# Practical application of biodiversity surrogates and percentage targets for conservation in Papua New Guinea

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ABSTRACT

A conservation planning study in Papua New Guinea (PNG) addresses the role of biodiversity surrogates and biodiversity targets, in the context of the trade-offs required for planning given real-world costs and constraints. In a trade-offs framework, surrogates must be judged in terms of their success in predicting general biodiversity complementarity values – the amount of additional biodiversity an area can contribute to a protected set. Wrong predictions of low complementarity (and consequent allocation of non-protective land uses) may be more worrisome than wrong predictions of high complementarity (and consequent allocation of protection, perhaps unnecessarily forgoing other land uses benefiting society). Trade-offs and targets work well when predictions of complementarity are based on surrogate information that is expressed as a continuum of variation. The PNG study used hierarchical variation for environmental domains and vegetation types, and a nominated target then dictated the level within those hierarchies that was used. Internationally-promoted targets provide a potential basis for comparative evaluation of biodiversity protection levels among countries or regions. However, conventional application of percentage targets, in focussing on proportions of total area or on proportions of habitat types, does not serve the goal of biodiversity protection or sustainability well because targets can be miss-used to restrict the amount of biodiversity protected. At the same time, recent complaints about percentage targets are equally misguided in claiming, based on species-area curves, that 10% targets imply 50% extinctions. We apply a new approach to percentage targets in PNG, in which the maximum diversity that could be protected by an unconstrained 10% of the total area of the country becomes the working biodiversity target. Reaching that same biodiversity target may then require more than 10% of the area, because of constraints (e.g., existing reserves) and costs. In the baseline analysis for PNG, we found that hierarchical variation

at the level of 564 vegetation types, combined with the 608 environmental domains, could be protected in an unconstrained 10% of the country. This process of determining a biodiversity target also revealed some “must-have” areas for any future conservation plan. Such must-have areas were also identified for a 15%-based target. The satisfaction of the 10%-based target in practice required 16.8% of PNG (Faith *et al.* 2001a). This low-cost proposed protected set corresponded to greater net benefits relative to our application of two conventional targets approaches.

## INTRODUCTION

There are three broad issues that have to be addressed in developing any conservation plan (Faith 1997a; Margules and Pressey 2000). The first is how to measure biodiversity, including the subsidiary questions of how to make best possible use of existing data and which geographical units to use as the allocation units for planning purposes. The second concerns the role of biodiversity targets against which success or failure can be judged. The third is how to achieve those targets in the light of real-world costs and constraints. The first two are considered here and the third is the subject of the following two papers (Faith *et al.* 2001a,b). These three papers, in contributing to a conservation plan for Papua New Guinea (PNG), further develop and apply a framework for measuring biodiversity (Faith and Walker 1996a) for carrying out trade-offs (Faith and Walker 1996b) and for integrating vulnerability/persistence issues (Faith and Walker 1996c).

The issues of measurement, targets and costs might appear to be largely independent concerns in conservation planning. After all, targets may be defined as amounts of land (e.g., IUCN 1993) independent of considerations of biodiversity surrogates or whether costs ("opportunity costs" reflecting any forgone opportunities implied by conservation of a given area) are to be taken into account. Further, taking costs into account using a biodiversity trade-offs approach (Faith *et al.* 1994,1996; Faith and Walker 1996b) does not place any particular demands on the way biodiversity is measured, and can proceed with or without a biodiversity target – sensitivity analysis and/or budget constraints may dictate the selection of biodiversity priority areas (Faith *et al.* 1994; Faith 1995a). Nevertheless, we see biodiversity targets as providing an important comparative benchmark for whole-country or regional studies, and we will argue here that the effective use of such targets is possible, but depends on the interplay of biodiversity surrogates, targets and costs.

Article 8 of the Convention on Biological Diversity requires each signatory country to develop guidelines for the selection of protected areas and to establish a representative protected areas network. Internationally-promoted targets provide a potential basis for comparative evaluation of biodiversity protection levels among countries or regions. The Brundtland report (The World Commission on Environment and Development 1987) recommended that each country set aside some proportion of its area to protect representative samples of ecosystems. The Caracas Action plan (IUCN 1993), and before that the Bali Action plan (Miller 1984) called for targeted percentages of the extent of natural features (e.g., forest types) to be represented in protected areas. The Caracas Action plan notes that "less than 5% of the planet's surface is afforded protection…with some key ecosystems…being under-represented…correcting this problem will require: developing an internationally recognised set of guidelines for evaluation of the present coverage of protected areas; identifying major gaps in this coverage; and setting targets to fill those gaps…" (IUCN 1993). It goes on to recommend that protected areas cover at least 10% of each biome.

The World Conservation Monitoring Centre (WCMC) estimates that around 8% of the world's forests are covered by IUCN Category I-IV protected areas (WCMC 1998; Kanowski *et al.* 1999). By 1999, 20 countries had committed to a protection goal of 10% of all forest types (Kanowski *et al.* 1999) and some had committed to exceeding it. Australia's target, for example, is 15% of the pre-1750 (pre-European settlement) extent of forest ecosystems (Commonwealth of Australia 1997). The World Bank-WWF forest alliance (1998) has a target of 10% protection of each forest type.

This study explores a new way to interpret such targets that avoids some of the difficulties in their conventional application. In our PNG study (Nix *et al*. 2001; Faith *et al*. 2001a,b), we adopted an initial target of 10%, but did not apply that as a percentage of land, nor as a percentage over habitat “types”. Instead, we have applied a percentage target in a novel way that is linked to our use of biodiversity surrogates and costs. To introduce this approach, we first discuss considerations relating to biodiversity surrogates, and then the consequent problems for the use of targets.

**Complementarity and biodiversity surrogates**

It is always necessary to use biodiversity surrogates, because our descriptive knowledge of what constitutes biodiversity is inadequate, and seems likely to remain so in the foreseeable future. Surrogates might be sub-sets of taxa such as birds, butterflies, plants, or species assemblages such as vegetation types or communities, or environmental variables or classes (hereafter called domains after Richards *et al.* 1990). Various combinations of these may be used (Margules 1999).

What information should a biodiversity measure, based on surrogates, provide? Clearly surrogates will not provide the same information as a complete listing of all components of biodiversity. Early work on surrogates focussed on patterns of species richness and evaluated the utility of surrogates based on prediction of species richness from place to place (e.g., Prendergast *et al.* 1993). But even if surrogates provided that kind of prediction, such information is not much use in identifying a *set* of areas that is rich as a set (Faith and Walker 1996d). The cornerstone of systematic conservation planning, complementarity (e.g., Vane-Wright *et al.* 1991, Pressey *et al.* 1993), reflects the amount of biodiversity that an area can contribute that is additional to what is represented in some given set (e.g., existing reserves or a partial set of proposed areas). If an area rich in species contains species already represented, then its complementarity value is low. Complementarity is important in building up sets of priority areas when resources are limited.

Complementarity is often discussed as a property relating only to a surrogate set of taxa, but surrogates should be judged based on how well they provide *predictions* of the complementarity values that would be observed if we had measured all of biodiversity (Faith 1996). "Simple complementarity for the observed indicator group must be distinguished from what is really of interest: the predicted <u>general</u> complementarity value" (Faith and Walker 1996d). This perspective lends further support to the idea that effective surrogates for biodiversity need not be lists of species, but can be ordination or clustering patterns that combine environmental and biotic information (Faith and Walker 1996a,c).

