A Biodiversity conservation plan for Papua New Guinea based on biodiversity trade-offs analysis

Daniel P. Faith[1], C. R. Margules[2], P. A. Walker[3]

published version:

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

[1]Australian Museum, 6 College St., Sydney, NSW, 2010

[2]CSIRO, Sustainable Ecosystems and the Rainforest Cooperative Research Centre, CSIRO Tropical Forest Research Centre, PO Box 780, Atherton, Qld. 4883, Australia.

[3]CSIRO, Sustainable Ecosystems, GPO Box 284, Canberra City, ACT, 2601, Australia

e-mail contact: dan.faith@austmus.gov.au

ABSTRACT

A rapid biodiversity assessment ("BioRap") project identified candidate areas for biodiversity protection in Papua New Guinea (PNG) and provides an ongoing evaluation framework for balancing biodiversity conservation and other land use needs. Achieving a biodiversity protection target with minimum opportunity cost was an important outcome given that biodiversity values overlap with forestry production values, and high forgone forestry opportunities would mean significant losses to land owners and the government. Allocation of 16.8% of PNG's land area to some form of biodiversity protection was required, in order to achieve the level of biodiversity representation/persistence that would have been possible using only 10% of the land area if there were no constraints on land allocation and no land use history. This result minimizes potential conflict with forestry production opportunities while also taking account of land use history, human population density and previous conservation assessments. The analysis provides more than a single set of proposed priority areas. It is a framework for progressively moving towards a country-wide conservation goal, while at the same time providing opportunities to alter the priority area set in light of new knowledge, changes in land use, and/or changes in economic and social conditions.

INTRODUCTION

As a signatory to the 1992 United Nations Convention on Biological Diversity, Papua New Guinea is committed to the conservation and sustainable use of biodiversity. Implementation of the Convention points to the importance of the "Ecosystem Approach", which encompasses the goal of balancing biodiversity conservation with other needs of society (for discussion, see IUCN 2000). The Papua New Guinea Rapid Biodiversity Appraisal Pilot Project was commissioned by the Global Environment Fund of the World Bank, and funded by World Bank and AusAID, to help facilitate Papua New Guinea's response to this Convention. The project uses the BioRap toolbox, which provides innovative methods for trade-offs approaches to balance biodiversity conservation and other land uses. This paper follows our final consultancy reports to the World Bank on the BioRap toolbox and its application in PNG (Nix *et al.* 2000). Companion papers (Nix *et al*. 2001; Faith *et al*. 2001a,b) provide background to the project, and describe biodiversity surrogates, target setting, and future implementation issues.

The BioRap study was defined within the context of goals to establish a national protected area network and to identify explicit options and constraints for land management within the forestry and agricultural sectors. The objective of this study was to devise a biodiversity conservation plan for Papua New Guinea (PNG), based on a set of biodiversity priority areas. These priority areas are to be subject to ongoing revision by Papua New Guinea Government agencies, in response to land use change, change in economic, social and political conditions, and change in ecological and biological knowledge. The project was also to be an in-country evaluation of the BioRap toolbox for systematic conservation planning.

Nix *et al.* (2000) and Faith *et al.* (2001a) discuss the biodiversity surrogates, comprising a combination of environmental data and available species data. Nix *et al.* (2000) have described the environmental database developed for the whole of Papua New Guinea using the ANUDEM and ANUSPLIN packages. This database was defined at a high spatial resolution (approximately 1 km pixels) and consisted of a digital elevation model (DEM), monthly mean climate surfaces and digital lithology. In addition, a biological database comprising 87 selected plant and animal taxa was also constructed, and spatial distributions of each of these taxa were modeled using the BIOCLIM program from the ANUCLIM package (Nix *et al.* 2000).

The BioRap toolbox provides a framework in which biodiversity conservation planning takes into account from the outset other land use needs, so as to achieve a balance between conflicting land use opportunities (Faith *et al.* 1994; Faith 1995). Conflict between biodiversity conservation and other land use opportunities (particularly logging) is an important consideration in PNG. Many of the areas already designated as suitable for logging contain biodiversity values deserving conservation (Sekhran and Miller 1994). At the same time, any forgone forestry opportunities mean losses not only in royalties for landowners, but also losses to the government in taxes and other revenues (Hunt and Filer 2000).

A balance in land use allocation is achieved through trade-offs analysis (Faith 1995). A trade-offs analysis requires appropriate information about land use constraints and opportunity costs of biodiversity conservation. The Papua New Guinea Resource Information System, known as PNGRIS, contains maps and information for the whole country, a on current land use, limitations on land use and population density (Bellamy and McAlpine 1995; Keig and Quigley 1995) that contribute to the constraints and preferences information used in our study. The land units for which this information is recorded are the Resource Management Units (RMUs), described further in Faith *et al.* (2001a). These 4470 units are widely used by government agencies in PNG, so were adopted as the planning allocation units for this Project.

Trade-offs are intimately linked to biodiversity targets (Faith *et al.* 2001a). For this study, we accepted the internationally agreed 10% target as our starting point for determining priority areas for biodiversity protection. This target was converted to a biodiversity goal (see Faith *et al* 2001a) by asking, "how many environmental domains (groups defined at some level of the hierarchical classification), when combined with a similarly–determined number of vegetation types (intersecting with physico-climatic zones) could be represented if any 10% of PNG could be chosen"? This level of variation turned out to be 608 environmental domains and 564 vegetation. The objective of the actual planning exercise then became to represent this same level of "baseline" variation (the 608 domains, 564 vegetation types, plus 10 species profile clusters and an additional goal of representing 11 rare and threatened species), in the real world of human population pressure, demands for timber and agricultural products, existing protected areas and previous assessments of conservation value. Clearly, factors such as a large total area of degraded land unsuitable for protection, or existing protected areas covering a large area, that are not representative, can mean that a much larger total protected area is needed to achieve representation of that “baseline” variation.

The 10%-based target is only seen as an initial international standard or performance indicator, and PNG may adopt a higher target. We also calculated the level of variation that could be represented in 15% of the country as a baseline, and then found which RMUs and how much additional area would be needed to meet that goal in practice.

