation is the lack of high quality good coverage environmental data such as detailed climate and soil maps. Higher geographical coverage of species distributions along with basic environmental data at the collection sites would largely increase the value of biodiversity inventories.

Data used to construct opportunity costs was if anything a greater limitation. GIS data on agricultural land-use capacity was of poor resolution and had to be compiled from multiple sources - particularly within national parks where no political interest has been taken in agriculture since their declaration. Although forest cover data was of high quality and resolution, GIS information on commercial forest inventories were not available and had to be compiled from scratch based on data from logging permits. These limitations are probably general for other conservation areas and constitute quite a serious limitation to accurate evaluation of opportunity costs at the resolution required for PSA evaluation.

The resolution of current land cover maps allowed a rasterisation of spatial characteristics to pixels of 25 hectares, while TARGET processing limitations at 5000 units of analysis meant that trade-off analyses had to be conducted using 100 hectare analysis units. Resolution of data in ACOSA is currently sufficient to evaluate "classical" protected area planning questions such as large area – non-incremental - expansion of the present system of national parks. However, the era of declaring new publicly owned national parks is probably over in Costa Rica, and the future of more effective biodiversity conservation lies in promoting conservation on private land. TARGET methodology can have a role to play if processing capacity is improved so that the resolution of available GIS data can be fully utilised.

The TARGET analysis units used in this paper are too large to allow the evaluation of a large percentage of PSA candidate areas smaller than 100 hectares. TARGET processing capabilities would have to be improved before the approach could be applied to evaluating environmental service payments in practice. Available GIS data holds out promise for practical applications - resolution of ECOMAPAS GIS data for ACOSA would have allowed for analysis of polygons as small as 15-25 hectares, given higher processing capacity in

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[8] Endemic vascular plant species were excluded from the TARGET analysis due to the large effect they have on the optimal solutions in TARGET. The consequences of including or excluding endemics will be explored in a separate paper.

TARGET software. Based on work in progress in the ECOMAPAS project at INBio, by 2005 several conservation areas in Costa Rica will have GIS data on land cover with sufficient resolution to evaluate areas as small as 2 hectares (the current lower limit for PSA applications).

Although ECOMAPAS data has the highest resolution of the data sets, the analysis if subject to the maximum resolution of the poorest information layer - vegetation units defined are quite coarse, and in addition half of them or more are agricultural land (not potential vegetation). This imposes the limitation of not having a measure of 'potential biodiveristy' for the entire conservation area or the country. Again, high resolution environmental maps are what is most needed for construction detailed biodiversity surrogates. It would be nevertheless difficult to think of a 2 hectare – resolution map for the entire country or even for a whole conservation area. Methodologies proposed should provide FONAFIFO or SINAC with a technique to use the data that are available now. For example, if a grid cell of 100 ha (or 25ha) is selected it could be followed up by an inspection of which attributes it is representing and where they are more likely to be found , followed by an inspection locally before finally signing the contract.

Despite current software and data limitations, the present study shows that the set PSA contracts awarded as of 2001 were not cost-efficient, with total opportunity costs on private lands set aside for forest protection, management or plantations (elligible PSA categories all) being around twice as high (around $90 million/year) as the most cost-efficient set identified using the TARGET optimisation algorithm. Analysis in figures 6 and 8 show that there is substantial additional biodiversity protection to be gained at about the same opportunity cost in extending the current PSA scheme to private lands outside existing corridors and buffer areas. We are of course assuming that monitoring and enforcement costs of the resulting more 'fragmented' PSA area are not significantly higher by unit of area than consentration within these corridors or buffer areas.

The study shows how a central planning authority such as FONAFIFO could use the TARGET approach to select more cost-efficient PSA areas in its annual evaluation. Even ignoring opportunity costs to agriculture and forestry, significant gains in additional biodiversity protection could be made by using the TARGET approach to select the areas with the highest biodiversity complementarity.

Appendix 1. TARGET methodology and background

Additional explanation of TARGET algorithm

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, read in using an “.sel” file. 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.

TARGET uses as its primary input data a list of "places", with each place having a list of those biodiversity 'attributes" present in the place (possibly with additional information about amounts).

The other core information is some kind of opportunity cost of conservation ("cost") associated with each place.

The core algorithm for TARGET automatically selects a set of places in order to balance representation of attributes with total cost of the set.

Representation of attributes is measured by having some kind of nominated target for the representation of each attribute. In the simplest case we may want 10% of the total number of times an attribute occurs in the region to be the level of representation in the set.

The other key to defining the problem is the notion of "balance". Because TARGET is a special kind of multi-criteria analysis (special in the way it treats biodiversity marginal gains), the balance is defined in any given analysis by some nominated weight assigned to the costs. We can think of this as putting the biodiversity gains and the costs on the same scale, so they can be compared.

The marginal gains referredto above are a key to TARGET. The biodiversity contribution of a place is not the total number of attributes that it has (# species etc.) but is the marginal gain it can offer - its "complementarity".

Complementarity

The contribution of an additional protected area to biodiversity conservation is the *marginal gain* in biodiversity (the *complementarity*) it provides - this may be large or small relative to other land use opportunities or opportunity costs.

The central component of TARGET algorithms then is the following:

A place is selected for addition to the set of places if and only if its current complementarity value exceeds its weighted cost. No additional places are selected if this rule cannot be met.

Note that the set may have been initiated in TARGET with a partial set of given places - e.g. the current national parks.

Note that a place outside the current set has a complementarity value equal to how much it could contribute to the representation targets for attributes. A place in the set has a complementarity value equal to how much loss there would be in the representation targets for attributes if the place were removed. A critical point is that as places are added to a set, the complementarity value of any place in the set can go down - some of its attributes may now be contributed by other places in the set, so its loss-if-deleted is lower. So, a second critical aspect of TARGET algorithms is that places are removed from the set if their complementarity value now does not exceed the corresponding weighted cost. Thus, TARGET analysis proceeds by iteratively adding and deleting places until no further places can be added. Variations on the basic algorithm allow the user to interactively impose additions and deletions and ask the software for the single best place to add or delete from the set.

The user can take advantage of TARGET capabilities to extend and modify the simple search provided by the basic algorithm. Different random starts (starting places put into the set) may be used to avoid "local optima". 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.

Major variations on the algorithms are based on the way in which targets and complementarity are defined.

First, consider the simple case of percent targets. For each attribute, the nominated % defines a total amount (e.g. number of times) that the attribute is to appear in the final set. These amounts can be added up over all attributes for a total amount - referred to as the distance we are away from achieving the overall target. Any place added to the set makes some contribution towards representing some attributes and so making this distance smaller. This progress is what is reported on the screen, both as a raw value as a percent of the initial distance which has been met.

An important special case is when the target for an attribute is not a percent but is an overall probability of persistence. Selecting a place can be seen as increasing the probability of persistence for member attributes in that place from some lower base value (say .30) to a higher nominated value (say .80). A set of places combine together to determine the overall probability of persistence of attributes. The complement of the probability of persistence is the probability of (local) extinction. We are interested in the overall regional probability that an attribute will go extinct everywhere - this is the product of probabilities for individual places - assuming independence.

What then is the complementarity value of a place? For each attribute, there is some increment in the probability of persistence, viewed as a multiplier on the old probability (e.g probability of extinction is now .5 of what it was). These multipliers are multiplied together for all attributes 9e.g. a place that makes probability of extinction .5 of what it was for 3 different attributes has a .5*.5*.5 gain). Of course, if the attribute has already reached its target probability of persistence the place's contribution for that attribute does not count toward its complementarity.

An important aspect of these algorithms with probabilities is that the places not selected for the set can still provide some baseline probability of persistence. Further, the probability assigned to a selected area may be lower or higher if membership of the set implies not formal protection but some partial protection from sympathetic management.

As before the complementarity values are iteratively compared to costs.

A final point on algorithms, within the same analysis, the weight can initially be set at a high value (so few places are selected) and then within the same run, the weight can be lowered, so allowing more places to join. This provides a simple way to get a trade-ofs curve 9recording results at each weight) and a good heuristic for getting an optimal solution in terms of achieving a target at least cost.

TARGET methodology, its origins and applications

Year when development began

1996 (formerly known as DIVERSITY-TD)

Previous ideas or approaches on which it builds

TARGET builds on the trade-offs methods developed in DIVERSITY-ED, and the probability of persistence methods developed in DIVERSITY-XD. While using variable costs and linking to multi-criteria analysis, TARGET also can be seen as building on early Australian developments in "minimum set" algorithms (Margules et al., 1988; Rebelo and Siegfried, 1992; Pressey et al., 1993; see also Kirkpatrick, 1983) that were based explicitly on the rationale that conservation resources are limited.

TARGET also builds on ideas/debates about regional sustainability:
Faith, D. P. (1995) *Biodiversity and regional sustainability analysis*. CSIRO, Canberra. 30pp.
Faith, D. P. and Walker, P. A. (1996) Integrating conservation and development: effective trade-offs between biodiversity and cost in the selection of protected areas. *Biodiversity and Conservation* 5, 417-429.

Reasons for development

The motivation for TARGET arose from problems raised in the course of the Comprehensive Regional Assessments process in Australia - issues relating to setting of targets, surrogates for biodiversity, and whether or not trade-offs are incorporated at the level of priority setting (TARGET is based on the idea that they must be). TARGET also has served as a platform for exploring probability of persistence approaches, as a response to the perceived need to avoid the "all or nothing" view of protection and optionally allocate land uses that provide "partial protection" in addition to other ecosystem services:

Faith, D. P. and Walker, P. A. (1996) Integrating conservation and development: incorporating vulnerability into biodiversity-assessment of areas. *Biodiversity and Conservation* 5, 431-446.