Our focus on making best-possible use of all data to predict complementarity contrasts with other frameworks that focus primarily on species data. For example, proponents of the hotspots approach of Conservation International argue: "While it has become popular in conservation circles to downplay the importance of species-based data, we believe that this is a fundamental weakness of the field that needs to be corrected. Species are the most basic, recognizable units for any analysis of this kind, and lack of an underpinning of solid species-based data will result in hollow priority-setting activities that will not stand the test of time" (Mittermeier *et al*. 1999). While we agree that priority-setting must reflect information about species (see Faith *et al*. 2001b), another "test of time" is important too. There is a prevailing need to determine conservation priorities within a short time-frame, where collection of "solid species-based data" impossible, and effective prediction of complementarity values of areas must make best-possible use of all available data.

Some of the reported weaknesses of biodiversity surrogates may arise solely from interpreting surrogates as providing something other than predicted complementarity (Faith and Willliams in prep). For example, van Jaarsveld *et al.* (1998) found a lack of correspondence between minimum sets of areas (sensu Margules *et al.* 1988; Pressey *et al.* 1993) for different biodiversity indicators, and claimed that this "largely undermines hopes for using 'indicator taxa' … as biodiversity planning tools". But two such indicators could nevertheless have high correspondence in the *complementarity* values they assign to areas over a wide range of scenarios, and so be quite useful in real planning exercises (Faith and Williams, unpublished data).

Margules and Pressey (2000) suggest that biodiversity surrogates need to tell us how "similar or different" areas are, and Colwell and Coddington (1994; see also Howard *et al.* 1998) equate complementarity with what amounts to a Bray-Curtis dissimilarity between two sites. Such information on its own, however, does not predict complementarity values (Faith and Walker

1996d). The true complementarity of an area can only be measured in the context of a set of other areas, in which case it provides an indication of the additional biodiversity supplied by that area. For example, if we use a set of clusters from a hierarchical pattern to predict complementarity (as in our PNG study), then the complementarity value of an area is the number of additional clusters represented when the area is added to the current selected set.

**Complementarity, trade-offs and targets**

Predicted complementarity links directly with the rationale for the biodiversity trade-offs methods (Faith *et al.* 1994, 1996) applied in our PNG study (Faith *et al.* 2001a,b); an area is selected as a biodiversity priority area if and only if its predicted complementarity value exceeds its (weighted) cost. Such trade-offs have implications for the process of measuring biodiversity and setting targets. Conventionally, a "staged" approach (reviewed in Margules and Pressey 2000) is used: the measure of biodiversity, providing some way to calculate complementarity values, is determined, a target amount of biodiversity is nominated independently, and a complementarity algorithm used to select areas efficiently (see also Pressey *et al.* 1993). In the staged approach, these steps occur successively, and the opportunity costs central to trade-offs may not be dealt with until after the area selection process (Margules and Pressey 2000).

We argue for a stronger interplay among surrogates, targets, and costs/constraints. This need can be understood by noting some of the pitfalls of some simple staged approaches. One well-documented problem is found in the conventional applications of percent targets to an *a priori* fixed number of attributes. For example, nomination of just two forest types (why not 200 or 2000?) as surrogate information for forests biodiversity means that a target of 15%

representation of the area of each type can be "satisfied" at very low cost, while the actual degree of biodiversity representation could in fact be low (for discussion of Australian examples, see Faith 1997a,b). This happens, for example, if the chosen 15% of a large heterogeneous type is located in the same remote areas such as mountain tops, which are cheap to protect, but only protect species from mountain tops. This same problem is apparent in the confusion underlying the well-publicized argument by Soule and Sanjayan (1998) that "the 10% goal is effectively a prescription for reducing global species richness by half or more." They ignore the practical implications of a 10% target for "each ecosystem." In PNG and elsewhere there are minimum-sized geographic units for selection, implying that the amount of land required to meet a 10% target depends on the number of ecosystems defined. At the extreme, if each of the original units is defined as a different "ecosystem", then the entire region is required (unless the allocation units are now split into smaller allocation portions) and all species are represented. This awkward dependence on how finely we subdivide nature means that a 10% goal does not necessarily imply any loss of species, let alone 50%.

Another problem with Soule and Sanjayan's (1998)criticism of a 10 (or any other) percentage target is that it follows the logic of species-area curves (see Macarthur and Wilson 1967), in which a 10%-sized fragment of a biome (analogous to an island) might be all that remains after the surrounding habitat is destroyed. While such area effects properly may influence expected probabilities of species persistence (and are discussed in Faith et al. 2001b), Soule and Sanjayan discuss implications of 10% samples without regard to whether that 10%, when selected by a planner, is homogeneous or heterogeneous. A homogeneous 12%-area sample of forests of PNG could represent fewer species than a heterogeneous 10% sample (because the 10% may sample many different species while the 12% duplicates species).

A percentage-of-total-area of a nominated number of types does not capture what is actually a continuum of variation. We need to make best possible use of available surrogate information to provide a calculus based on such a continuum, so that 1) the effect of targets does not depend on arbitrarily "chopping up" a continuum, 2) overall complementarity can be predicted, again without depending on arbitrarily "chopping up" a continuum, and 3) percent targets do not have to address amounts of land, but can more directly reflect what is of interest - amounts of biodiversity represented and protected. Thus, we take the interplay of surrogates, targets and costs to mean that biodiversity surrogates are most usefully defined for the purposes of conservation planning as a continuum of variation.

Examples of continuous patterns are hierarchies and ordinations. Such an open-ended continuous pattern describes finer and finer levels of variation. How finely that may be dissected – a number of clusters in the case of a hierarchical pattern, a number of effective attributes sampled in the case of ordinations (Faith and Walker 1996a) - can then be derived after a percentage target is nominated. The maximum heterogeneity/diversity that could be protected by a best 10%-of-total-area sample becomes the working biodiversity target. Reaching that biodiversity target might then require more than 10% of the area, given constraints (e.g., existing reserves) and costs. Costs (e.g., forgone logging opportunities) affect the outcome in that our initial 10% of land-area must be replaced by a larger percentage of the total area, in order to reach the same level of biodiversity representation in the face of costs and constraints.

This perspective on surrogates and targets in turn highlights the importance of trade-offs. Trying to reach that same level of representation in the face of costs and constraints puts a premium on finding a least–cost solution, which may be difficult to find if costs are only taken into account after the selection process (an alternative option according to Margules and Pressey 2000). Faith *et al.* (1994) found little overlap between cost-ignored and cost-minimized sets of areas, suggesting that post-hoc adjustments to accommodate costs might be unlikely to lead to least–cost solutions. Faith *et al.* (2001a) discuss this problem further and illustrate the trade-offs procedures for finding optimal planning solutions.

## THE NEW APPROACH TO TARGETS

We propose a tighter linkage between surrogates, targets, and costs in which the required degree of biodiversity representation (and persistence; see below) is not an *a priori* determination (such as 10%), but only emerges after an initial priority-areas analysis that serves a baseline for actual planning.

Our approach assumes that biodiversity over a set of areas is described as a continuous pattern, such as a numerical hierarchical classification, or an ordination. It is this structure, inherent in numerical classifications and ordinations, that can be used to set targets. In the case of a hierarchical classification, the idea is to find the level in the hierarchy - the number of clusters - that can be protected in a total of, say, 10% of a region, country or biome, pretending there are no people, no opportunity costs and no land use history. Once this level is found in the baseline analysis, the target then becomes this same level of representation and protection in a new set of places that takes into account opportunity costs and land use history (Fig. 1; see also Faith 1997a,b). For PNG, these constraints include existing protected areas (Fig. 2). The resulting set of places that reaches the target form an initial set of biodiversity priority areas. They are the areas to which scarce conservation resources should be directed. Some may become formal protected areas, though others may simply be managed in an appropriate way.

Two initial tasks for implementing this approach, described below for PNG, are to decide on the map units and the data layers that are to provide biodiversity surrogate information, summarized as a continuous pattern. Any pixel or grid cell within a larger map unit or polygon can then be identified with a cluster at any level of a hierarchy (or, for a pixel in ordination space, identified with sets of implied attributes; see Faith and Walker 1996a). In practice, we have used repeated analysis trials with finer scales of clustering to explore the hierarchical continuum.