In the following sections, we first report on the trade-offs analyses that address these targets. We then evaluate the results relative to our information on biodiversity, costs and constraints. We also demonstrate how the initial “best set” of biodiversity priority areas can be altered based on new information and changing status of land use. These evaluations and alterations of the initial map highlight the fact that this kind of trade-offs analysis is an ongoing process. Some of the many issues relating to the ongoing implementation of a protected areas system, combined with off-reserve protection and economic incentives, are addressed in Faith *et al.* (2001b).

METHODS: PRIORITY SETTING

Biodiversity priority setting methods include a range of methods developed originally in Australia (e.g., Kirkpatrick 1983; Margules 1989; Margules *et al.* 1988; 1994; Pressey and Nicholls 1989a,b; Pressey *et al.* 1993) and now applied elsewhere (e.g., Rebelo and Siegfried 1992; Kershaw *et al.* 1994; Lombard 1995). These earlier methods were designed to find sets of areas, which fully represent biodiversity features, while minimizing the area required to do so. The approach adopted here departs from those methods by incorporating opportunity costs (for example, forgone timber production) using a trade-offs approach (Faith *et al.* 1994; Faith *et al.* 1996) which incorporates the concept of complementarity established in the earlier methods as the basis for biodiversity values of areas.

This form of multi-criteria analysis (see also Faith and Walker 1996a,b) searches for a balance between (often) conflicting objectives, and is linked to a form of "regional sustainability" (Faith 1995). Sustainability is often referred to in the context of individual areas, but a balance may also be sought regionally through the allocation of different land uses to different areas. Attempts to achieve such a balance raise several issues. Reaching a biodiversity target does not by itself imply a high degree of sustainability. Costs and constraints must be taken into account so that solutions can be found along a realistic trade-offs curve, providing high net benefits (Faith 1995). Constraints, such as those implied by land lost through degradation, can mean that the available trade-offs curve no longer provides high net benefits (as in the trade-offs curves in figure 1 of Faith *et al.* (2001a), where the darker curve implies lower regional sustainability levels).

This study addresses explicit trade-offs involved in achieving a biodiversity target in a set of priority areas. Biodiversity priority areas were found by establishing the level of heterogeneity achievable in 10% of PNG (Faith *et al.* 2001a), then finding that set of areas which together reach this goal efficiently, while minimizing foregone forestry opportunities, avoiding areas of agricultural potential, incorporating existing protected areas, avoiding areas of high land use intensity and high human population density and preferring, where possible, that they coincide with areas chosen previously by experts as high biodiversity priority areas. The TARGET software (Walker and Faith 1998) was used for these analyses.

TARGET (or 'TD' for targets and diversity) is one module of the DIVERSITY software package (Faith and Walker 1994, 1996a) which forms part of the BioRap toolbox. TARGET assumes that the areas in a region are described as containing one or more different biodiversity "attributes", which are to be the surrogates for all biodiversity. Within each area, each surrogate also has some quantitative value associated with it - this value might, for example, correspond to the total number of hectares of that attribute within that area. Each attribute is assigned a target for representation. This might be constant over all attributes (e.g., 10% of total area) or vary to reflect the degree of threat or persistence of different attributes (see Faith and Walker 1996c, 1997; Faith *et al.* 2001b). In the PNG study, the target level of representation was simply a single representative of each attribute from the set of attributes determined by the 10%-based target.

TARGET implements the multicriteria approach based on biodiversity complementarity values, described in Faith *et al.* (1994, 1996). 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 (that is, its marginal contribution to overall biodiversity representation) exceeds its weighted cost. This marginal contribution of a given area simply reflects how much additional contribution it makes to the overall regional achievement of the biodiversity target.

For any given area in PNG, the software calculates the number of so-far-under-represented attributes that the area could contribute to the list of selected areas. The software iteratively adds and deletes areas from a list of nominated areas (the "select list") so as to approach the target levels of representation. When cost trade-offs are used, 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.

TARGET allows a range of search strategies to be implemented. One can start "from scratch" or with all but a set of preferred areas masked out. Alternatively, it is possible to use a set of randomly selected areas as a starting point – the method adds and deletes areas in searching for a set whose members collectively achieve a nominated biodiversity goal and also all have complementarity values exceeding their (weighted) costs. The simple search provided by the basic algorithm can be extended and modified. For example, the search can begin with a high weighting on costs, such that targets are not met, and this partial result read in to a subsequent analysis with lower weight on costs. This strategy, which best minimizes costs, can be applied iteratively until the biodiversity target is met. Similar iterative approaches might initially mask out some areas, giving preference to others until later iterations. Both of these strategies were used to derive the set of biodiversity priority areas shown in Figure 2a below. Of course, it is also possible to find the cost to biodiversity of making the resources available for meeting a production target, such as a certain timber volume, for example. TARGET allows the search for a set of areas for a given biodiversity level, budget level, or where dictated by weightings. When several "costs" are involved, the approach uses weightings applied to each (as in Faith *et al* 1996).

METHODS: BIODIVERSITY INPUTS

The data used to guide the priority area selection process can be grouped into five classes; biodiversity surrogate attributes, opportunity costs, commitments, masks and preferences (Faith *et al.* 2001a). PNG is in the fortunate position of having the two detailed and well-maintained data bases, PNGRIS and FIM (described in Nix *et al.* 2000). These contain relevant information on land uses, production potential and human population density. Both were used to extract some of the attributes employed in selecting priority areas, either as biodiversity surrogates, costs or constraints.

Faith *et al.* (2001a) describe the derivation, based on a 10%-based target, of 1193 biodiversity "attributes" used to select priority areas. These are 608 environmental domains, 564 vegetation types, 10 species clusters and 11 rare and threatened species.