The more recent development of TARGET has responded to the reality that few "whole" sets of areas from computer-based methods are ever implemented, so that the practical focus should be on scenarios and outputting of dynamic complementarity values for decision support and links to economic instruments:

Faith, D. P., Carter, G., Cassis, G., Ferrier, S., Wilkie, L. (2003) Complementarity, biodiversity viability analysis, and policy-based algorithms for conservation. *Environmental Science and Policy* 6 (2003) 311–328 Faith et al 2003 Environmental Science and Policy (PDF 362kb

Attributes of areas and features used

ED can use any definition of "areas", described by environmental and/or biotic attributes. These attributes optionally may have recorded "amounts" for each area.

Hardware and associated software requirements

Laptop, Microsoft Windows, and additional software for nominated GIS/mapping links.

Summary of previous applications

A major application was the World Bank funded "BioRap" study for Papua New Guinea; see: Faith, D. P., Nix, H. A., C. R. Margules, Hutchinson, M. F.Walker, P. A., West, J., Stein, J., Kesteven, J. L., Allison, A. and Natera,G. (2001) The BioRap Biodiversity Assessment and Planning Study for Papua New Guinea. *Pacific Conservation Biology*. Volume 6, Issue 4, 2001, Pages 279-28. Further details.

Faith, D. P., C. R. Margules, P. A. Walker, J. Stein, G. Natera (2001) Practical application of biodiversity surrogates and percentage targets for conservation in Papua New Guinea. *Pacific Conservation Biology* Volume 6, Issue 4, 2001, Pages 289-303. Further details.

Faith, D. P., C. R. Margules, P. A. Walker (2001) A biodiversity conservation plan for Papua New Guinea based on biodiversity trade-offs analysis *Pacific Conservation Biology*. Volume 6, Issue 4, 2001, Pages 304-324. Further details.

Faith, D. P., P. A. Walker and C. R. Margules (2001) Some future prospects for systematic biodiversity planning in Papua New Guinea - and for biodiversity planning in general. *Pacific Conservation Biology*. Volume 6, Issue 4, 2001, Pages 325-343. Further details.

Faith, D. P. (2001) Overlap of Species Richness and Development-Opportunity Does not Imply Conflict. *Science* 293 [online] URL: http://www.sciencemag.org/cgi/eletters/293/5535/1591#354 (response to Huston, M. A. et al. (2001) People and biodiversity in Africa, *Science* 293:1591-1592, and to Balmford, A. et al. (2001) Conservation conflicts across Africa, *Science* 291:2616-2619.)

Faith, D. P. (2001) Cost-effective biodiversity planning. *Science* 293 [online] URL: http://www.sciencemag.org/cgi/eletters/293/5538/2207

Faith, D. P. and P. A. Walker (2002) The role of trade-offs in biodiversity conservation planning: linking local management, regional planning and global conservation efforts. *J. Biosciences (Suppl. 2)* 27:101-115. (Download PDF).

Current and planned applications

Research applications or pilot studies include:

- New South Wales biodiversity viability analysis -

Faith, D. P., Carter, G., Cassis, G., Ferrier, S., Wilkie, L. (2003) Complementarity, biodiversity viability analysis, and policy-based algorithms for conservation. *Environmental Science and Policy* 6 (2003) 311–328 Faith et al 2003 Environmental Science and Policy (PDF 362kb

- Costa Rica – present study
- W. Australia project "Auction for Landscape Recovery" in Southwest Australia, with WWF Australia, with the Avon Catchment Council and University of Western Australia, CSIRO, Murdoch University, Department of Conservation and Land Management, North

East Wheatbelt Regional Association of Councils, Wheatbelt Development Commission, WA Farmers Federation, and Greening Australia WA - using TARGET in combination with auctions to obtain optimal sets of conservation payments for biodiversity over the region.

- Wet tropics, Queensland with the Cooperative Research Centre - regional priority setting
- Pilbara region, W.A., the WA Future Fund, and Rio Tinto - regional planning incorporating "partial protection"
- Tourism and biodiversity planning in the Douglas Shire, Qld.

Key capabilities that make this software distinctive

The algorithm for trade-offs, based on variable weights, avoids weaknesses of simple benefit/cost ratio approaches; see:
Faith, D. P. (2002) Those Complementarity Analyses Do Not Reveal Extent of Conservation Conflict in Africa. *Science* Online
http://www.sciencemag.org/cgi/eletters/293/5535/1591#381.

Implementation of probability of persistence allows for allocation of land uses to areas that provide "partial protection". TARGET provides for the proper setting of biodiversity targets in a trade-offs setting.

Key limitations

Visualizations of some outputs is limited. Some newer changes are not fully described in the current manual and workshop material.

Further development underway or planned

TARGET is about to undergo rapid changes. We plan to further enhance its use for targeting economic instruments in regional biodiversity planning; see:
Faith, D. P., Carter, G., Cassis, G., Ferrier, S., Wilkie, L. (2003) Complementarity, biodiversity viability analysis, and policy-based algorithms for conservation. *Environmental Science and Policy* 6 (2003) 311–328 Faith et al 2003 Environmental Science and Policy (PDF 362kb

Documentation
Manual in need of update, plus up-to-date set of 14 exercises for tutorials and workshops

Support and training available
Workshop materials for 14 exercises covering the range of capabilities of the software.

Availability and cost
Available through research collaboration or other agreed provision, for free, for non-research applications.

Web site or email address for further information
Contact Dan Faith at the Australian Museum danf@austmus.gov.au
web site: http://www.amonline.net.au/systematics/staff_faith.htm
or Paul Walker CSIRO, Canberra.

Appendix 2. Surrogate indicators for biodiversity

Land units and biodiversity surrogates database

The first step was to identify the planning units to provide the basis of the database and the subsequent priority setting analysis. Since a land property map is not available for the whole ACOSA, we used a regular grid with 1x1 km^2 cells as the basic unit of analysis. The grid consisted of 4762 cells and it was overlaid on the ACOSA ecosystems map (Kappelle et al., 2002), using the ArcView GIS tool. See figure 2A.1.

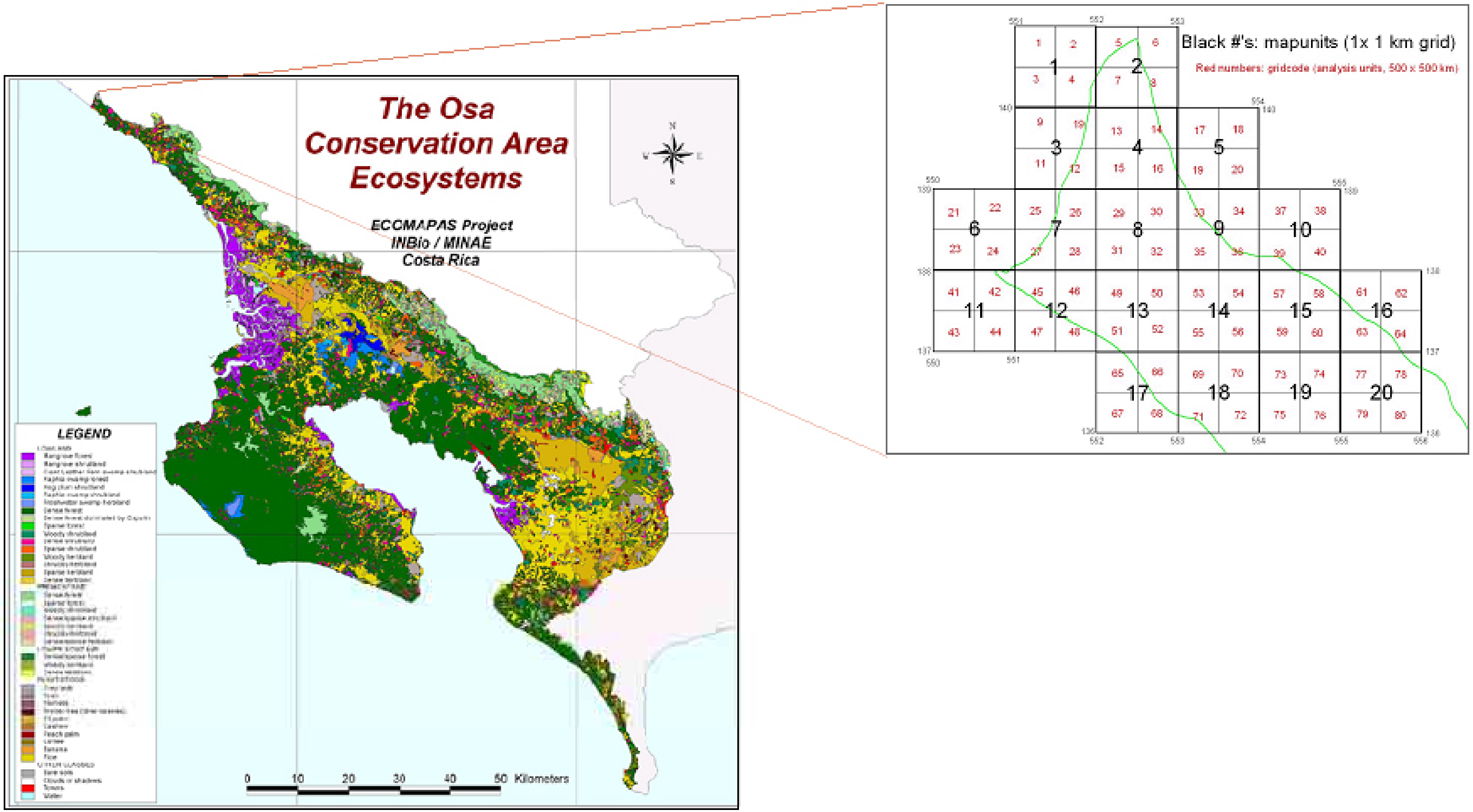
Data for climate, altitude, geology, land form and soils were digitised from existing cartography (Kapelle et al.2003) and converted into spatially registered ArcView polygon coverages. These variables consisted of 20 climate classes, 16 geological formations, 4 soil orders, 6 land-form classes, 9 elevation bands, and open water. The area (in ha) of the environmental variable classes in each of the 1x1 km cell was computed using the package ArcView 3.2 by overlying the grid with the digitised maps.