In each analysis, we used TARGET software (Walker and Faith 1998; see also Faith and Walker 1996e, 1997 and Faith *et al.* 2001a,b) to select areas (polygons) in order to represent all the clusters defined at a given level. The input consisted of a listing of all polygons and, for each polygon, a recording of all the clusters contained in it. Because the purpose of the baseline analysis is to determine how much biodiversity can be represented *and protected* in 10% of the country, attribute occurrences and /or areas that are inadequate (e.g., too small) according to persistence/viability models can be excluded. A variety of persistence/viability criteria might be used. The linking of targets to biodiversity persistence need not be based on species-area curves; representativeness can be linked to persistence models from a variety of sources, and incorporated in the usual calculus of complementarity using probability values (Faith and Walker 1996c, 1997; Faith *et al.* 2001b).

TARGET can search for sets of areas that represent biodiversity while minimising cost (Faith *et al.* 1994). The cost file for TARGET contains, for purposes of the baseline analyses, the area of each polygon. The use of polygon area as a cost enables us to represent any nominated number of clusters in the minimum total area possible. To search for the minimum-area solution, any single run of TARGET then proceeds by nominating a weight for the costs. The software then iteratively adds and deletes areas from a "select list", ensuring along the way that the complementary value for a selected area exceeds its weighted cost. No further areas are selected when no further area has a high enough complementarity to exceed its weighted cost. If too high a weight is nominated, the analysis will stop without representing all clusters. Over successive runs, the weight can be reduced, optionally starting with the results of the previous run, to ensure all clusters are eventually represented and that costs are minimized.

The baseline analyses used to determine how much biodiversity can be represented in 10% of the country may requires adjustment of the number of clusters derived from the hierarchy. For example, a new set of analyses is carried out with a larger number of clusters from the hierarchy if the initial analyses represented all clusters, but did not select enough areas to total approximately 10% of the country in total area. The final baseline analysis will be the one in which the choice of weighting and cluster-level is such that 10% of the country was selected. This indicates approximately the maximum amount of biodiversity represented in that total area (the hollow circle along the dashed line in Figure 1). We then record that list of clusters/attributes and this provides our biodiversity target for all later analyses. In the next section, the measures of biodiversity for carrying out this analysis in PNG are described.

## MEASURING BIODIVERSITY IN PNG

### Mapping units

Papua New Guinea occupies more or less the eastern half of the large tropical island of New Guinea and its associated off-shore islands. Most of the land surface, with the exception of some coastal areas and valleys in the highlands, is covered by tropical forest. In 1975, forest covered 330,650 $km^2$, approximately 70% of the total land area of 464,100 $km^2$. The other 30% also contains substantial areas of primary and secondary forest, but in a mosaic with village agriculture and grasslands. The Papua New Guinea Resource Information System, known as PNGRIS, contains maps and information on current land use, population density, geology, slope, landform, inundation, vegetation, soils, and limitations on land use for the whole country, (Bellamy and McAlpine 1995; Keig and Quigley 1995). The land units for which this information is recorded, and within which it is stored, are called Resource Map Units (RMUs; Figure 3). These units are widely used and understood by many different Government agencies in PNG, so they were used as the planning allocation units for this study. The RMUs were mapped from aerial photographs during the extensive land resource surveys carried out by the Australian Commonwealth Scientific and Industrial Research Organisation (CSIRO) in the 1970s. They number 4,470 and vary in size from 0.045$km^2$ to 8508$km^2$, with a mean of 96$km^2$ and a standard deviation of 292$km^2$. All assembled environmental and biological data described below were combined into the RMUs and data files were generated listing the attributes (environmental and biological data) present in each RMU. These files were used to implement the conservation planning methods described by Faith *et al.* (2001a,b).

**Biodiversity surrogates**

Since our descriptive knowledge of what species there are and where they are is inadequate, dramatically so in Papua New Guinea, biodiversity surrogates are critical to planning. Potential surrogates include sub-sets of taxa such as birds, mammals, butterflies, etc., or assemblages of taxa such as vegetation types or communities, or environmental variables or classes. A sound practical strategy is to adopt as many of these surrogates as possible to maximise the likelihood of representing more of biodiversity in selected priority areas. The biodiversity surrogates information available for the PNG study included:

- Environmental domains (described in Nix *et al.* 2000)
- Vegetation types (described below)
- Species distribution models classified as species bioclimatic profile clusters (described in Nix *et al.* 2000)

*Environmental domains*

Nix *et al.* (2000) describe the method of deriving environmental domains in PNG from the 50 attributes representing bioclimates, terrain, landform and lithological types. Preliminary classifications without the lithology were used to estimate the approximate number of classes (the level in the classification pattern) in combination with the vegetation continuum, that could be sampled in 10% of PNG.

*Vegetation types*

There are 642 different vegetation types in PNG's forest inventory mapping data base (FIM; McAlpine and Quigley 1998). A few are non-vegetation classes such as open water and urban areas. These were deleted. Many other types distinguish degrees of disturbance. For example, type B is mixed forest and type B8 is mixed forest 80% undisturbed. Any type that was 70% or more undisturbed was merged with its primary, wholly undisturbed, type. Thus, in the example above, B and B8 were merged to form the new type B. All types that were 60% or less undisturbed (that is, 40% or more of them was disturbed) were not regarded as suitable biodiversity surrogates and were deleted. Types that were combinations of two or more original types, but were only distinguished on the basis that in the first type one was dominant and in the second type it was the other one that was dominant, were merged. For example, Hm/Wsw, medium crowned forest dominant over swamp woodland, was merged with Wsw/Hm8, swamp woodland dominant over medium crowned forest 80% undisturbed. This new merged type was also merged, on the basis of percentage disturbed as above, with Hm9/Wsw8, medium crowned forest 90% undisturbed dominant over swamp woodland 80% undisturbed. This procedure resulted in 208 new vegetation types (a complete listing is available from the authors).

The vegetation types are based mainly on structural features and it seems certain, for instance, that a swamp woodland in the north-west of the country will contain different species than a swamp woodland in the south-east of the country. Thus, the environmental domain classification can be continued up to a nominated group level to produce some number, N, of broad-scale physio-climatic zones. The intersection of 208 vegetation types with these N zones resulted in new combinations of vegetation types with physio-climatic zones. The group level chosen for this purpose was required to result in a number of vegetation type attributes which, when combined with a number of domains, could be represented in any 10% of the country.

Two kinds of information, described below, were not used as part of the continuum model of biodiversity, but did provide additional attributes for the representation process.

*Species bioclimatic profile clusters*

Species groups were produced in Nix *et al.* (2000). To generate a predicted bioclimatic distribution for each species group, a BIOCLIM profile was produced from the combined specimen records for all members of the group. The predicted distribution of the group was then determined by matching the values of the bioclimatic parameters estimated for each grid point on the 0.01 degree DEM to the bioclimatic profile values with the BIOMAP program. A species group was predicted to occur at a grid point if the values of all 16 bioclimatic parameters (Nix *et al.* 2000) were within the range of the corresponding BIOCLIM profile. Unlike the environmental domains, more than 1 species group could be predicted to occur at a grid point.

The grids of predicted distributions were converted to a polygon coverage and overlaid on the RMUs. The summary Table from this combined coverage gave the area of each of the 10 species groups predicted to occur within each RMU.

*Rare and threatened species*

Rare and threatened species are also included in our planning analyses, but are not surrogates for biodiversity.  Their inclusion in the TARGET planning analyses not only ensures that the biodiversity surrogates “net” does not miss them, but also provides a possible surrogate for other rare or threatened species. The same area containing one or more of these species may contain other rare taxa.