Opportunity costs

Index of timber volume

A Forest Inventory Mapping (FIM) system (McAlpine and Quigley 1998) evolved from PNGRIS. It was developed to provide information on the type and extent of the forest resource and its use by the forest industry. It is a national coverage at a scale of 1:100,000. Information on forest and non-forest vegetation types, land tenure, timber volumes and other variables is recorded within Forest Mapping Units, or FMUs. FMUs are generally smaller than RMUs and each FMU is coded as one and only one vegetation type. For this study, FMUs were overlain on RMUs and the area of each FMU (i.e., vegetation type) within each RMU was recorded. Not all of the information in FIM is generally available, especially information on timber volumes and proposed timber concessions. However, an index of timber volume was made available for this project by the PNG Forest Authority on a scale from 0 for very low volume to 5 for very high volume. These values were aggregated to the level of the RMUs using a weighted sum of the FMU values. For example, if an RMU contained FMUs of rank 3 with area of 100 km^2, and FMUs of rank 0 with area 50 km^2, then the combined RMU value was 3x100 + 0x50 = 300. These values were then log-transformed. The rank values were multiplied by the proportion of the FMU in a given RMU and the resulting values summed over RMUs. This is not an estimate of timber volume per unit area and it means that larger RMUs may have high timber volume estimates, even when timber volume per unit area is low. Figure 1a is a map of timber volume indices. This map corresponds well with Map 1 of the National Forest Plan for Papua New Guinea (PNGFA 1996).

Agricultural potential

This was a simple model proposed by the PNG Department of Agriculture and Livestock. RMUs with slope classes 1- 4 (from less than 2° up to 10-20°) and drainage classes 1 and 2 (well-drained and imperfectly drained) in PNGRIS were designated as having agricultural potential and all other RMUs were designated with none. Figure 1b is the resulting presence/absence map showing the 1525 RMUs with agricultural potential under this simple model. Clearly, there is scope for improving this model, and this should be followed up as part of the implementation of BioRap in PNG. Excluding areas of seasonal inundation and/or developing models for different agricultural products are two examples of how it could be improved. In the analyses, preference was given to the selection of RMUs having low agricultural potential (see section below).

Commitments

These are attributes, which might be used to commit RMUs to a priority set regardless of their complementarity value. Existing protected areas formed the only commitment attribute used in this study. The status information for these areas was supplied by the PNG Office of Environment and Conservation (OEC). Rare and threatened species could also have been used as commitment attributes, so that RMUs with rare and threatened species could be committed to the priority set up front, instead of being used as attributes for the calculation of complementarity, as they were here. This is an option that OEC might explore as the BioRap tools are implemented. Figure 1c is a map of existing protected areas, fitted to RMU boundaries (which is why some boundaries are so convoluted). Table 1 summarises the properties of the set of existing protected areas.

Masks

Masks are characteristics which can be used to exclude RMUs from consideration for membership of the BPA set. There were two such characteristics used for these analyses; land use intensity, and RMUs less than $10km^2$ in area. In addition, any biodiversity attributes with an extent of less than $1km^2$ in any RMU were not counted as occurring in that RMU. Each of these masks represented an attempt to better ensure the viability/persistence of biodiversity within proposed protected areas (see also Faith *et al*. 2001b).

Land use intensity

RMUs which have more than half of their area in PNGRIS land use intensity classes 0 – 4 (i.e. very high with tree crops, very high, high, moderate and low) were masked out of the initial analysis. A total of 954 RMUs have more half their area falling into these land use intensity classes. It was found, however, that our biodiversity target level of representation could not be reached when these areas were masked out. That is, some biodiversity attributes only occur in intensively used areas. The strategy in this case was to first run an analysis with these RMUs masked. At the completion of that analysis, no more RMUs could be added to the set, but the biodiversity target was not achieved. The set of RMUs found this way was saved and a new analysis was commenced with this set as a starting point, and with intensively used RMUs now available for selection. When this was done, the target could be achieved with the addition of a small number of extra RMUs, as shown in the results section below. Figure 1d is a map of RMUs with current high land use intensity.

Small RMUs

It was decided that RMUs less than 10 sq. km. in area were too small to be candidates for biodiversity priority areas because they were unlikely to be large enough to retain many of their species in the long term. They were excluded therefore from consideration. This is an arbitrary cut-off and many RMUs larger than this are probably still too small to form viable priority areas over time. The most practical way of managing smaller priority areas is to group them into larger management units such as Wildlife Management Areas (WMAs). This would seem to be a workable solution, for example, where there are clusters of small priority areas in highland regions. Of course, there would be costs associated with increasing the total area in this way, which have not been included, and therefore not traded-off, in the analysis used to select the current priority area set.

Small coverage by attributes

Some attributes are only represented by very small areas within RMUs. In many cases this may simply be the result of overlaying attributes on map units where boundaries do not properly coincide. Small slivers of attributes may thus occur within RMUs to which they may not properly belong. In order to minimise this problem, any attribute occurrence of less than 1km^2 within an RMU was ignored in the analyses.

Preferences

Preferences refer to features that, all else being equal, it would be preferable to include or exclude from the priority area set. Areas with low human population density and areas previously identified by experts as having high conservation value are two preferences used in this study and described below. Although it is listed as an opportunity cost above, absence of agricultural potential was treated as a preference in our analyses because it was determined that the cost trade-off component of the analysis should be done with timber volume, currently a more valuable commodity than agricultural production. This was done by carrying out an initial round of selections in which only areas having low agricultural potential (along with other preference criteria) were made available for selection.

The Conservation Needs Assessment (CNA)

CNA priority 1 areas (Alcorn 1993; Beehler 1993) were mapped and used to help guide the selection of Priority areas. An RMU falling within a CNA priority 1 area was selected over an RMU falling outside these areas, all else being equal. This preference was achieved in the course of building up a set of proposed areas, by maintaining masking and cost trade-offs operations, but looking first for a suitable RMU that was also a CNA priority area. In Figure 1e, the boundaries of the areas shown vary slightly from original CNA maps in that entire RMUS are assigned here to CNA priority 1 if most of their area overlapped with a priority 1 area.

Human population density

Population density information, extracted from PNGRIS, was treated in exactly the same way as CNA priority 1 areas, giving preference to low population density. All else being equal, an RMU with low population density was chosen over an RMU with high population density. Figure 1f is a map of human population density from PNGRIS, which shows that there are few areas with a high human population density.