The environmental attributes were then, created by combining each class of climate, soil, landform, geology and altitude. These resulted into 678 actual combinations. Three additional attributes resulted from the combination of open water, altitude and climate classes, and 4 attributes resulted from the combination of climate, soil, landform and elevation band with mosaics of geological classes that could not be distinguished at the grid-cell level.

Each mapping unit (grid-cells in figure 2A.1) was allocated the area of the attributes that was derived from the polygons on the biophysical maps (climate, soil, geology, landform and vegetation macro-types). The ACOSA boundaries of the different digitised maps were compared and searches were conducted to detect boundary errors (area mismatches) that result from digitising. When the polygon areas of the overlain variable classes differed within a grid cell, the area allocated to the environmental attribute (product of crossing variable classes) was that of the variable class with lowest coverage. A biodiversity attribute was consider to be represented in a land unit when the cover in a grid cell was larger than 5 % (5 ha).

Finally, the biodiversity attributes were coded for each land unit and the files were prepared in TARGET-readable format.

Figure A2.1 Converting biophysical polygons to attributes in analysis units used by TARGET



Source: ECOMAPAS, INBio/MINAE

Climate

The climate database was created by digitising and combining climate maps from four different sources. We used twenty climate types (Table A2.1) derived by (Kappelle et al 2003) from overlying the variables and corresponding classes that define the Climate Types according to Herrera (1986, map scale 1:250.000) and the 3 Thermal and 3 Humidity Provinces, and the length of the dry season from Herrera & Gómez 1993 (map scale 1:685000, ‘Biotic Units map’).

The 9 variables that define the Climate Types in Herrera (1986) characterise the climate in terms of 3 major gradients, humidity (mean annual rainfall, annual potential evapotranspiration (PET), hydric and aridity indices), seasonality (occurrence and length of the dry period) and temperature (mean annual temperature) (Table 1). Hydric index reflects the relationship between PET and mean annual precipitation ((P/PET)-1)*100.

Humidity provinces by Herrera 1986, are geographic areas with ranges defined by precipitation and PET (Kappelle et al. 2003). In ACOSA; there are three humidity provinces: sub-humid, humid, and very humid. The ranges of the Thermal Provinces (Herrera 1986) are defined by altitudinal belts (Kappelle et al. 2003). In ACOSA the three provinces are: tropical (0 – 500 m), subtropical (500 – 1200 m) and Temperate (1200 – 2100 m) (Kappelle et al. 2003).

The length of the dry season based on days with soil water deficit was digitised from the maps by Herrera 1986 based on geographical areas with ranges delimited. A dry month is defined in their map as ” a month in which precipitation is less than 50% of ETP” .

Geology, landforms and soils

The geological data were obtained by digitising the map by Tournon & Alvarado 1997. There are 6 geological classes in ACOSA that characterise 16 formations (Table A2.2). Five classes correspond to rocks of sedimentary and intrusive origin, including recent swamps and fluvial, colluvial and coastal deposits (Kappelle et al. 2003). Two classes have volcanic origin and are characterised by basaltic rocks from the Cretaceous and Eocene, i.e. Complejo Nicoya and Grupo Golfito, respectively.

Landform (Table A2.3) data were digitised from the geomorphology map by Madrigal & Rojas 1980 (Kappelle et al. 2003) where six land form classes are distinguished for ACOSA. Soil type classes (Table 4) were obtained by digitising the map of soil orders by Pérez et al. (1978 SEPSA, in Kappelle et al. 2003).

Other environmental data

Additional environmental data were 9, 200 meters elevation bands derived from digitised 1:200.000 topographic maps (Instituto Geográfico Nacional (IGN), 1988. Talamanca & Golfito Topographic sheets. Scale map 1:200.000 scale. San José, Costa Rica.).

Areas with water

Based on colour photography (INBio) at 1:40 000 taken 1995 and 1996. Photos were interpreted and georeferenced at INBio.

Vegetation macro-types

Vegetation macro-types (Gómez 1986) were also used as one measure of biodiversity. The macro-types geographical data base was obtained by digitising the map of by Gómez (1986b, scale 1: 200 000).

Twelve types are found in ACOSA of a total of 55 for the entire country (Table A2.5). The vegetation macro-types have been derived by the knowledge of experts about forest types, dominant species, elevation, soil type and geomorphology. The unit limits in the map have been drawn based on the field experience.

Endemic species

At present, four plant species have been published as endemics for ACOSA (Ardón & García 1998). However, the inventory database (Atta) at the Institute of Biodiversity Atta, included in March 2003 178 endemic vascular plant species for the conservation area[9]. Geo-referenced data of species endemic to ACOSA were obtained from the Atta database. Of these 59 were considered to be 'true' endemics of ACOSA and included in selected TARGET runs. Including these endemics raises the total number of attributes to 744.

Endemic species are usually of high priority for biodiversity conservation world wide and in Costa Rica . However, we have been cautious in using endemic species as an attribute to characterise the biological diversity of land units. The data on presence of endemic species in ACOSA was excluded from TARGET analysis here because it was thought that available distributions had been biased by intensive sampling in threatened and easily accessible areas. First, since records of endemic species are very scattered, our priority setting software, will give a high biodiversity complementarity value to land units with any record of endemics. Also, there is still ongoing species identification and description work in Costa Rica. During the progress of INBio's Inventory Program, 367 new species for science of plants have been identified. Because the knowledge of species is still in progress and the area surveyed is necessarily limited, a considerable number of species currently regarded as endemics may be species that have simply not been yet recorded elsewhere.

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[9]

Table A2. 1 Climate types characterised by 11 parameters derived from crossing the classes that define climate types in Herrera 1986 (*), and the 3 Thermal and 3 Humidity Provinces in Herrera 1986 (¤) . PET: potential evapotranspiration, HI: Hydric Index (1) Aridity Index, and length of the dry season (no. of days).

Type	Humidity Province ¤	Thermal Province ¤	Hydric deficit *	Mean annual rainfall (range, mm) *	Mean Annual Temperature (range C^o) *	ETP (mm) *	AI (%) * [10]	HI (%) * [11]	Seasonality (days) *[12]
B2	Sub-humid Humid	Tropical	Moderate	1710 - 2052	25 - 27	>1710	10 - 20	0 – 20	35 - 70
B4	Sub-humid Humid	Subtropical	Very high	1565 - 2052	21 - 26	1565 - 1710	>20	0 – 20	>70
C2	Humid	Tropical	Moderate	2050 - 2400	23 - 27	>1710	10 - 20	20 – 40	35 - 70
C4	Humid	Subtropical	Very high	1900 - 2400	21 - 26	1565 - 1710	>20	20 – 40	>70
D2	Humid	Tropical	Moderate	2400 - 2740	23 - 27	>1710	10 - 20	40 – 60	35 - 70
D5	Humid	Subtropical	Moderate	2200 - 2800	21 - 25	1565 - 1710	10 - 20	40 – 60	35 - 70
D8	Humid	Subtropical	Moderate	2000 - 2500	18 - 24	1420 - 1565	10 - 20	40 – 60	35 - 70
E2	Humid	Tropical	Moderate	2740 - 3100	23 - 27	>1710	10 - 20	60 – 80	35 - 70
E3	Humid	Tropical	Low	2740 - 3100	25 – 27	>1710	0 - 10	60 – 80	<35 intermittent
E5	Humid	Subtropical	Moderate	2500 - 3100	22 – 26	1565 - 1710	10 - 20	60 – 80	35 - 70

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[10] Aridity index (AI): relationship between the intensity and duration of the dry season, expressed as a percentage of EPT

[11] Hydric index (HI). Relationship between the annual potential evapotranspiration (PET) and the mean annual precipitation (P): HI= [(P/PET)-1]x 100 (Kappelle et al. 2002)

[12] No. of days with a soil water deficit

F2	Humid	Tropical	Moderate	3080 - 3420	23 – 27	>1710	10 - 20	80 – 100	35 - 70
F3	Humid	Tropical	Low	3080 - 3420	25 – 27	>1710	0 - 10	80 – 100	<35 intermittent
F5	Humid	Subtropical	Moderate	2800 - 3420	21 – 23	1565 – 1710	10 - 20	80 – 100	35 - 70
G1	Very Humid	Tropical	Moderate	3420 - 6840	23 – 27	>1710	10 - 20	100 – 300	35 - 70
G2	Very Humid	Tropical	Low	3420 - 6840	23 – 27	>1710	0 - 10	100 – 300	<35 intermittent
G2(a)	Very Humid	Tropical	Without	3420 - 6840	25 – 27	>1710	0 - 2	100 – 300	< 10
G3	Very Humid	Subtropical	Moderate	3100 - 6840	21 – 23	1565 – 1710	10 - 20	100 – 300	35 - 70
G4	Very Humid	Subtropical	Low or without	3100 - 6840	21 – 23	1565 – 1710	0 - 10	100 – 300	<35 intermittent
G6	Very Humid	Subtropical	Moderate	2840 - 4000	18 – 21	1420 – 1565	10 -20	100 – 300	35 - 70 days
G7	Very Humid	Subtropical	Very low	2840 - 6260	18 – 22	1420 – 1565	0 - 10	100 – 300	<35 intermittent

Table A2.2 16 Geological formations in ACOSA according to Tournon & Alvarado 1995.