A list of the rarest and most threatened bird and mammal species was taken from Beehler (1993). These are shown in Table 1 along with the number of RMUs in which they are found. Data for Queen Alexandra's Birdwing Butterfly (*Ornithoptera alexandrae*) were supplied by the PNG Department of Environment and Conservation. Eleven of the species found in 119 or fewer RMUs were included as attributes to be represented in the set of priority areas. *Dorcopsis atrata* is found in only on Goodenough Island in one, or perhaps two RMUs. Goodenough Island always makes it into the BPA set because of its distinctive environment, so there was no need to include this species as an attribute. Species occurring in more than 119 RMUs were expected to be represented in any set of BPAs because they are widespread and this is indeed the case. They are all represented in the set of areas chosen following implementation of the selection methods described in Faith *et al.* (2001a).

*Other information*

The goal of representing this variation was complemented by the incorporation of additional biodiversity information. Areas identified as priority 1 biotic hotspots in the Conservation Needs Assessment (CNA; Alcorn 1993; Beehler 1993) were used as preferences in the selection of priority areas. All else being equal, an area falling within a CNA priority 1 area was selected over an area not falling within a CNA priority 1 area. This was done in a deliberate attempt to take advantage of the knowledge acquired by experts in their fields and summarised in the CNA study (Faith *et al.* 2001a).

The detail within the biodiversity surrogate types listed above reflects our current knowledge of the environment and the biota of PNG. Current knowledge in PNG is biased towards descriptions of the environment and forest types, rather than the locations of species. Field records of the locations of species are sparse and poorly documented so the amount of species-based information that could be used in selecting biodiversity priority areas was limited. In many other countries and regions species data may be more readily available and might therefore form a more significant component of the biodiversity surrogates used for conservation planning. On the other hand, the PNGRIS (Papua New Guinea Resource Information System) and FIM (Forest Inventory Mapping) data bases (Nix *et al.* 2000) available in PNG provide a great deal of the biodiversity surrogate information, as well as costs and constraints information used in the biodiversity priority area selection process (Faith *et al.* 2001a), and data sources such as these may not be available in other countries and regions.

**Results**

A 10%-based target formed our initial target level for the PNG study, but we also explored a larger 15%-based target. For each target level, we determined a baseline number of domains and vegetation type clusters using the procedure described above.

The intersection of 208 vegetation types with N=10 zones resulted in 564 combinations of vegetation types with physio-climatic zones. The 10 group level was chosen because it resulted in a number of vegetation type attributes (564) which, when combined with 608 domains, could be represented in an unconstrained 10% of the country. The relative of weighting of the continuum for domains and for vegetation was somewhat arbitrary;

our use of approximately the same number of clusters for each reflects an approximate equal weighting.

The 10 species clusters (discussed above) were not included in the analysis to determine the biodiversity representation target; however, these 10 classes were so extensive in distribution that they would have no effect on the required area needed.

The resulting set of biodiversity surrogates used to select biodiversity priority areas in PNG is shown in Table 2. There is a total of 1193 attributes consisting of 608 environmental domains, 564 vegetation types, 10 species clusters and 11 rare and threatened species.

Figure 4 shows the set of areas selected to maximise biodiversity representation and to total approximately 10% of the country. For the 10%-based target, 258 RMUs totaled 47958 km2 (for the 15%-based target, 365 RMUs totaled 69283 $km^2$, but represented more attributes). These baseline areas in principle only function to determine how much biodiversity might have been protected in the absence of constraints. But there is also information in this map that has a direct bearing on the selection of areas under costs and constraints (Faith *et al.* 2001a,b). Some of the areas can be identified as "must-haves". They represent one form of "complementarity hotspot" (Faith and Walker 1996d) and must be selected if the target level of biodiversity representation is to be achieved (see also the "irreplaceability" of Pressey *et al.* 1993). We identified such areas by selecting all PNG areas using the TARGET software, and then determining, using TARGET diagnostic outputs, which areas still had a non-zero complementarity. Such areas uniquely contributed components to the target level of representation. This analysis was repeated for the 15% target level as well. Thus, the process of determining a biodiversity target for later planning already determines some “must-have” areas (Fig. 5).

## COMPARISON WITH OTHER APPROACHES

We have determined that RMUs totaling 10% of the area of PNG could represent a 1172-cluster-level of biodiversity in the absence of any costs or constraints. That hypothetical analysis provides a biodiversity target for real-world planning. Faith *et al.* (2001a) describes a priority set of areas that achieves this same level of representation in the presence of cost and constraints (a total area of 16.8% of the country and a “timber cost” of 93218 units). It will be useful to contrast this approach with two more conventional ways that a 10% target might have been implemented. In one case, we examine a scenario where protected areas adding up to approximately 10% of the total area are formed from a combination of the existing protected areas, plus gradual additions of new areas that are not in demand for other land uses. We simulate that result by starting with the existing set of protected areas and adding areas with lowest timber volume ratings until the 10% area level is achieved (Fig. 6a). Opportunity costs would be low, having used areas not attractive for other land uses, but the total biodiversity representation was only about 80% of the representation target set in the way described above. The country would be credited with achieving its 10% target, but not in fact perform well in actual biodiversity protected in nominated protected areas. Further, the shortfall in other cases could well be greater than the 20% found here.

In the second scenario, we examine an approach that directly attempts to address biodiversity representation, but does so inefficiently. We suppose that the pre-defined vegetation types are used as biodiversity indicators, and the target is interpreted as requiring 10% representation of each one of these types (Fig. 6b). We find that a set of areas selected to achieve this target only represents about 2/3 of the representation target that was set using the method described above, yet the level of forgone timber volume is more than 100,000 units (compared to 93,218).

Targets of 10, 12, or 15%, expressed simply as percentages of total area, continue to be advocated (e.g., Balmford *et al.* 2000; Howard *et al.* 2000). Such targets continue to allow protection of the least productive and least threatened landscapes (see also Pressey 1994; Margules and Pressey 2000). Further, these targets are misleading as a basis for making recommendations about the costs of biodiversity representation. Fifteen percent of the total area could be very cheap or very expensive in terms of opportunity costs, yet Balmford *et al.* (2000), for example, assume that any 15% of total area is equally costly. These difficulties lend support to the argument that standard implementations of 10% targets may not represent biodiversity all that well, and may not appropriately balance other land use opportunities.

## DISCUSSION

Percent targets of 10-15% certainly can be implemented in ways that do not capture the realities of biodiversity conservation planning, and can lead to inadequate protection of biodiversity, as described above. However, the widely publicized argument that any country that adopts a 10% target commits 50% of its species to extinction (Soulé and Sanjayan 1998) is not valid when percentage targets are used to nominate sets of protected areas that provide targeted levels of representation and persistence of biodiversity. Used properly, 10 or 15% targets can promote high levels of biodiversity protection. Not much is gained by appeals (Sanjayan and Soul 1997) to "prominent conservation biologists", whom Sanjayan and Soul (1997) cite as proposing targets necessary for protection that are much larger than 10-12%. One of their examples is extracted from Margules *et al*. (1988), and represented as a proposed target of 75.3% of area for "Australian River Valleys". In fact, that percent of area was needed (for the floodplain of the Macleay River, not all river valleys) to represent each "wetland type". We have already noted the problem of defining "types" – in that study, the percent requirement could have been 100% if enough types had been defined. It cannot be argued that such analyses imply that we must have a large percentage area protected.

The argument for expert consensus that large amounts of protected area are needed is misplaced. More areas protected will always ensure protection of more species. The emphasis instead must be on 1) how to use targets as effective comparative performance indicators among regions and countries, 2) how to achieve maximum net benefits for society given any nominated target level, and 3) how to count in partial protection from other land uses to move beyond initial target levels of protection.