RESULTS

The Current Best Set of Biodiversity Priority Areas

A set of biodiversity priority areas, which meets the 10%-based target and satisfies the objectives of minimising foregone opportunity costs, while avoiding areas of high land use intensity and high population density, including existing protected areas and preferring CNA high priority areas, is shown in Figure 2a. While this level of biodiversity representation could be achieved in our baseline analysis using only 10% of the country, achieving this same goal given costs, constraints and preferences meant that approximately 16.8% of the country was required. The summary properties for this set are listed in Table 2 below.

Timber volume

Biodiversity priority areas will inevitably be subject to review and re-evaluation over time, to incorporate new knowledge on biodiversity as it is accumulated and to take account of changing economic and social conditions. These planning methods are designed to function as an aid to the conservation decision-making process in an ongoing way. The data sets should be updated and the analyses run again at regular intervals.

One example of such a re-analysis would be the search for substitute areas for those originally selected, but later assessed as inappropriate for biodiversity protection because they have been logged over (see below). The procedure is to delete a nominated area and then use TARGET to search for one or more replacements. We carried out an initial search for substitutes for any of the areas that were in the set but had high timber volume ratings. In summary, area 2384 in the original selected set had a timber index value of 1890. Substitute areas 2410 and 2452 together contribute the same features to the biodiversity goal, but have timber index values of 702 and 3.2 respectively. The new set of 398 areas had a total timber value cost of 93,218 units as opposed to the original 94,403 units (these results are reflected in Table 2 and Fig. 2).

Nix *et al.* (2000) further discuss how the methods can be used to identify different solutions depending on the emphasis placed on different attributes and different goals.

Figure 2b highlights the low degree of overlap of these biodiversity priority areas with areas having high potential for timber production, as estimated using the timber volume index map. The analysis identified a set of biodiversity priority areas that not only achieved the target level of biodiversity representation but also minimized the implied forgone forestry opportunities.

Many of the priority areas that do overlap with high timber volume areas are those that were determined to be essential (discussed below). These areas would have to be in any priority set that achieves the biodiversity target, consequently they would be selected no matter what their assessed timber volume. Other current priority areas may have substitutes that could be selected instead. However, because TARGET has tried to find the solution having least opportunity cost, in most cases the substitute area (or areas) would be expected to have a higher opportunity cost. An example of a successful substitution is described below.

Agricultural potential

The map in Figure 2c highlights the low degree of overlap of the biodiversity priority set with the areas having agricultural potential. While agricultural potential was not used as an “opportunity cost” in the TARGET analyses, some preference was given to the selection of priority areas with low potential. The total number of RMUs having an agricultural potential rating according to our simple index is 1510. Only 110 of these RMUs are within the priority set.

Conservation needs assessment areas

Figure 2d illustrates the high degree of representation of the CNA priority 1 areas by the current best set of priority areas. This is not an unexpected result, since RMUs coinciding with CNA priority areas were preferred to RMUs, which did not fall within CNA priority areas. Only the CNA priority 1 area in the West Sepik does not appear to overlap with the biodiversity priority set. However, areas from the biodiversity priority set do occur in the Toricelli Range and on the Sepik River floodplain, to the immediate north and south of this CNA area. The degree to which the set of priority areas represents an effective refinement of the CNA process is also revealed by examining the extent to which they overlap the individual “hotspot” areas designated by taxonomic experts as part of the CNA study. Table 3, based on data from Beehler (1993), summarises the very high representation, in the current best set of priority areas, of the key biodiversity areas identified by experts in CNA study.

An alternative was to use the CNA areas as an independent test of our biodiversity surrogates. A weak test could be made by not including them in the TARGET analysis, and overlaying the selected set of priority areas to see how well they coincided with a set of areas chosen by experts for their conservation value. However, this was rejected as it would have meant excluding potentially valuable information on biodiversity held by experts, from our analysis. While the current analysis demonstrates how all available information can be used, including expert opinion, a separate re-analysis has been carried out to evaluate correspondence between our surrogates and the CNA areas (Faith *et al.* 2001b).

Representation of rare species

The representation of at least one area known to contain each of 11 rare and threatened species was included in the biodiversity target. The representation of Queen Alexandra's Birdwing Butterfly, *Ornithoptera alexandrae*, is shown in Figure 3, as an example. The overall geographic spread of this species was, perhaps fortuitously, well represented in the priority area set.

How do we use the current priority set in the planning process?

The current priority set is the current “best” set in light of the nominated target and all of the constraints. Unless it is the case that this priority set was to be implemented immediately, it is necessary to consider the special attention that might be given to a subsets of this set. Such considerations are useful even if the overall priority set does not change. However, it is necessary to re-evaluate the set as new information, including new costs or constraints, come to hand. We present examples of such modifications below, illustrating the way in which ongoing evaluations and re-assessments of priority areas can be made.

Figure 4a shows the relative complementarity values of the members of the current priority set. The high complementarity areas and the 'must-have' areas, those that cannot be substituted for any others if the biodiversity target is to be reached, (Fig. 4b) might be the prime candidates for immediate allocation of scarce conservation resources.

Figure 4c shows all the members of the current priority set having more than half their area in the highest PNGRIS land use intensity class. These might also be candidates for special attention – either urgency for action on formal protection, searching for substitutes where possible, or even rehabilitation. A similar map, not reproduced here, was produced for areas having highest population density.

The timber volume index ranking of members of the current priority set is shown in Figure 4d. Once again, priority areas with high timber volume might be candidates for early action, since they are potentially vulnerable for logging. In addition, below we consider priority areas that overlap with the PNGFA forest plan areas of interest. The recent report, "A future for our forests" (National Research Institute 2000) recommends that "areas of forest identified as having high biodiversity values by the Conservation Needs Assessment and BioRAP process should be considered as possible constraints on forestry operations. The conditions under which such constraints would operate would need to be defined." The discussion above and maps from Fig. 4 suggest to us that the form of "constraints" on high value biodiversity areas could be realized through a process where the current set be recorded with PNGFA and OEC and must-have areas for the 15%-based target be "no-go" areas, while others be provisional no-go areas, unless substitute areas are identified and agreed to by PNGFA and Office of Environment and Conservation (OEC). Faith *et al*. (2001b) explore some other incentives/constraints strategies, including possible assignment of high environmental levies based on complementarity values.