Code	Formation	Era	Geological period	Type
A	Puerto Armuelles	Tertiary	Pliocene-quaternary	Sedimentary
Bc	Brito Calizo	Tertiary	Eocene-Palaeocene	Sedimentary
Ch	Charco Azul	Tertiary	Pliocene	Sedimentary
Cn	Complejo de Nicoya	Cretaceous		Volcanic
Df	Fluvial, colluvial and coastal deposits	Quaternary	Recent alluvial	Sedimentary
G	Golfito	Cretaceous		Sedimentary
Ga	Grupo Aguacate	Tertiary		Volcanic
Ia	Intrusive acid, Talamanca	Tertiary	Miocene intrusive	Intrusive
Mp	Mangroves and swamps	Quaternary	Recent alluvial	Sedimentary
Pd	Pie de Monte	Tertiary	Pliocene-quaternary	Sedimentary
Sg	Sabana Grande	Cretaceous		Sedimentary
Sk	Suretka	Tertiary	Pliocene	Sedimentary
T	Térraba	Tertiary	Oligocene-Miocene	Sedimentary
Tl	Térraba: unidad Lagarto	Tertiary	Oligocene-Miocene	Sedimentary
Tz	Térraba: unidad Zapote	Tertiary	Oligocene-Miocene	Sedimentary
U	Uscari	Tertiary	Oligocene-Miocene	Sedimentary

Table A2.3 Land forms (source Kapelle et al. 2003, following Madrigal & Rojas (1980).

Code	Form	Distribution
A	Denudation forms	Along steep slopes and erosion scarps
B	Forms of volcanic origin	High plain of San Vito
C	Alluvial sedimentation forms	On alluvial and coastal plains and on Térraba-Sierpe wetland
D	Forms of structural origin	Fault valley
E	Littoral forms of marine origin	
F	Forms of tectonic and erosive origin	

Table A2.4: Four soil orders in ACOSA following Pérez et al. 1978, (in Kapelle et al. 2003)

Order	Soil description (following Kapelle et al. 2003)
Ultisol	**Reddish, deep clayey and acidic soils.**
Mollisol	Intermediate textures, dark, developed on fluvial deposits, with some drainage limitations.
Entisol	i) Sandy coastal soil with almost no development ii) Poorly drained soils with heavy texture and tidal influence (generally with mangrove vegetation).
Inceptisol	i) Reddish superficial, poorly developed soils, with low base saturation associated with similar, slightly more developed soils on hilly terrain and mountain areas. ii) Red, deep soils with low base saturation, associated with shallow soils with little development, on hilly terrain and in mountains. iii) Dark, deep soil, derived from volcanic ashes, with low base saturation, wet throughout the year, in mountainous areas.

Table A2.5: Vegetation macro-types (Gómez 1986b):

No	Type	Description, vegetation	Description, geomorphology	Description, soil
22	Seasonal formation	Seasonal evergreen tropical forest.	On formations of tectonic and erosive origin. Moderate topography to high strong slopes.	Ultisols, clayish, red, acidic poorly drained.
26	Non-Seasonal formation	Lowland tropical rainforest	On alluvial sediments and flat topography.	Mollisols, poorly drained, easily flooded.
27	Non-Seasonal formation	Lowland tropical rainforest	On formations of tectonic and erosive sediments. Irregual topography, slopes between 15-60%.	Inceptisols, poorly developed.
28	Non-Seasonal formation	Lowland tropical rainforest	On formations of marine sediments or tectonic and erosive sediments. Steep topography on slopes between 30-60%.	Inceptisols.
29	Non-Seasonal formation	Lowland tropical rainforest	On alluvial, tectonic, erosive and volcanic sediments. Irregual topography with slopes between 15-60%.	Inceptisols.
30	Non-Seasonal formation	Lowland tropical rainforest on slopes between 5-15%.		Inceptisol soils, with low CEC on terraces and piedmont
31	Non-Seasonal formation	Alluvial tropical rain vegetation	On alluvial sediments, poorly drained soils, entisols. Flat topography, with slopes between 5-10%.	Entisols, poorly drained soils.

31a	Non-Seasonal formation	Herbaceous swamps: Dominant vegetation grasses and sedges, with or without open water or floating vegetation.		
31b	Non-Seasonal formation	Inundated forests, dominant vegetation is forests with monospecific stands or where few species are dominant.		
31c	Non-Seasonal formation	Mangroves. Associations of Rizophora, Avicennia, Pelliciera, Conocarpus, etc.		
33	Non-Seasonal formation	Lowland tropical rainforest	On alluvial sedimentary formations, on hilly terrain.	Suelos inceptisoles
36	Non-Seasonal formation	Lowland tropical rainforest	On alluvial sedimentary formations, on hilly terrain, moderate terrain with slopes between 5-30%	Suelos inceptisoles derivados de materiales volcánicos, oscuros, con baja saturación de bases y húmedos todo el año
99		Open water, lagoons.		

Appendix 3. Data methods and analysis for opportunity cost indicators

Agricultural opportunity cost

Foregone returns to agriculture from biodiversity conservation was determined based on the following main steps:

1. Identity land-use capacity classes

Soil, topography and climatic variables are commonly used to determine 8 land-use capacity classes in Costa Rica (Decree 23214 MAG-MIRENEM (1994). Variables include slope, soil depth, soil texture, pedregosity, fertility, drainage, toxicity and salinity, dry season, precipitation and wind. Land-use capacity coverage of this kind was compiled based on three different GIS sources at scales of 1:50 000 to 1:200 000. (Vega and Vega 2002). Figure A2.a. illustrates differences in resolution of land-use capacity data - amongst others little detailed mapping was available within national park areas of Corcovado and Piedras Blancas because agricultural activities are excluded by law. Data sources for these areas are also older (OPSA-MAG, 1978).

Land-use capacity classes I-III allow the establishment of annual crops with class I presenting the least number of constraints on crop growth. Class IV presents serious constraints on annual crops permits annual crops only occasionally with active soil conservation. Class V-VI are apt for pasture and perennial crops such as fruit trees and coffee, albeit with soil conservation measures. Class VII is only appropriate for forestry, while class VIII are not appropriate for any other activities than conservation (with slopes >75%).

2. Determine returns to optimal crop types by land-use capacity class.

There was no geographical information at crop level available for ACOSA so we used national level statistics to determine average yields by crop types common to the study area (table A3.1). Optimal crop types are determined by matching crop requirements to the biophysical limitations of each land-use capacity class. Financial returns were calculated using market prices compiled from national statistics. For each land-use capacity class average returns were calculated weighted by the planted area of respective crop types in the Brunca region, of which ACOSA is a part. Using a weighted average normalises possible errors for any particular crop across the study area. Weighting also normalises errors that are introduced by particular market conditions for the years price and yield statistics were obtained (Vega and Vega 2002).

Returns to land-use capacity classes VF-VII were based on returns to plantation forestry. Returns to class VIII was based on the expropriation value paid by the State to private land owners given that any other land use than conservation is banned by law and no official statistics are available on actual returns to un-sustainable activities on land in this category. Calculating agro-forestry returns to classes VII- VIII is arguably a case of double counting when foregone returns to forestry are calculated for the same land because it may be unlikely that agro-forestry activities are established on newly deforested land. These micro-level adaptions are not accounted for (as the model which is meant to deal with prioritisation of conservation across a whole region).

Actual cropping alternatives to forest conservation depend amongst others on access to transportation to market, technology and to credit. Lacking geographical information on these variables, opportunity cost were calculated assuming no cost access to these factors, in effect over-valuing returns to agriculture across the study area.

Table A3.1. Annual equivalent returns to different competing land-use activities

Activity	Area (1996)	Land-use capacity class	Return ($/ha yr.)
Avocado	614	IV	1,909
Rice	40,967	II	147
Banana	52,000	II	1,317
Managed forest[13]	200,000	VII	108
Coffee	108,000	IV	647
Sugar Cane	48,000	III	623
Coconut	3,000	II	830
Beans	33,245	II	377
Livestock, meat[14]	980,000	VI	-11
Livestock, milk	500,000	VI	409
Livestock, dual purpose	520,000	VI	459
Lemon mecino	800	III	230
Mango	7,945	IV	-28
Maracuyá	36	III	1,920
Melon	4,371	II	339
Orange	23,500	IV	460
Ñame	849	II	3,340
African Palm	27,239	III	646
Palmito Pejibaye	4,500	III	1,230
Potatoe	2,794	II	320
Pineapple	8,195	II	4,831
Forest plantation	100,000	VII	248
Plantain	7,000	II	2,509
Water Melon	677	II	4,106
Tiquisque	1,608	II	2,649
Tomatoe	211	II	2,220
Yuca	5,469	II	1,209

Source: Based on Castro 1999 y Vega 1999 recalculated using 11% discount rate.