Our approach addresses the real problems of representation and, rather than viewing percentage extinctions as a consequence of nominated targets, we incorporate viability-persistence into our prescribed targets. Thus, our 10%-based target framework incorporates both representation and persistence. The target is a degree of protected biodiversity; if some samples of biodiversity components in the baseline would not be judged as providing persistence (say, because they are too small) then these are not counted. We excluded from our baseline calculations of representativeness any occurrences of attributes less than some area-threshold. RMUs less than 10 $km^2$ were also excluded. Thus, the new target was properly a representativeness and persistence target. Our "persistence" elements, however, were quite crude in form and future work will develop these inputs further (see Faith *et al.* 2001b).

Species of particular interest, particularly large mammals, raise important viability/persistence concerns in conservation planning. While our biodiversity targets focus on biodiversity, not biospecifics, we included goals to represent rare and endangered species as additional constraints on the selection of priority areas for protection. One other option, not considered here, is that representation of "icon" species can be part of the baseline analysis – determining the overall level of biodiversity plus icon species protection achievable in a nominated percentage of total area. Alternatively, the degree of protection for the icon species may be based on some other measure of persistence in the baseline analysis, and subsequent planning in the face of costs and constraints must reach this same persistence target.

A 10%-based target implemented in the way described here provides an effective comparative framework among countries or regions. As an initial performance indicator, a country's performance is satisfactory only if it reaches the level of biodiversity protection it could have achieved with an unconstrained 10% (whether that amount of biodiversity is larger or smaller than another country does not matter in such evaluations). Such comparisons will not be possible when targets are set as 10% of area or 10% of each forest type. An example of such targets is the target of 10% of the total area-coverage of each forest type, proposed by the World Bank/WWF forest Alliance (1998). The only comparative evaluation possible under those targets is that some countries or regions may be unnecessarily foreclosing opportunities to protect maximum biodiversity at least cost. We suggest an alternative to the World Bank/WWF Forest Alliance target of 10% of each forest type. The amount of each forest type needed instead should depend upon its heterogeneity and degree of persistence in absence of action (see also Faith *et al.* 2000a,b). Otherwise, resources may be wasted in acquiring 10% of an extensive, homogeneous, forest type (Fig. 7).

A 10%-based target can provide a strong comparative performance indicator, with the ability later to "raise the bar" to a higher target. An interesting outcome of the decision to accept 10% as our initial target level for the PNG study, but also explore a larger 15% target, was that "must-have" areas under a 15% target are recognized early on. We recommend that, even when a lower target is accepted, the implications of a larger target for such must-have areas also be investigated, as it was in this study. Environmental levies, carbon offsets, and biodiversity offsets (Faith *et al.* 2001b) then may facilitate both the implementation of a 10% target and the move towards a higher target level over time.

Percent targets have also been seen as potentially removing incentives for implementing off-reserve conservation actions (e.g., Kanowski *et al.* 1999). But as applied in this study, targets provide a strong incentive for off-reserve conservation. Such off-reserve conservation can contribute some partial contribution to achieving targeted biodiversity protection and at the same time reduce opportunity costs and increase net benefits. Thus, partial protection, measured as an increment in persistence of components of biodiversity (Faith *et al.* 2001b) provides a way of keeping the total amount of “protected” area needed to achieve the 10%-level low even in the face of costs and constraints.

Another kind of comparison among countries or regions will be interesting. Faith *et al.* (2001a) found that, of all the factors in PNG acting as constraints on the real-world pursuit of the target level of representation (opportunity costs, degraded land, existing reserve systems, etc), the unrepresentative existing reserve system caused the greatest increase in total amount of land needed (16.8% rather than 10% of total area). In contrast, minimising forestry conflict cost very little in terms of extra area needed. It will be interesting to see if this contrast between footprints of the past or anticipated steps in the future is true for other countries as well. If true, it argues doubly for the urgent use of complementarity and trade-offs methods in biodiversity planning.

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## REFERENCES

Alcorn, J. B. (ed), 1993. Papua New Guinea Conservation Needs Assessment Vol. 1. Biodiversity Support Program and Government of Papua New Guinea, Department of Environment and Conservation. Corporate Press Inc., Landover, Maryland.

Balmford, A., Gaston, K. J. and Rodrigues, A. S. L., 2000. Integrating costs of conservation into international priority setting. *Con. Biol.* **14:** 597-605.

Beehler, B. M. (ed), 1993. Papua New Guinea Conservation Needs Assessment Vol. 2. Biodiversity Support Program, Government of Papua New Guinea, Department of Environment and Conservation. Corporate Press Inc., Landover, Maryland.

Bellamy, J. A. and McAlpine, J. R., 1995. Papua New Guinea: Inventory of Natural Resources, Population Distribution and Land Use Handbook. Second Edition. PNGRIS Publication No.6, AusAID, Canberra.

Colwell, R. K. and Coddington, J. A., 1994. Estimating terrestrial biodiversity through extrapolation. *Philosophical Transactions of the Royal Society, London*, *B*, **345**: 45-48.

Commonwealth of Australia, 1997. Nationally Agreed Criteria for the Establishment of a Comprehensive, Adequate and Representative Reserve System for Forests in Australia. Australian Government Publishing Service, Canberra.

Faith, D. P., 1995a. Biodiversity and regional sustainability analysis.  CSIRO, Canberra.

Faith, D. P., 1995b. Commonwealth proposed criteria for national forest conservation reserves: Will a used CAR cause problems down the road? Submission to commonwealth government of Australia.

Faith, D. P., 1996. On methods for evaluating alternative surrogates for regional biodiversity assessments. Consultancy report to the Department of Environment, Sport and Territories.

Faith, D. P., 1997a. Some considerations in the design of a national biodiversity monitoring system for Brazil's protected areas. *in* Proceedings and papers of the international workshop on biodiversity monitoring in federal protected areas: defining the methodology. ed by D.S. Baker, L. M. Ferreira and P. W.Saile. Pirenopolis. IBAMA/GTZ.

Faith, D. P., 1997b. Biodiversity assessment and opportunity costs Pp. 87-103 *in* Investing in Biodiversity: the Cairns conference. ed by anon. OECD, Paris.

Faith, D. P. and Walker, P. A., 1996a. Environmental diversity: on the best-possible use of surrogate data for assessing the relative biodiversity of sets of areas. *Biodiversity and Conservation* **5:** 399-415.

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

Faith, D. P. and Walker, P. A., 1996d. How do indicator groups provide information about the relative biodiversity of different sets of areas?, on hotspots, complementarity and pattern-based approaches. *Biodiversity Letters* **3:** 18-25.

Faith, D. P. and Walker, P. A., 1996e. DIVERSITY - TD. Pp. 63-74 *in* BioRap, rapid assessment of biodiversity. Volume three, tools for assessing biodiversity priority areas ed by D. P. Faith and A. O. Nicholls. Centre for resource and environmental studies, Australian National University, Canberra.

Faith, D. P. and Walker, P. A., 1997. Regional sustainability and protected areas: biodiversity protection as part of regional integration of conservation and production. Pp. 297 – 314 *in* National parks and protected areas: selection, delimitation, and management. ed by J. Pigram and R. C. Sundell. U. of New England Press.

Faith, D. P., Walker, P. A., Ive, J. R. and Belbin, L., 1994. Integrating conservation and forestry production: effective trade-offs between biodiversity and production in regional land-use assessment. Pp. 74-75 *in* Conserving biological diversity in temperate forest ecosystems - towards sustainable management ed by anon.

Faith, D. P., Walker, P. A., Ive, J. and Belbin, L., 1996. Integrating conservation and forestry production: exploring trade-offs between biodiversity and production in regional land-use assessment. *Forest Ecology and Management* **85:** 251-260.

Faith, D. P., Margules, C. R. and Walker, P. A., 2001a. Biodiversity conservation plan for Papua New Guinea based on biodiversity trade-offs analysis *Pacific Conservation Biology*

Faith, D. P., Walker, P. A. and Margules, C. R., 2001b. Some future prospects for systematic biodiversity planning in Papua New Guinea – and for biodiversity planning in general. *Pacific Conservation Biology*.