Timber volume per unit area as an alternative cost

One of the issues relating to the definition of forest production costs was how best to summarize the total forestry production potential of an RMU. The current best set of priority areas was derived using costs based on an estimate of the total timber volume in each RMU. However, timber volume per unit area would be a reasonable alternative measure of cost. The map in Figure 5a shows that, of all the areas having high timber volume per unit area, only a small number have been selected as members of the current best set (50 areas shown in red). Apparently, minimising the selection of RMUs with high total timber volume was also effective in minimising the selection of RMUs that had high timber volume per unit area.

Among that set of 50 priority areas, 6 areas had distinctively high values for timber volume per unit area. These are shown in Figure 5b and summarised in Table 4. These 6 RMUs were deleted from the proposed set and a search was made for substitutes. Three substitute areas were found for this set of 6. Figure 5b shows the substitutions that were made. The opportunity cost (index of timber volume) was reduced from 93,218 to 92,562 units (see summary properties in Table 2 for analysis of Figure 2a) This lower cost result highlights the fact that our TARGET algorithm only approximates the least-cost solution, and subsequent swaps may improve the result.

Overlap of priority areas with forest plan areas of interest

The forest plan for PNG (PNGFA 1996) shows areas designated as current production areas and areas designated as having “forest potential” or “potential for forestry production”. For each province, we noted areas of apparent overlap with the priority set, noting where appropriate whether the priority area was a “must-have” (Fig. 4b). Overall, there is little overlap of the priority set with current forestry areas, though we noted potential conflict in some provinces.

In Western Province, there is no overlap with major existing production areas (Makapa, Oriomo, Wawoi Guavi), but there is overlap with some of the Fly-Strickland “potential areas for future development.” These priority areas are notable as must-have areas, which cannot be substituted if the biodiversity target is to be reached (Fig. 4b). There is overlap of the priority set also with Balimo Fly and Semabo FMA potential forestry areas. A possible substitutable priority area overlaps with the Tapila Wipim potential production area. Large must-have members of the current priority set near the Irian Jaya border overlap with areas designated as “forest potential”. A Greenpeace Forest Report (Brunton 1998) reports that a veneer mill has been built at Emeti, south of Wawoi Guavi. This area overlaps with the anticipated (15%-based target) must-have area north of the Fly River.

In Gulf Province, the large existing Wildlife Management Area overlaps with several forestry production areas, but there may be little activity in these areas at present (Brunton 1998). Additional overlaps exist, for example, where there is a riverine must-have area adjoining/overlapping with forestry production areas. In Central Province, there are complex patterns of small bits of overlap with production areas and potential production areas, while in Madang and Southern Highlands there is overlap with "forest potential" areas.

New Britain presents particular challenges, in showing moderate overlap of "logged over" areas with the current priority set. Therefore, we examined whether substitute areas might be found for some or all of these overlap areas (and this procedure may be followed in other provinces). Starting with the priority set, all priority areas within the New Britain provinces, except those determined earlier to be irreplaceable (6 areas in New Britain), were deleted from the set. This reduced set of 363 areas was then used as a starting point for a new TARGET analysis. In this analysis, all areas except those in New Britain provinces (1243 areas) were made available for selection. The initial result consisted of 384 members. However, it was not possible to reach the target. In order to do so, additional areas in New Britain were required, but these need not necessarily be logged over areas. Once these were added, the new total was 401 RMUs with a total area of 76420 square kilometers, a timber volume index equal to 92607 units, and 104 RMUs with agricultural potential. In the revised map (Fig. 6), note the much reduced use of areas in New Britain to achieve the target. The possible logged-over areas that are still needed to reach the target (the green areas in the map in Figure 6) could be priority candidates for rehabilitation. This procedure could be part of an on-going evaluation and re-analysis using updated information on current status of forest plan areas.

CONCLUSIONS, COMPARISONS AND DISCUSSION

A set of biodiversity priority areas which together represent 608 environmental domains, 564 vegetation types, 10 species bioclimatic profile clusters and 11 rare and threatened species, has been identified for Papua New Guinea. This set of areas also includes all existing protected areas and samples all CNA priority 1 areas (with the possible exception of one in north-west Sepik; Figure 2d). In addition, the set minimizes foregone opportunities for timber production, avoids areas of high agricultural potential, avoids areas of high existing land use intensity and gives preference to areas of low human population density. A total of 16.8% of PNG was required when 1) existing protected areas were included, 2) areas were excluded that were judged unsuitable as biodiversity priority area candidates because of past land use, and 3) areas offering other land use opportunities were deliberately avoided.

We reached a biodiversity target in a way that provides a potential benchmark for comparison with other countries. The total number of environmental domains and vegetation types was determined by finding the number that could be represented in 10% of PNG, assuming that there were no people and no opportunity costs. It was possible to do this because the classifications are hierarchical, (in the case of the vegetation types, made partly hierarchical by overlaying types onto broad physico-climatic zones) with finer distinctions between classes expressed at lower levels in the hierarchy and broader distinctions at higher levels. This highlights the fact that more classes, and in theory more biodiversity, could be sampled if the target was, say, 15% (see Faith *et al.* 2001a). Such a target should be considered in future planning.

The approach to biodiversity planning described here recognizes that such planning is an ongoing iterative process. The data sets and the computer software supporting the current set of biodiversity priority areas, and the skills needed to use them, have been delivered by this project to relevant PNG government officers. The current set of biodiversity priority areas can be expected to change as knowledge accumulates and as social and economic conditions change. Faith *et al.* (1999 and 2001b) outline approaches to linking these maps to implementation issues, such as environmental levies and carbon offsets.