Table A3.2 Weighted average return by land-use capacity class $ ha^{-1} yr^{-1} (11% discount rate)

Land-use capacity class	Return ($/ha yr.)
Class II	3,350
Class III	671
Class IV	652
Class VF-VII	155
Class VI	152
Class VIII	47

Source: (Vega and Vega 2002)

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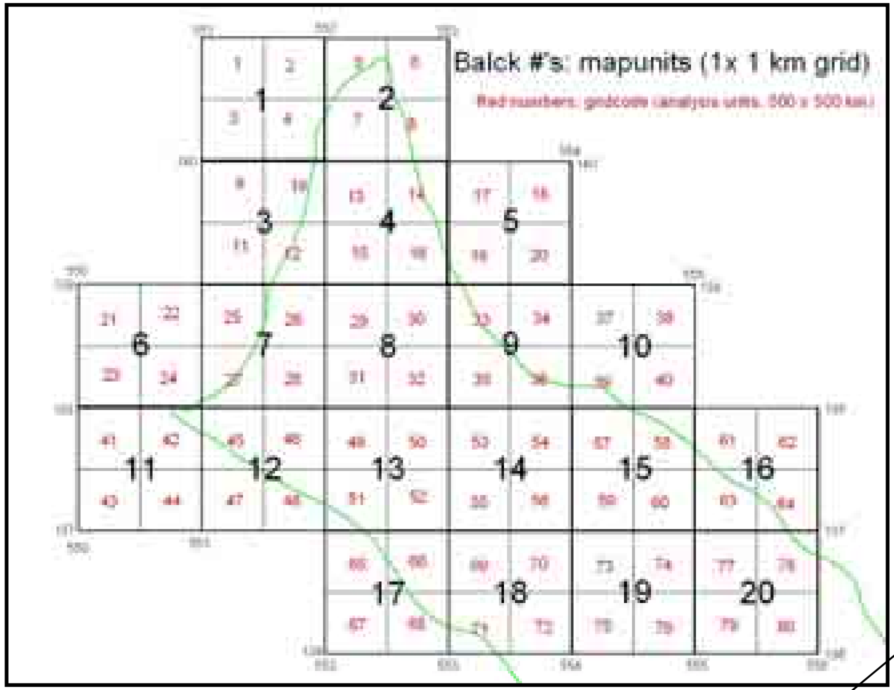
[13] Assumes a sustainable extraction of approx. 20 m3/ha of wood.

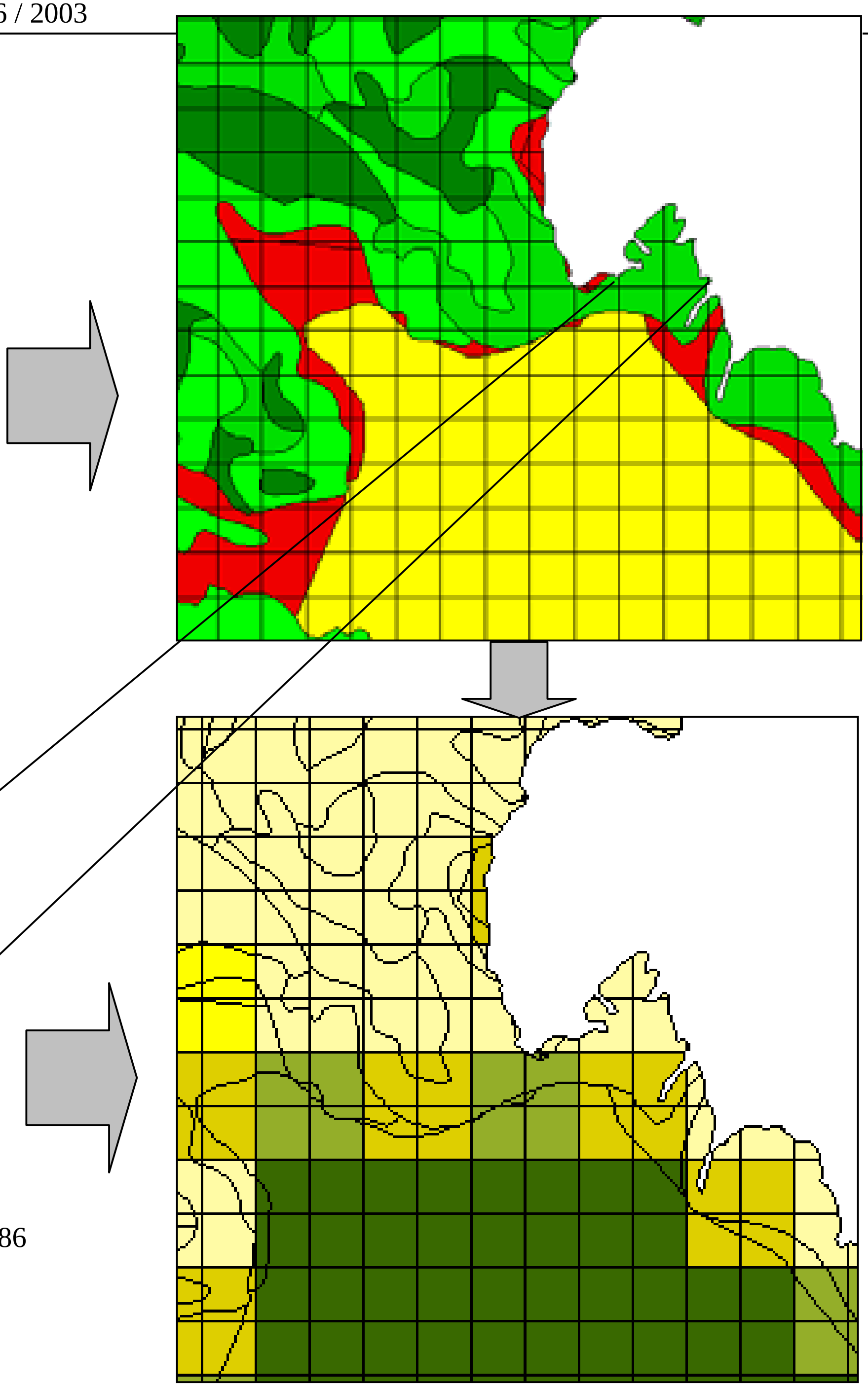
[14] Meat livestock showed returns of -$663/ha for farms smaller than 80 has and $1293/ha for farms greater than 80 ha. An average weighted by area is given in the table.

3. Calculation of weighted agricultural opportunity cost at mapping unit level.

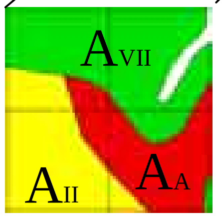
Figures A3.1 illustrates how data on agricultural returns associated with land-use capacity polygons in the whole study area were converted to 25 ha grid cells (raster) and then 1x1 km mapping units for purposes of analysis in TARGET. Although biodiversity and opportunity cost attribute data are available at 25 ha resolution, using a 1 km^2 in the trade-off analysis was a restriction set by the processing capacity of TARGET. Agricultural opportunity cost was weighted by the proportion of the grid cell in each land-use class (A_V/A_{total}) as illustrated by the calculation of C. Figures A3.2 shows the resulting agricultural opportunity cost map in grid cell format, based on the original land-use capacity map.