Howard, P. C., Davenport, T. R. B., Kigenyi, F. W., Viskanic, P., Baltzer, M. C., Dickinson, C. J., Lwanga, J. L., Mathews, R. A. and Mupada, E., 2000. Protected area planning in the tropics: Uganda's national system of forest nature reserves. *Con Biol.* **14:** 858-875.

Howard, P. C., Viskanic, P., Davenport, T. R. B., Kigenyi, F. W., Baltzer, M., Dickinson, C. J., Lwanga, J. S., Matthews, R. A. and Balmford, A., 1998. Complementarity and the use of indicator groups for reserve selection in Uganda. *Nature* **394**: 472-475.

IUCN, 1993. Parks for life: report of the IVth world congress on national parks and protected areas, IUCN, Gland, Switzerland.

Kanowski, P. J., Gilmour, D. A., Margules, C. R. and Potter, C. S., 1999. International Forest Conservation: Protected Areas and Beyond. Commonwealth of Australia, Canberra.

Keig, G. and Quigley, J., 1995. Papua New Guinea Resource Information System. User's Guide. Version 2, June 1995.

Mac Arthur, R. H. and Wilson, E. O., 1967. The theory of island biogeography. Princeton University Press. Princeton, New Jersey.

McAlpine, J. and Quigley, J., 1998. Forest resources of Papua New Guinea: summary statistics from the forest inventory mapping (FIM) system.

Margules, C. R., 1999. Conservation planning at the landscape scale. Pp. 83-87 *in* Issues in Landscape Ecology. ed by John A. Wiens and Michael R. Moss. International Association of Landscape Ecology, Pioneer Press, Colorado.

Margules, C.R., Nicholls, A. O. and Pressey, R. L., 1988. Selecting networks of reserves to maximise biological diversity. *Biological Conservation*, **43:** 63-76.

Margules, C.R. and Pressey, R. L., 2000. Systematic Conservation Planning. *Nature,* **405:** 243-253.

Miller, K. R., 1984. "The Bali Action plan: A framework for the future of protected areas" Pp. 756-764 *in* National Parks, conservation, and development. ed by J. A. McNeely and K. R. Miller. Smithsonian Institution Press, Washington D.C.

Mittermeier, R., Myers, N., and Mittermeier, C. G., 1999. Hotspots: Earth's Biologically Richest and Most Threatened Ecoregions. CEMEX. Mexico City and Washington, DC.

Nix, H. A., Faith, D. P. , Hutchinson, M. F. , Margules, C. R. , West, J. , Allison, A., Kesteven, J. L., Natera, G., Slater, W., Stein, J. L. and Walker. P., 2000. *The BioRap Toolbox: A National Study of Biodiversity Assessment and Planning for Papua New Guinea. Consultancy report to the World Bank.* CSIRO Press. Canberra.

Prendergast, J. R. *et al.*, 1993. Rare species, the coincidence of diversity hotspots and conservation strategies. *Nature* **365:** 335-337.

Pressey, R. L., Humphries, C. J., Margules, C. R., Vane-Wright, R. I. and Williams, P. H., 1993. Beyond opportunism: key principles for systematic reserve selection. *Trends in Ecology and Evolution*, **8**: 124-128.

Pressey, R. L., 1994. Ad hoc reservations: Forward or backward steps in developing representative reserve systems? *Conservation Biology*, **8**: 662-668.

Pressey, R. L., 2000. Towards a framework for implementing a representative system of forest protected areas

Richards, B. N., Bridges, R. G., Curtin, R. A., Nix, H. A., Shepherd, K. R. and Turner, J., 1990. Joint Scientific Committee Report on Biological Conservation in the South East Forests. Australian Government Publishing Service, Canberra.

Sanjayan, M. A. and Soul, M., 1997. Moving beyond Brundtland: the conservation value of British Columbia's 12 percent protected area strategy. http://www.greenpeace.org/~comms/97/forest/soule.htm.

Soulé, M. E. and Sanjayan, M. A., 1998. Conservation Targets: do they help? *Science*, **279**: 2060-2061.

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

van Jaarsveld, A.S. *et al.*, 1998. Biodiversity assessment and conservation strategies. *Science* **279**: 2106.

Walker, P. A. and Faith, D. P., 1998. TARGET software package. CSIRO, Canberra.

World Bank/WWF Alliance, 1998. Research and Analysis Component Activity Concept Notes. September 1998. World Bank and WWF. http://www-esd.worldbank.org/wwf/

World Commission on Environment and Development, 1987. Our common future. Oxford University Press, Oxford, U.K.

World Conservation Monitoring Centre, 1998. http://www.wcmc.org.uk/forest

Table 1.
Papua New Guinea's rarest and most threatened birds and mammals (from Beehler 1993; p. 119) and one butterfly, with information on number of RMUs for each.

| Species | Common name | Number of RMUs |
|---|---|---|
| **Birds** | | |
| *Accipiter buergersi* | Chestnut-mantled Goshawk | 802 |
| *Caloenas nicobarica* | Nicobar Pigeon | 816 |
| *Goura Scheepmakeri* | Southern Crowned Pigeon | 855 |
| *Goura victoria* | Victoria Crowned Pigeon | 951 |
| *Psittrichas fulgidus* | Pesquet's Parrot | 555 |
| *Pitta superba* | Superb Pitta | 35 |
| *Phipidura semirubra* | Manus Rufous Fantail | 50 |
| *Archboldia papuensis* | Archbold's Bowerbird | 119 |
| *Sericulus bakeri* | Fire-maned Bowerbird | 9 |
| *Macgregoria pulchra* | Macgregor's bird of Paradise | 11 |
| *Epimachus fastuosus* | Black Sicklebill | 280 |
| *Paradisaea rudolphi* | Blue Bird of Paradise | 363 |
| Mammals | | |
| *Zaglossus bruijni* | Long-beaked Echidna | Wide distribution |
| *Echymipera echinista* | Fly Spiny Bandicoot | Western Prov. Lowlands, very low densities |
| *Dendrolagus scottae* | Scott's Tree Kangaroo | 4 |
| *Dorcopsis atrata* | Goodenough Wallaby | Goodenough Island |
| *Thylogale calabi* | Calaby's Thylogale | 28 |
| *Spilocuscus rufoniger* | Black-spotted Cuscus | 2 |
| *Dactylopsila tatei* | Fergusson Striped Possum | 3 |
| *Aproteles bulmerae* | Bulmer's Fruit Bat | 10 |
| Butterfly | | |
| *Ornithoptera alexandrae* | Queen Alexandra's Birdwing Butterfly | 12 |

Table 2.
The biodiversity surrogates adopted to guide selection of priority areas in PNG. The numbers for the first two, environmental domains and vegetation types, were determined according to the level of heterogeneity in their classifications that could be sampled in a set of areas totaling 10% of the country.

| **Surrogate range** | **Attribute number** | **Description** |
|---|---|---|
| | | |
| 1-608 | 1-608 | Environmental domains |
| 1-564 | 609-1172 | Vegetation types |
| 1-10 | 1173-1182 | Species clusters |
| 1-11 | 1183-1193 | Rare and threatened species |

Figure legends

Figure 1.
Trade-offs curves, adapted from Faith (1997b), illustrating 10%-based biodiversity targets. Any land-use allocation defines a point in this space. Desirable allocations are those towards the lower left. The hollow circle represents the selection of a set of areas with maximum total biodiversity, with the constraint that it total 10% of the total area, but without regard to costs or other constraints. The triangle depicts one maximally biodiverse set of areas that would have been selected if costs but no other constraints, including total area, were taken into account. It lies along a trade-offs curve of best-possible sets, the choice depending on the relative weighting of costs and biodiversity. The triangle is that solution along the curve yielding the same total biodiversity as the hollow-circle solution. The square is the best possible set achieving the same level of biodiversity protection but with various constraints, including an existing reserve system. It lies on the darker trade-offs curve which represents the best-possible trade-offs under those constraints. The position of this curve, to the upper right of the lighter curve, implies that net benefits (regional sustainability) cannot be a great as in the absence of these constraints. The dark circle shows a hypothetical solution achieving the same biodiversity protection level, but not taking costs into account.