This study represents the first ever whole-country study based on systematic biodiversity trade-offs methods. Some comparisons with other approaches are interesting. We have tabulated some alternative analyses of the PNG data (Table 5). First, we examine some differences in total cost. If we had interpreted "efficiency" as minimum number of areas as in conventional minimum sets approaches (e.g., Pressey *et al.* 1993), the actual cost in timber volume units for the proposed set would have gone up by more than 20% (last column, Table 5). This result reinforces the comparisons from simple case studies (Faith *et al.* 1994, 1996). It is interesting that taking area as the cost in our trade-offs analyses would approximate the results, calculated in terms of timber costs, that are found when using timber volume costs directly (5th column, Table 5). We do not, however, take this to mean that area might be recommended more generally as a stand-in for opportunity costs (contra Balmford *et al.* 2000); in other regions and for other opportunities, opportunity costs could be unrelated to area.

Our current best set achieves the 10%-based target with a cost of 93,218 timber volume units, but that cost would have been only 71,280 units if the existing protected areas were not included up front as commitments. The cost from the existing protected areas alone is 34,771 units (Table 5). The total area of the current priority set follows the same pattern. Without committing existing protected areas, the total area needed to achieve the 10%-base target would not be 16.8%, but just 12.9% of total PNG area.

All these reported analyses ignored, for the purpose of calculating representativeness, attribute occurrences in an RMU of less than 1 kilometer squared, based on a viability argument. Our initial explorations when these occurrences were counted suggested that this is another factor, in addition to existing reserves, that can dramatically influence total area required to reach a target. Faith *et al.* (2001b) discuss these viability/persistence issues further.

Achieving the 10%-based target required 16.8% of total area of PNG. Would we find a higher or lower total area in other regions/countries? It would be interesting to determine the total area needed elsewhere to achieve a 10%-based target, and interesting to determine as well which costs and constraints account for any extra area needed over 10%.

Failure to consider biodiversity targets and trade-offs early in the planning process can limit the subsequent capacity of a region/country to achieve effective trade-offs. Our biodiversity target in PNG cost 93,218 timber volume units, with 34,771 units alone contributed by the commitment to an existing set of protected areas that are not particularly representative. That cost is much more than an estimated cost of 58,000 units or less suggested by the baseline analysis (column 2, Table 5). We presented a similar hypothetical example (Faith 1995) in a theoretical study on how past land use could limit the achievable degree of balance – the best-possible "regional sustainability" level. Early consideration of targets and costs can avoid reducing the capacity for compromise and balance (see also Pressey 1994).

A long period of time has passed between our initial case study exploring the utility of trade-offs approaches for biodiversity planning (Faith *et al.* 1994, 1996), their incorporation into the BioRap toolbox, and this real-world application of the methods in PNG. The development of these tools occurred against the backdrop of recent biodiversity planning processes in Australia (Commonwealth of Australia 1997). While not taken up at the time, these trade-offs approaches have now directly influenced the Federal Government environment department's new planning system (Commonwealth of Australia 1999). The role of science in influencing biodiversity planning in Australia is also discussed in Pressey (1998) and Ferrier *et al.* (2000).

Prendergast *et al.* (1999) recently argued that what they perceive as gaps between theory and practice in selecting nature reserves might be overcome if the research was published in management journals. But their paper unintentionally highlights another problem, given that they advocate publishing new methods in management journals while remaining unaware themselves of the new methods published in management journals (e.g., Faith *et al.* 1996). If there is no real synthesis by scientists of the scientific developments, the wheel keeps getting re-invented, and methods incorporating cost, for example, remain novelties (as in Prendergast *et al.* 1999 and

Balmford *et al.* 2000). Applications are needed, rather than more studies that again show that algorithms that achieve a target by minimizing costs will indeed do the best at minimising costs.

Re-discoveries of the established links between complementarity and costs present new confusions. For example, Balmford and Gaston (1999) argue that anticipated complementarity-based cost savings (arising from a smaller number of areas used) justify new surveys to obtain the species lists they believe are necessary for conservation. Certainly, the application of complementarity does lead to cheaper representation than any selection of areas that ignores complementarity. But we don't necessarily need “species lists for each candidate site” (Balmford and Gaston 1999) in order to make savings. Thus, the major premise for their argument for new surveys is incorrect. In our PNG study, as in the earlier case studies, *existing data* provide the basis for using complementarity and reaching biodiversity targets at low cost. Thus, while Balmford and Gaston would call for new surveys, we advocate the kind of rapid assessment carried out in this project using surrogates, which at the end of the day are all that is available if results are to be obtained in time for effective conservation action in countries such as PNG. That assessment not only can determine which areas should be protected now, but also point to the most urgent information needs for ongoing assessments and planning.

Cost trade-offs may not be equally applicable at all levels of planning. We have joined others in arguing for consideration of a suitable costs framework in international priority setting (Mace *et al.* 2000), but we doubt the utility of a recently proposed use of costs for prioritising among countries (Balmford *et al.* 2000). In that scheme, based on finding a representative set of countries having low cost, a country having unique biodiversity components and low estimated opportunity costs of conservation would end up as a high priority. This might be one form of guidance for international conservation efforts. However, given that their priority set never represents all biodiversity, it presumes that protecting the biodiversity of countries with high opportunity costs is a lost cause. We would argue that if anything the opposite might pertain. Any country in which the opportunity costs of achieving a target (say, a 10%-based target) were estimated to be high, would be one deserving a *high*, not low, priority for conservation investment. High opportunity costs imply high potential conflicts. Investment could be used to facilitate within-country planning based on trade-offs so as to urgently achieve a balance between biodiversity protection and production, before sustainable options were lost (see also Faith in press).

The problem of prioritizing at different geographic scales is relevant also to PNG, where there will be a need for within province biodiversity planning. At present, we have no formal link to propose between whole-country and within province planning. It may be useful to carry out area substitution within provinces, starting with the priority set members, and also identifying those areas that require urgent decisions –to be made (as discussed earlier).