Figure A3.1 Definition of study area in grid cells



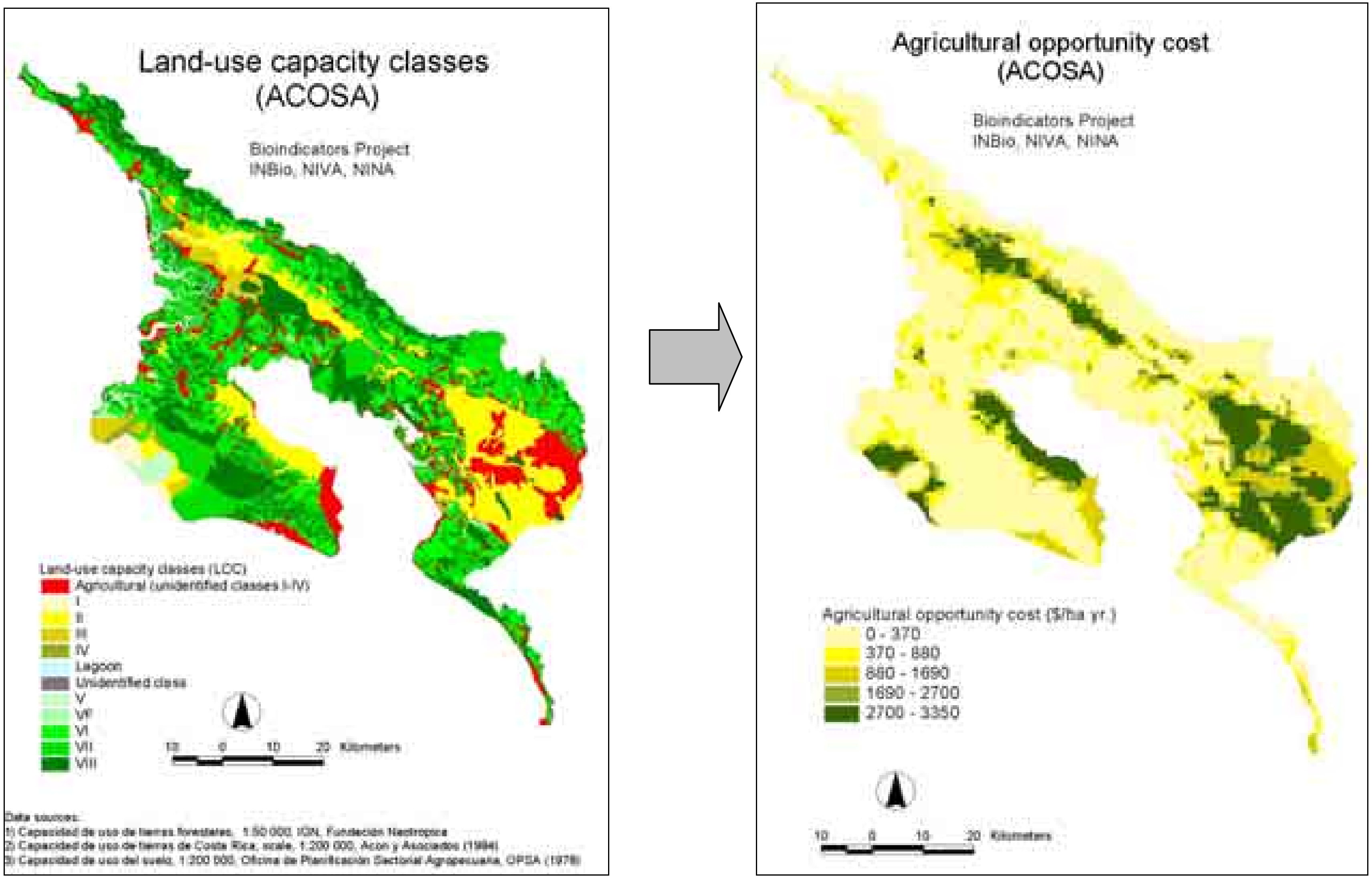


C_{2186}= (C_A*A_A+C_{II}*A_{II}+C_{VII}*A_{VII}) / A_{total}
where
C = opportunity cost
A = polygon area
A_{total}= total mapping unit area (=<100 has)



Mapping unit no. 2186

Figure A3.2 Transformation of land-use capacity to agricultural opportunity costs



Data sources:
1) Capacidad de uso de tierras forestales, 1:50 000, IGN, Fundación Neotropica
2) Capacidad de uso de tierras de Costa Rica, scale, 1:200 000, Acon y Asociados (1984)
3) Capacidad de uso del suelo, 1:200 000, Oficina de Planificación Sectorial Agropecuaria, OPSA (1978)

Forestry opportunity cost

Foregone returns to forestry from biodiversity conserrvation were calculated using the following steps:

1. Determining commercial timber volume by forest ecosystem type

Total standing timber volume by commercial species was not available for the ACOSA area. As a second best 28 forest management plans approved in ACOSA with information on total farm area and extracted timber volume by specie class were consulted (Vega 2002). These forest management plans were geographically digitised (pers. com. Tirso Maldonado) and overlaid with the INBio-ECOMAPAS forest ecosystem map (figure A3.4) in order to identify timber volumes with forest ecosystem types. ECOMAPAS is based on aerial photographs from 1996 with ground truthing conducted in 2000. 20 of the 28 management plans were found to be within lowland dense forest, while the other four forest ecosystem types were represented with only 1-2 data points. In cases where a forest type had no data on extracted timber volume it was assigned the timber volume of the adjacent forest ecosystem type with data (Table A3.3).

Mangrove forests were not included in the calculations as previous work has shown forestry to be commercially unviable (Barton 1995).

Table A3.3 Distribution of commercial timber volume by forest ecosystem in ACOSA

Forest Ecosystem	**Area (ha)**	**% of forest area ACOSA**	**Average commercial timber volume m3/ha**
Lowland dense forest	164,465.42	80.00%	24.10
Low mountain dense forest	1,815.58	0.90%	20.05
Premontane dense forest	21,853.67	10.60%	20.05
Lowland sparse forest	2,801.95	1.40%	31.36
Premontane sparse forest	265.639	0.10%	25.85
Forest plantation	14,259.56	6.90%	20.00
Total	**205,655.19**	100%	

The assumptions used here are that extracted timbre volume is a good proxy for available commercial timber volume by area and that forest ecosystem types are homogenous across the study area Despite forestry regulations that require 40% of timber volume to be left standing, total volumes observed in management plans are believed by forestry engineers to be unsustainable (i.e. the underestimate of total standing volume may be up to 40%, but is probably smaller).

this may be a good proxy over time as the minimum harvesting cycle of 15 years is generally too short to replace the most valuable commercial species. The similarity in commercial timber volumes illustrates the paucity of using extracted timber as a proxy for standing commercial timber, while discrepancies such as higher volumes for sparse compared to dense forest is an artefact of the limited number of observations for these forest types. This data can only be improved with scientific forest inventories and experimental plots in a representative sample of the different forest types.

2. Determine average returns to forestry by forest ecosystem type

Commercial timber species were grouped into the price categories commonly used by loggers and sawmills (Fine Nazareno, Semi-hard classified, Semi-hard common, "Formaleta" softwoods and plantation species such as Melina). Average sawmill prices by category were compiled based on national statistics. Prices therefore include logging and transport costs leading to an overvaluation, relative to prices loggers pay farmers for access to standing timber. Average per hectare returns were calculated by multiplying the %-wise volumetric distribution of timber types with the total volumes per forest types. Due to limited data on species composition for the other forest types, this was only possible for Lowland Dense Forest, with the same volumetric distribution being applied to the other 4 natural forest types. Differences in calculated returns in Table A3.4 are therefore only due to differences in total volume for each forest type. The table illustrates that differences in per hectare forestry returns are small and probably not significant. Returns were converted to equivalent annual returns using a discount rate of 11%.

Table A3.4 Average returns per hectare to logging by forest ecosystem in ACOSA

Ecosistema	**Returns ($/ha)**	**Equivalent annual returns $/ha/año**
Lowland dense forest	871.28	121.2
Low mountain dense forest	724.56	100.8
Premontane dense forest	724.56	100.8
Lowland sparse forest	1,133.48	157.6
Premontane sparse forest	863.47	120.1
Total-Promedio	**879.8**	**122.4**

Note: discount rate of 11% and 15 year rotation.

Ideally, an annualised value for clear-cutting of forest would be added to foregone agricultural returns to arrive at total opportunity cost. Our approach underestimates opportunity costs of conserving forested areas by the difference between the value of *extracted* timber volume under the management plans, and the value of *actual* standing timber, multiplied by the annuity factor of 14% (11% discount rate for 15 years). Due to lacking forest inventories and experimental growth plots in the area, we have not corrected these figures as the underestimate in forestry values is small compared to total per hectare opportunity costs[15]. Actual extracted timber volume is usually a good proxy for standing commercial timber volume due to poor enforcement of approved forest management plans by the ACOSA authorities. (Vega 2002)

3. Calculation of weighted forestry opportunity cost at mapping unit level.

Figure A3.3 illustrates how forest type polygons were assigned a opportunity cost and converted to 1 km2 mapping units for analysis in TARGET, using the same weighted average methodology as for agriculture. As above data was available at 25 ha grid cells, but data processing limitations lead us to use a lower resolution. Figure A3.3 illustrates "edge effects" in estuaries and mangrove areas where the definition of the study area does not exactly coincide with ecosystem land cover information. Possible errors are eliminated by weighting forestry returns by the proportion of the area within a mapping unit for which there is

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[15] Despite forestry regulations that require 40% of timber volume to be left standing, total volumes observed in management plans are believed by forestry engineers to be unsustainable (i.e. the underestimate of total standing volume may be up to 40%, but is probably smaller).

information on land cover.   Figures A3.4 shows the conversion of the original forest ecosystem map to forest opportunity costs, using the methodology described above.