Figure 2.
Areas in green show the overlap of RMUs with the existing protected areas for PNG.

Figure 3.
The 4,470 Resource Mapping Units (RMUs) used as allocation units for the biodiversity priority areas.

Figure 4.
A map of PNG showing (in green) areas (RMUs) selected to form a baseline set that maximizes biodiversity representation/persistence using 10% of the total country area.

Figure 5.
Areas in red are those that must be in any set that achieves the representation/persistence target defined by the 10%-based target guideline. Areas in black are those that must be in any set that achieves the representation/persistence target defined by the 15%-based target guideline.

Figure 6.
Two conventional approaches to 10% targets applied to PNG.
a) A set of areas (in black) totaling 10% of total area, selected using existing protected areas plus an *ad hoc* set of areas with low value for timber production.
b) A set of areas (in green) selected based on a representation target of 10% of each vegetation type.

Figure 7.
A figure re-drawn from Faith (1995b), illustrating the effect of probabilities of persistence on number of protected areas needed to reach a nominated regional persistence level. The curve connecting solid circles is based on persistence values where no-protection implies 0.01 probability of persistence of forest type in a given area, while protection implies a 0.50 probability of persistence. The number of protected areas required (y-axis) is defined as the

minimum number to achieve an overall regional probability of persistence of 0.95. The x axis is the number of areas in the region of a given type. For comparison, the curve connecting hollow squares is for a simple rule that requires protection of 15% of a given type (value along y-axis is simply 15% of total number of equal-sized areas).

FIGURE 1

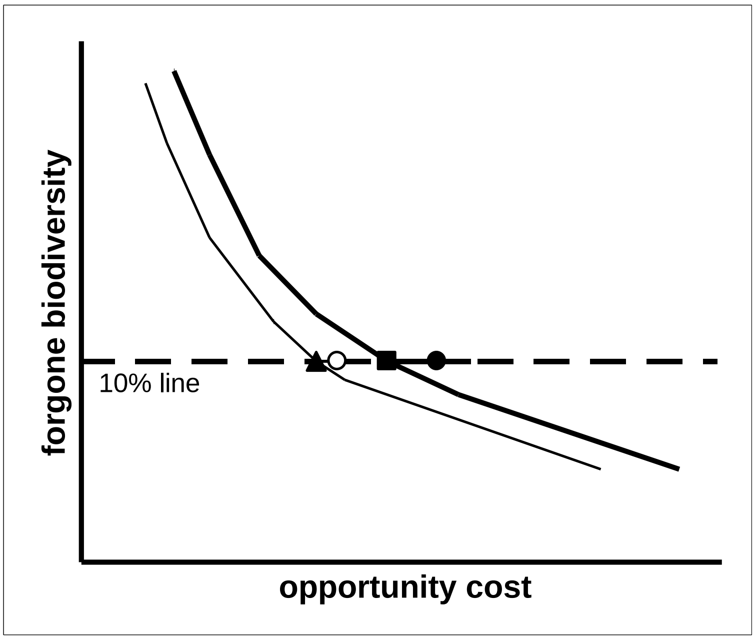
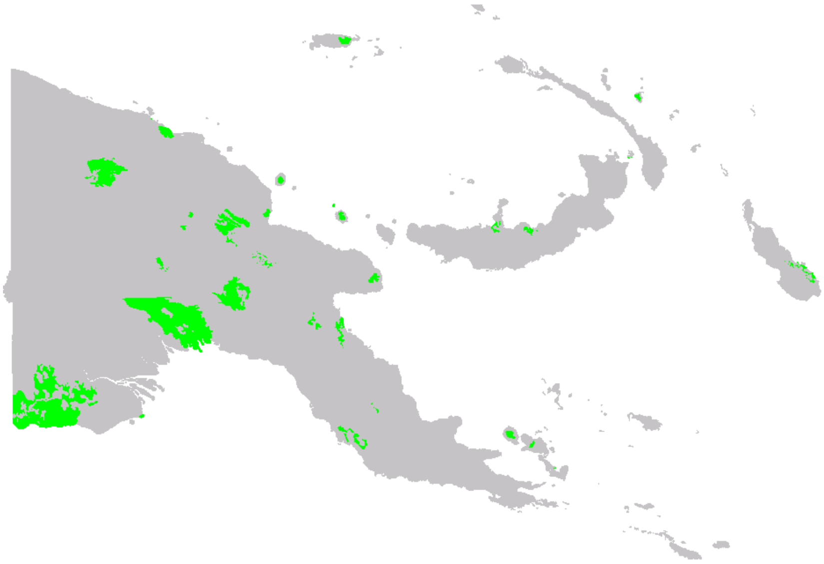