The need for within-province planning highlights again that the set of priority areas identified in this study is only the “current best set”. Planning is an ongoing iterative process and any set of priority areas can be expected to change as a result of factors such as new decisions on land uses, changes in economic, social and political conditions, and changes in ecological and biological knowledge. It is almost inevitable that some such changes will occur. Even if it were decided in PNG to implement the current best set of priority areas, it would take time to negotiate with all stakeholders. It is likely that only a few priority areas could be accorded some form of protection within, say, a year, which means it would take many years to implement the entire plan. Thus, areas not selected in the current best set may assume higher priority in the future. However, there is always a sub-set of areas which are irreplaceable (Pressey *et al.* 1993) if the biodiversity target is to be achieved and it will always be necessary to include these in any set of biodiversity priority areas. It is not feasible for any set of priority areas alone to represent all of biodiversity (unless they cover the whole of the country). Areas not selected in the current best set still contain biodiversity and some will contain components of biodiversity not represented in the current best set of priority areas.

The priority areas were selected in a way that minimized the number that were attractive/vulnerable for other land uses (specifically timber and agriculture) – in other words, such areas often were given *low* priority for protection. This approach contrasts with others (see Margules and Pressey 2000) that give *high* priority for protection to areas that are attractive for/vulnerable to other land uses. Our view is that regional sustainability and corresponding net benefits for society depend on balancing biodiversity and other land uses, as attempted in this study. It is notable that the biodiversity target was achieved here at low cost – the scope for balance and compromise was great. Indeed, opportunity costs were among the least important factors determining the increase in total area needed over that in the baseline 10% analysis. Inclusion of existing protected areas and exclusion of very small samples of the target biodiversity features (less than $1km^2$ occurrences) were most important.

These results suggest that the major demand on effective protected area systems may not be the competing land uses so much as other design issues relating to persistence.

Many of the RMUs selected are small, probably too small to form viable protected areas either from the point of view of ecological persistence or management. If the smaller members of this set were to be chosen as potential protected areas it would be rational and necessary to proceed with clusters of them forming the basis of negotiated Wildlife Management Areas. Wildlife Management Areas (WMAs) form the mechanism currently used in PNG to negotiate biodiversity protection. Many of the existing protected areas shown in Figure 1c are WMAs, especially the larger ones. These reappear in Figure 2a as members of the current best set of biodiversity priority areas because existing protected areas were committed to selection. Another approach to dealing with this problem would be to incorporate an adjacency option into the area selection software. This would allow for the possibility of choosing an area adjacent to one already chosen. Choosing adjacent areas implies a cost that may have to be traded-off with other demands. In the workshops accompanying the PNG study, TARGET was used to restrict new selected areas to be adjacent to existing proposed areas. The degree of restriction depended on an “importance weighting”. Adjacency options are being programmed into the TARGET software (Walker *et al.* unpublished) as part of a current project to identify biodiversity priority areas in tropical Queensland, minimising lost opportunities for tourism.

We have described how the trade-offs procedure used here represents a departure from traditional methods. In conventional systematic conservation planning, “efficiency” is all about how well biodiversity representation targets are achieved relative to number or area of reserves (e.g., Margules *et al.* 1988; 1994; Pressey and Nicholls 1989a,b; Pressey *et al.* 1993). We link efficiency instead to "regional sustainability" (Faith 1995) – a balancing act that encompasses general opportunity costs, in a framework that may or may not have biodiversity targets.

The departure from traditional approaches includes more than abandoning "minimum sets". We see "complementarity" itself, which conventionally is defined as amounts of biodiversity, as incorporating both representativeness and persistence (Faith and Walker (1996c). That more general formulation plays an important role in trade-offs analyses, allowing partial protection, design issues and other aspects to be taken into account. Faith et al. (2001b) treat some of these issues in their paper on future planning in PNG.

ACKNOWLEDGEMENTS

We thank Kathy MacKinnon of GEF and the World Bank for her enthusiastic support and guidance throughout this study. We also thank A. Allison, B. Smythe, M. Hedemark, J. Kesteven, W. Slater, and the staff of the Department (Office) of Environment and Conservation in Port Moresby. World Bank and AusAid provided funding for this study. We thank M. Calver for comments on the manuscript, and H. Recher for his help with lagging co-writers.

REFERENCES

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

Balmford, A. and Gaston, K. J., 1999. Why biodiversity surveys are good value. *Nature* **398:** 204-205.

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.

Brunton, B., 1998. Forest Update. Greenpeace Pacific. World Rainforest Report 39. http://forests.org/ric/wrr39/pngripot.htm.

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.

Commonwealth of Australia, 1999. EcoPlan: a decision support system for environmental and landuse planning. Environment Australia. Canberra.

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

Faith, D. P., in press. The role of trade-offs in biodiversity conservation planning: linking local management, regional planning and global conservation efforts. *J. Biosciences.*

Faith, D. P. and Walker, P. A., 1994. DIVERSITY: a software package for sampling phylogenetic and environmental diversity. Reference and user's guide. v. 2.1. CSIRO Canberra.

Faith, D. P. and Walker, P. A., 1996a. 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., 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., 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, Armidale.

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. Centre for resource and environmental studies, Australian National University, Canberra.

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. Walker, P. A. Stein, J. and Natera, G., 2001a. Practical application of biodiversity surrogates and percentage targets for conservation in Papua New Guinea *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*.

Ferrier, S., Pressey, R. L. and Barrett, T. W., 2000. A new predictor of the irreplaceability of areas for achieving a conservation goal, its application to real-world planning, and a research agenda for further refinement. *Biological Conservation* **93:** 303-325.

Hunt, C. and Filer C., 2000. Recommendations from conference. Post-Courier Online. Port Moresby.

IUCN, 2000. The ecosystem approach. Recommendations to the fifth meeting of SBSTTA.

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

Kershaw, M., Williams, P.H. and Mace, G.M., 1994. Conservation of Afrotropical antelopes: consequences and efficiency of using different site selection methods and diversity criteria. *Biodiversity and Conservation* **3**: 354-372.

Kirkpatrick, J. B., 1983. An iterative method for establishing priorities for the selection of nature reserves: an example from Tasmania. *Biological Conservation* **25**: 127-134.

Lombard, A. T., 1995. Introduction to an evaluation of the protection status of South Africa's vertebrates. South African Journal of Zoology **30**: 63-70.

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

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

Mackey, B. G., Nix, H. A., Stein, J. A. and Bullen, F. T., 1989. Assessing the representativeness of the Wet Tropics of Queensland, World Heritage Property. *Biological Conservation* **50**: 270-299.