Figure A3.3 Forest polygons to grid cells conversion and weighted opportunity

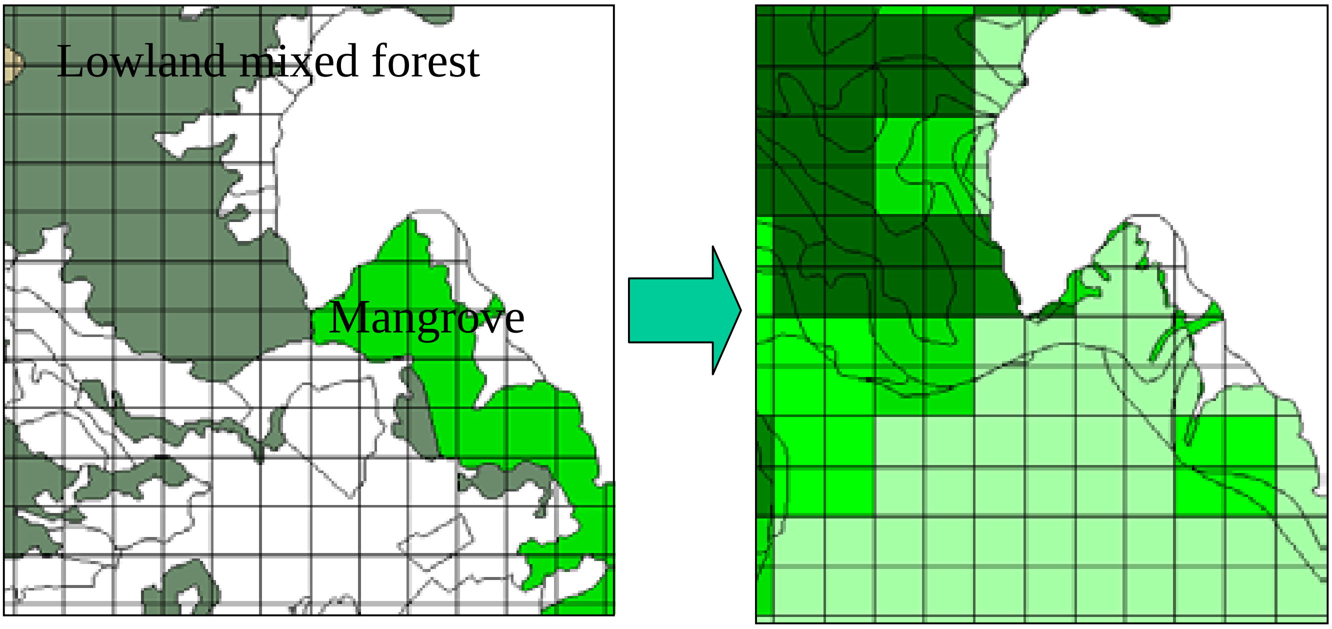
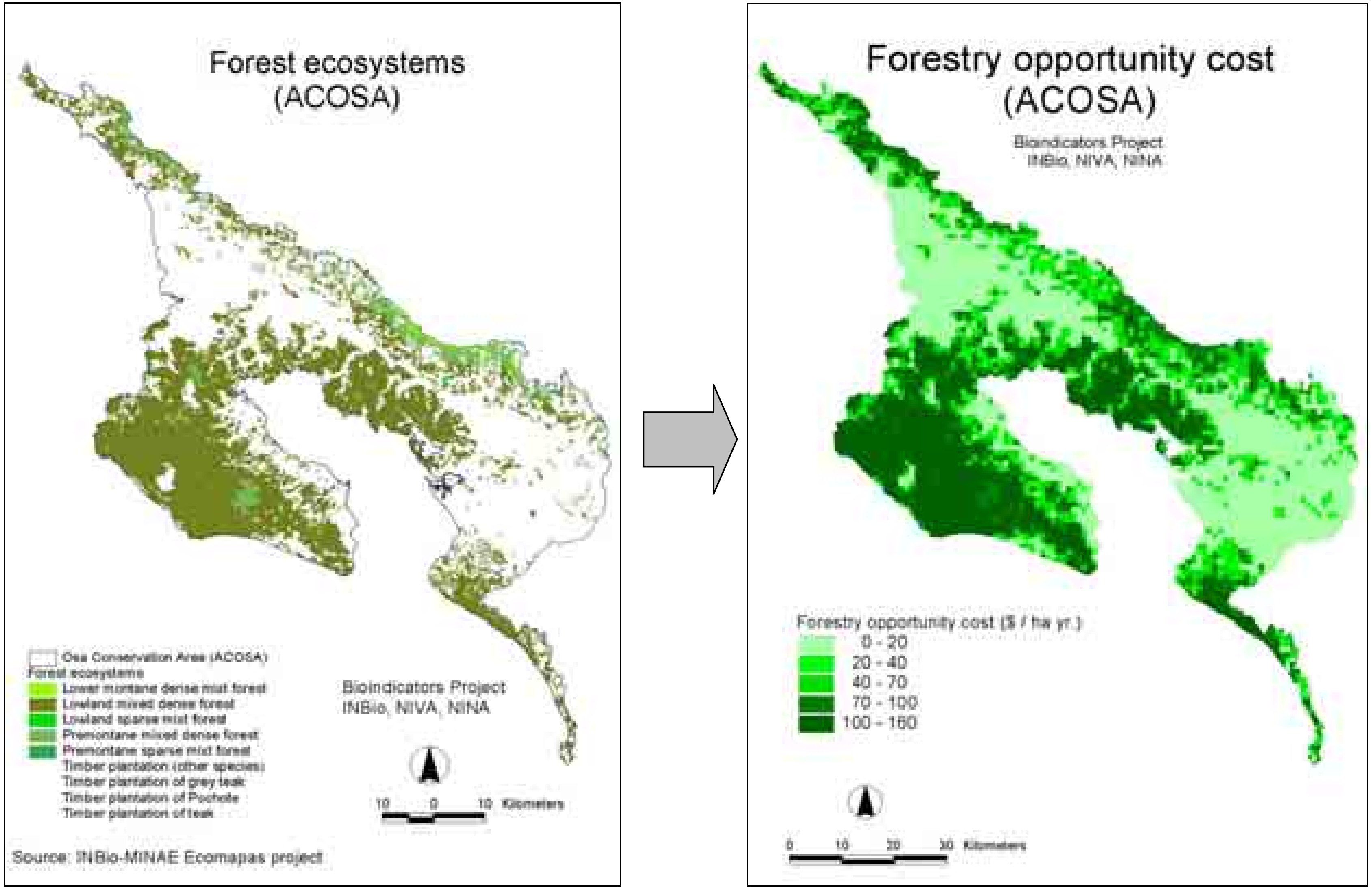


Figure A3.4 Transformation from forest cover to forestry opportunity costs



Source: INBio-MINAE Ecomapas project

Aggregating agricultural and forestry opportunity cost

Land currently under forest which is passed into conservation must forego both returns from logging and then agriculture as land use changes. Annual forestry and agricultural opportunity costs are therefore added by grid cell to arrive at aggregate opportunity cost illustrated in figure A5. Several limitations to the opportunity cost approach have been noted previously. For aggregate opportunity costs two further limitations should be mentioned:

a) All figures are based on uncorrected market prices representing financial rather than economic opportunity cost.

b) No corrections are made for the external effects of different types of land use. Land-use capacity classes with steep slopes are increasingly prone to soil-erosion and faster run-off and may lead to downstream externalities such as flooding and siltation which are not accounted for here.

c) Where logging is not followed by forest plantations or other perennial crops adapted to cland-use capacity class VII, adding agro-forestry and forest returns leads to double counting/ over-valuation of opportunity costs.

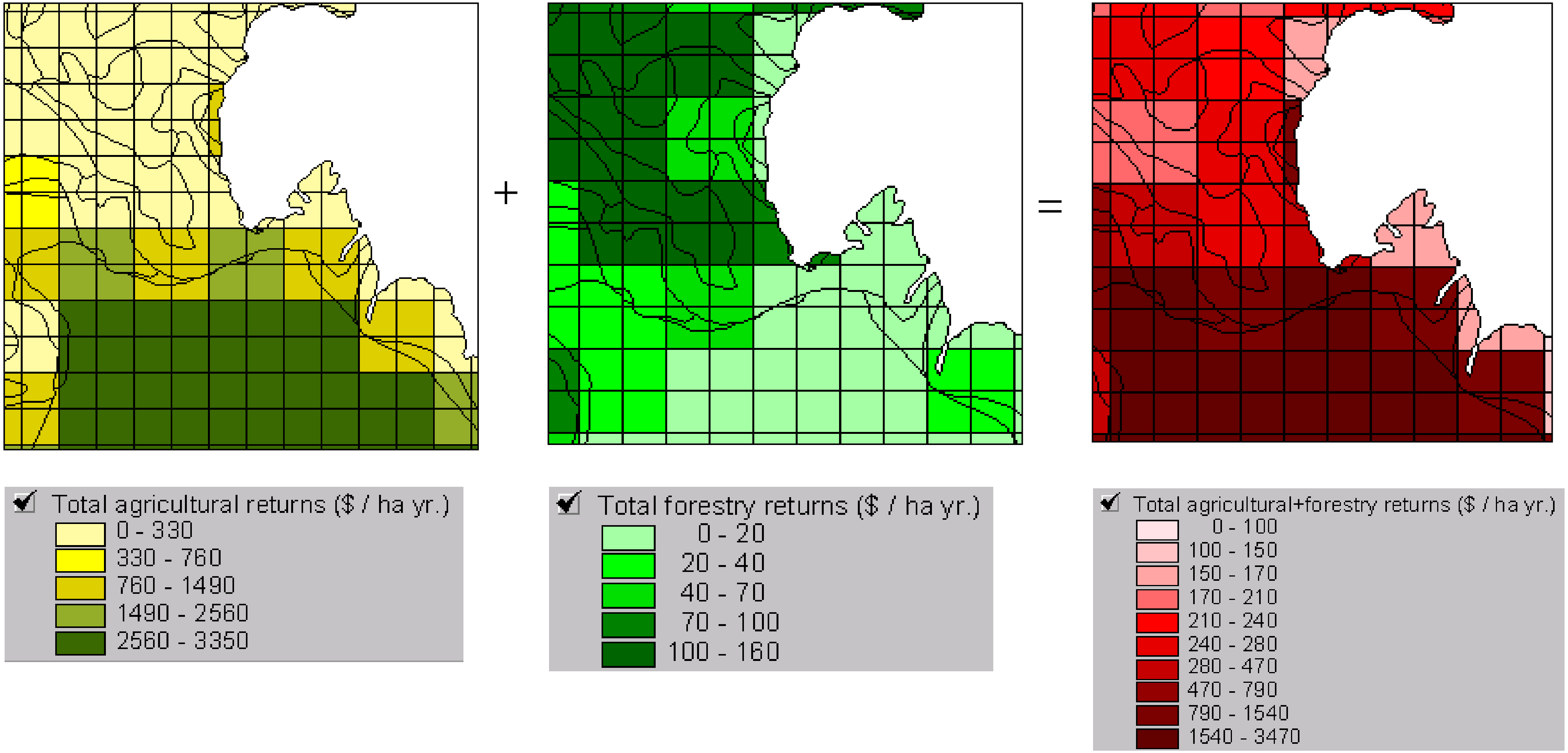
d) Overvaluation of opportunity costs to class VIII are also present to the extent that no productive activities are practiced there after logging (in accordance with land-use capacity methodology).

e) Forestry opportunity costs are also most overvalued for extraction from class VIII land as average timber prices do not reflect the above-average production costs of forestry on e.g. steep slopes.