FIGURE 2



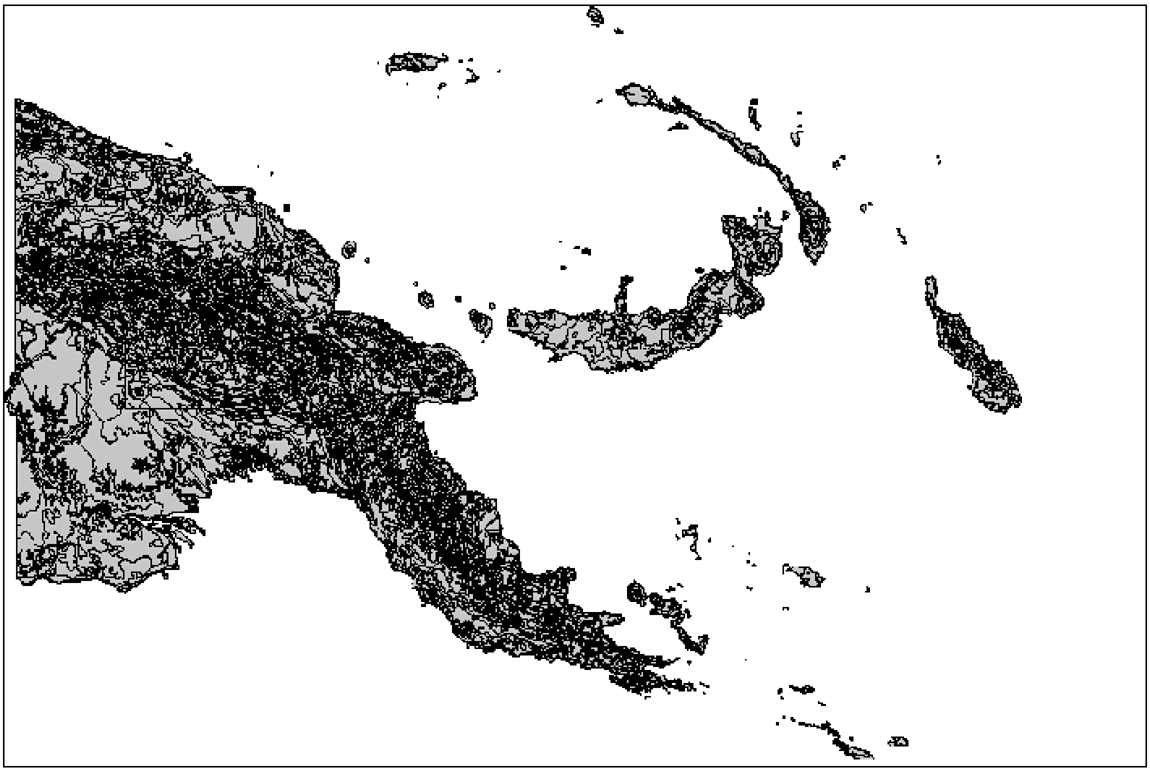


FIGURE 3

FIGURE 4

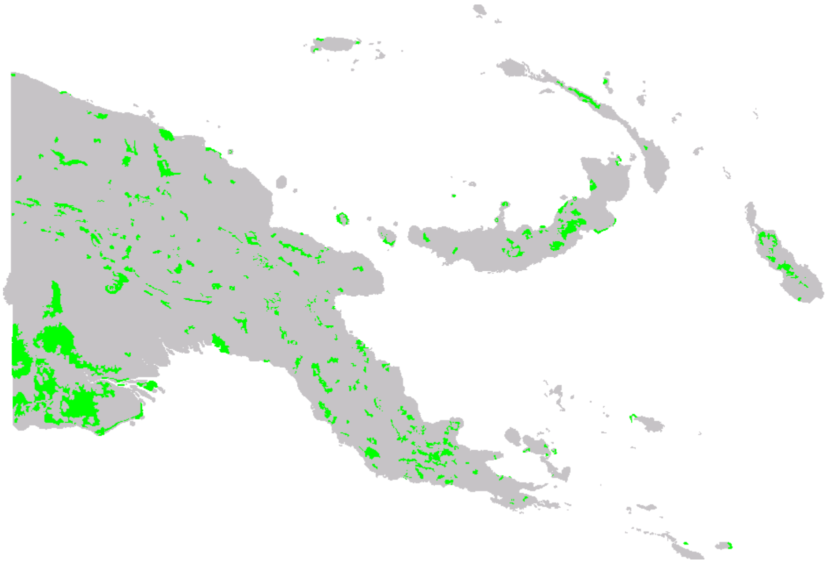


FIGURE 5

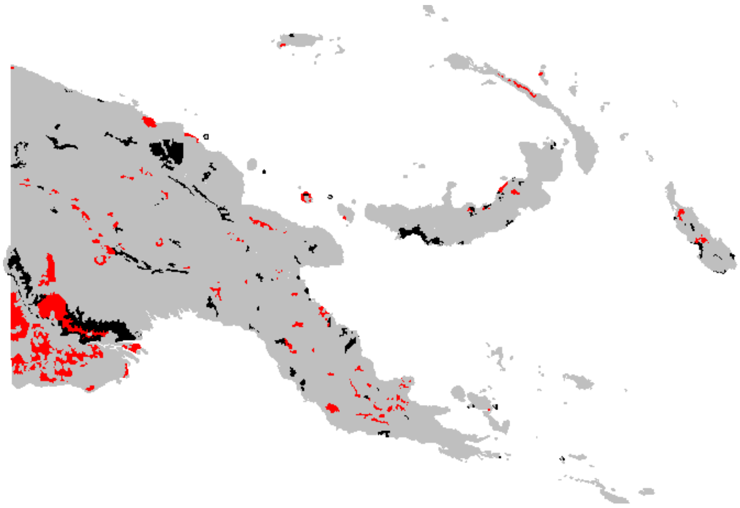


FIGURE 6

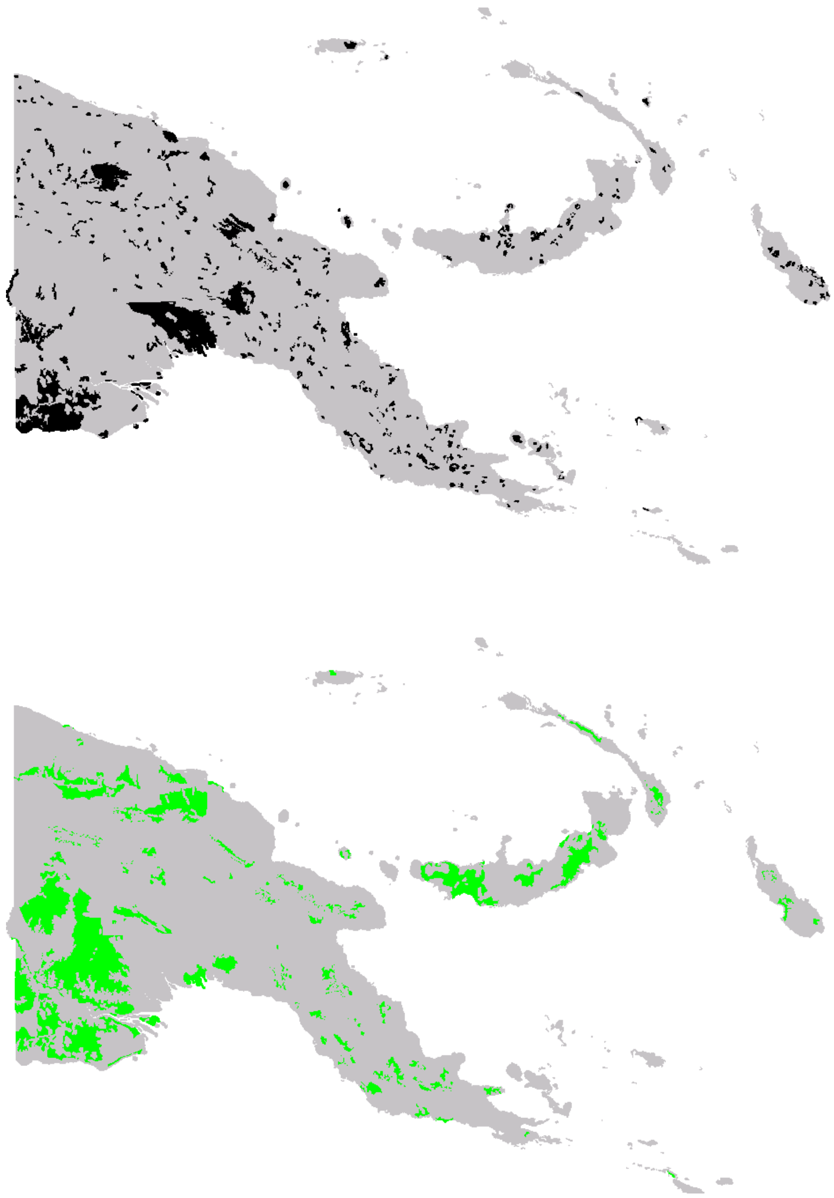
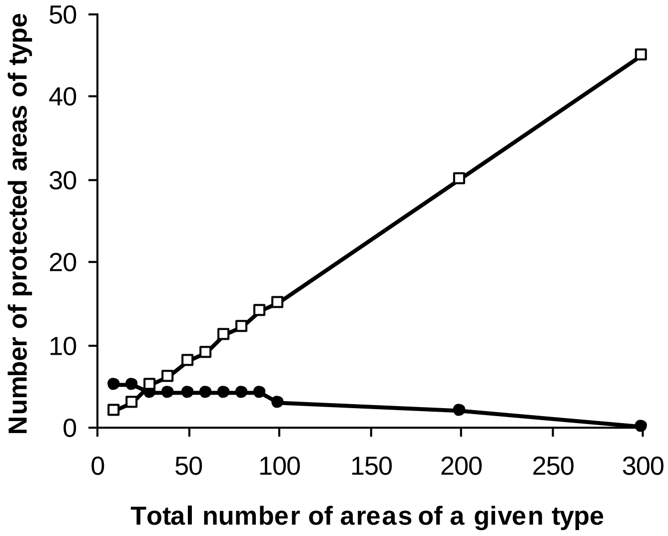


FIGURE 7


Number of protected areas of type
Total number of areas of a given type
0
10
20
30
40
50
0
50
100
150
200
250
300