These assumptions lead to biases in areas selected by the TARGET trade-off methodology: for (a) absolute values are probably affected fairly evenly across the study area; (b) biases towards the selection of areas in land-use classes VII-VIII relative to trade-offs which include externalities; (c-e) bias the selection of biodiversity conservation away slightly from areas in land-use capacity classes VII-VIII, because calculated financial opportunity costs are higher than they probably are for land-owners in practice .

To the extent that the trade-off analysis should reflect societal choices (including externalities) we cannot draw any conclusions about the net direction of biases due to errors in accounting for opportunity costs. We feel the current data is sufficient to illustrate the potential for trade-off analysis and relative prioritisation of areas for conservation. Due to the biases mentioned we would be cautious in using the opportunity cost data generated here for natural resource accounting exercises.

Figure A3.5. Total agricultural and forestry opportunity



References

Ardon and Garcia (1998). Taller Regional de la Estrategia Nacional de Biodiversidad: Área de Conservación Osa. Estrategía Nacional de Biodiversidad. COABIO - SINAC - INBio. San José.

Austin, M.P. 1991. Vegetation theory in relation to cost-efficient surveys. Pages 17-22. In Margules, C.R. & Austin, M.P., editors. Nature Conservation: Cost effective biological surveys and data analysis. CSIRO, Australia.

Barrantes, G., E.Vega, et al. (2002). Determinación de los costos de manejo y protección en ACOSA (Bioindicators Project: NOTAT N-03/014). San Jose, Instituto para Politicas de Sostenibilidad**:** 26.

Barton, D. N. (1995). Valoración económica parcial de alternativas de manejo para los humedales de Térraba-Sierpe, Costa Rica, Maestría en Política Económica para Centroamérica y el Caribe, Universidad Nacional de Costa Rica (UNA).

Bateman, I. J., A. A. Lovett, et al. (2003). Applied Environmental Economics. A GIS Apporach to Cost-Benefit Analysis, Cambridge University Press.

Camacho, A. and V. Reyes (2002). Pago por servicios ambientales. Octavo Informe sobre el Estado de la Nación en Desarrollo Humano Sostenible. San Jose, Estado de la Nacion.

Cornell, J. D. (2000). Assessing the Role of Parks for Protecting Forest Resources Using GIS and Spatial Modelling. Quantifying Sustainable Development. The Future of Tropical Economies. C. S. Hall, Academic Press**:** 761.

Faith, D. P., G. Carter, et al. (2003). "Complementarity, biodiversity viability analysis, and policy-based algorithms for conservation." Environmental Science and Policy **in press**.

Faith, D. P., G. Carter, et al. (in press). "Complementarity, biodiversity viability analysis, and policy-based algorithms for conservation." Environmental Science and Policy.

Faith, D. P., C. R. Margules, et al. (2001). "A biodiversity conservation plan for Papua New guinea based on biodiversity trade-offs analysis." Pacific Conservation Biology **6**(4): 304-324.

Faith, D. P., C. R. Margules, et al. (2001). "A biodiversity conservation plan for Papua New Guinea based on biodiversity trade-offs analysis." Pacific Conservation Biology. **6 Pages**(4): 304-324.

Faith, D. P., C. R. Margules, et al. (2001). "Practical application of biodiversity surrogates and percentage targets for conservation in Papua New Guinea." Pacific Conservation Biology **6**(4): 289-303.

Faith, D. P., H. A. Nix, et al. (2001). "The BioRap Biodiversity Assessment and Planning Study for Papua New Guinea." Pacific Conservation Biology **6**(4): 279-28.

Faith, D. P. and P. A. Walker (1995). DIVERSITY: a software package for sampling phylogenetic and environmental diversity. Reference and user's guide. v. 2.1., CSIRO Division of Wildlife and Ecology. Canberra.

Faith, D. P. and P. A. Walker, Eds. (1996). DIVERSITY -TD. Pp-63-74 in Bio Rap, rapid assessment of biodiversity. Volume three, tools for assessing biodiversity priority areas.

Faith, D. P. and P. A. Walker (1996). " Integrating conservation and development: effective trade-offs between biodiversity and cost in the selection of protected areas." Biodiversity and Conservation **5**: 417-429.

Faith, D. P., P. A. Walker, et al. (1996). "Integrating conservation and forestry production: exploring trade-offs between biodiversity and production in regional land-use assessment." Forest Ecology and Management(85): 251-260.

Faith, D. P., P. A. Walker, et al. (2001). "Some future prospects for systematic biodiversity planning in Papua New Guinea - and for biodiversity planning in general." Pacific Conservation Biology Pages **6**(4): 325-343.

Garcia V., R. (1996). Propuesta Técnica de Ordenamiento Territorial con Fines de Conservación de Biodiversidad en Costa Rica: Proyecto GRUAS, Ministerio del Ambiente y Energía de Costa Rica (MINAE), Sistema Nacional de Areas de Conservación (SINAC)**:** 114.

Gomez and Herrera (1993). Mapa de Unidades Bióticas de Costa Rica. Scale 1:685.000. US Fish and Wildlife Service - TNC - INCAFO - CBCCR - INBio - Fundación Gómez-Dueñas. San José.

Herrera (1986). Clima de Costa Rica. Vol. 2. In: L.D. Gómez, ed., Vegetación y Clima de Costa Rica. With 10 maps (scale 1:200.000). EUNED. San José.

Kappele, M., M.Castro, et al. (2003). Ecosystems of the Osa Conservation Area (ACOSA), INBIO.

Madrigal and Rojas (1980). Manual Descriptivo del Mapa Geomorfológico de Costa Rica (scale 1:200,000). Secretaría Ejecutiva de Planificación Sectorial Agropecuaria y de Recursos Naturales Renovables. San José.

MAG-MIRENEM (1995). Metdología para la determinación de la capacidad de uso de las tierras de Costa Rica. San José, Ministerio de Agricultura y Ganadería (MAG).

Miranda, M. (2003). Institutional Capacities for Sustainable Progress. Experiences from Costa Rica. Faculteit Geowetenschappen. Utrecht, University of Utrecht**:** 159.

Nasi, R., S. Wunder, et al. (2002). Forest ecosystem services: can they pay our way out of deforestation. Forestry Roundtable, UNFF II, March 11 2002, Costa Rica, Center for International Forestry Research (CIFOR).

Pagiola, S., J. Bishop, et al., Eds. (2002). Selling Forest Environmental Services. Market-based Mechnisms for Conservation Development. London, Earthscan.

Pfaff, A. and A. Sanchez (2003, in press). "Deforestation Pressure & Biological Reserve Planning: A conceptual approach & an illustrative application for Costa Rica." Resource and Energy Economics.

Powell, G., J. Barborak, et al. (2000). " Assessing representativeness of protected natural areas in Costa Rica for conserving biodiversity: a preliminary gap analysis." Biological Conservation **93**: 35-41.

Pressey, R.L. & Bedward, M. 1991. Mapping the environment at different scales: Benefits and costs for nature conservation. Pages 7-13. In Margules, C.R. & Austin, M.P., editors. Nature Conservation: Cost effective biological surveys and data analysis. CSIRO, Australia.

Rosero-Bixby, L., T. Maldonado-Ulloa, et al. (2002). "Bosque y población en la Peninsula de Osa, Costa Rica." Revista de biología tropical **50**(2): 585-598.

Tournon and Alvarado (1997). Mapa Geológico de Costa Rica. Scale 1:500,000. Editorial Tecnológico de Costa Rica. Cartago.

Vega, E. and M. Vega (2002). Determinación del costo de oportunidad y clasificación por clases de capacidad de uso (Bioindicators Project: NOTAT N-03/012), Instituto de Políticas para la Sostenibilidad**:** 34.

Vega, M. (2002). Determinación del rendimiento forestal en el Area de Conservación Osa (Bioindicators project: NOTAT N-03/013), Instituto de Políticas para la Sostenibilidad (IPS)**:** 24.

Vreugdenhill, D. (1992). Biodiversity Protection and Investment Needs for the Minimum Conservation System in Costa Rica (consultant report to World Bank Forestry Sector Review for Costa Rica), World Bank**:** 43.

World_Bank (2000). A Grant from the Global Environmental Facility Trust Fund of SDR 6.1 (US$ 8 million equivalent) to the National Forestry Financing Fund for the Ecomarkets Project. Washington DC, Environmentally and Socially Sustainable Development, Central America Department, Latin America and the Caribbean Regional Offfice, World Bank.