Margules, C. R., 1989. Introduction to some Australian developments in conservation evaluation. *Biological Conservation* **50**: 1-11.

Margules, C. R., Cresswell, I. D. and Nicholls, A. O., 1994. A scientific basis for establishing networks of protected areas. Pp. 327-350 *in* Systematics and

Conservation evaluation. ed by P. L. Forey, C. J. Humphries and R. I. Vane-Wright. Clarendon Press, Oxford.

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.

National Research Institute, 2000. A future for our forests. Port Moresby.

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. , Walker. P., 2000. The BioRap Toolbox: A National Study of Biodiversity Assessment and Planning for Papua New Guinea. CSIRO Press. Canberra.

PNGFA, 1996. The National Forest Plan for Papua New Guinea. Port Moresby, Papua New Guinea.

Prendergast, J. R., Quinn, R. M. and Lawton, J. H., 1999. The gaps between theory and practice in selecting nature reserves. *Con. Biol.* **13:** 484-492.

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., 1998. Algorithms, politics and timber: an example of the role of science in a public, political negotiation process over new conservation areas in production forests. Pp 73-87 *in* Ecology for Everyone: Communicating Ecology to Scientists, the Public and Politicians. ed by R. Willis and R. Hobbs. Surrey Beatty and Sons, Chipping Norton.

Pressey, R. L. and Nicholls, A. O., 1989a. Efficiency in conservation evaluation: scoring versus iterative approaches. *Biological Conservation*, **50**: 199-218.

Pressey, R. L. and Nicholls, A. O., 1989b. Application of a numerical algorithm to the selection of reserves in semi-arid New South Wales. *Biological Conservation*, **50**: 263-278.

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

Rebelo, A. G. and Siegfried, W. R., 1992. Where should nature reserves be located in the Cape Floristic Region, South Africa? Models for the spatial configuration of a reserve network aimed at maximising the protection of floral diversity. *Conservation Biology* **6**: 243-252.

Sekhran, N. and Miller, S. (eds), 1994. Papua New Guinea Country Study on Biological Diversity Department of Environment and Conservation: Port Moresby

Stein, J. L., 1998. Classification Procedures and Preparation of Files for TARGET Analysis. Centre for Resource and Environmental Studies, Australian National University, Canberra.

Walker, P. A. and Faith, D. P. 1998. TARGET Software Priority Area Setting. CSIRO, Canberra.

Table 1. Summary properties of the set of existing protected areas

Number of RMUs	172
Area	30,913 km^2
Population	73,656
Number of RMUs with agricultural potential	45
Timber volume index total	34,771
Number of RMUs overlapping with CNA priority 1 areas	102

Table 2. Summary statistics for the current best set of biodiversity priority areas

number of RMUs	398
total area	77,215 km sqrd.
population	209,895
agricultural potential index total	102
timber volume index total	93,218
number of CNA priority 1 areas	180
# with high land-use-intensity	17

Table 3.
The overlap of our biodiversity priority areas with high value areas for different taxonomic groups from the CNA study. In the case of vertebrates, the comparison is with that of four different expert maps. The current best set of priority areas contains areas both to the north (Toricelli Range) and south (Sepik floodplain) of the CNA priority 1 area in the western Sepik district. These areas may overlap with the priorities of some of these experts, but the summarised map of CNA areas is drawn at too broad a scale for an accurate determination.

Species	**Representation**
Plants	13/14 represented, and 1 in west Sepik probable
Vertebrates	25/31 represented and 3 more possible, including 1 in west Sepik
Vertebrates	25/31 represented. 5 are islands and 1 in west Sepik is probable
Vertebrates	7/7
Vertebrates	4/5
Freshwater invertebrates	1/4 and 1 in west Sepik probable
Fishes and herpetofauna	27/30

Table 4. The six RMUs from the initial priority set of areas having a high timber volume index. Further TARGET analysis found substitutes for these areas.

Province Number	**RMU Number**	**Timber volume index per unit area**
10	61	4.0
10	83	4.0
11	142	4.1
11	143	4.0
11	144	4.0
12	18	9.9

Table 5. Descriptions of existing protected areas and five alternative sets of areas (different columns), for key factors (rows) relating to costs, constraints and preferences. nc = not calculated. The baseline set is the set covering 10% of PNG that was used to help set the biodiversity target. Implied costs and constraint values are shown for the baseline set, but were not used to derive that set. "All costs/constraints" corresponds to the current best set of biodiversity priority areas. In the last three columns, the analysis in each case uses all factors but with the listed modification. "LUI < .5" means the number of selected areas that have less than 50% of their area falling in the PNGRIS highest land use intensity class.

	existing protected	baseline set	all costs/ constraints	no existing protected areas included	area as cost	minimum set
# areas	172	258	398	305	405	392
timber cost	34,771	58,124	93,218	71,280	93,927	112,397
total area	30,913	47,958	77,215	59,470	71,759	89,466
LUI < .5	161	36	381	298	388	375
population size	73656	140,951	209,895	195,871	157,986	226,371
# with agricultural potential	45	74	102	66	102	97
# areas > 10k2	159	nc	371	287	376	370
CNA-1 overlap	102	42	180	133	193	178

Figure legends

Figure 1. Maps showing costs, preferences and masks information for TARGET analyses.
a) Coded timber volume ratings for RMUs. Yellow is highest class, followed by orange.
b) RMUs (orange) having agricultural potential according to a simple index.
c) Overlap (green) of existing protected areas with RMUs.
d) RMUs (orange) with current high land use intensity.
e) Overlap (black) of RMUs with areas having highest priority in the Conservation Needs Assessment.
f) RMU overlap with human population density classes. Yellow is highest category, followed by orange and then purple.

Figure 2.
Diagnostic maps based on the current best set of priority areas, combined with information on costs, preferences and constraints. Green RMUs in each case are those in the proposed set overlapping with coloured areas in Figure 1 maps.
a) the current best set of priority areas
b) portion of proposed set that overlaps with high timber volume areas
c) portion of proposed set that overlaps with agricultural potential areas
d) portion of proposed set that overlaps with CNA priority one areas

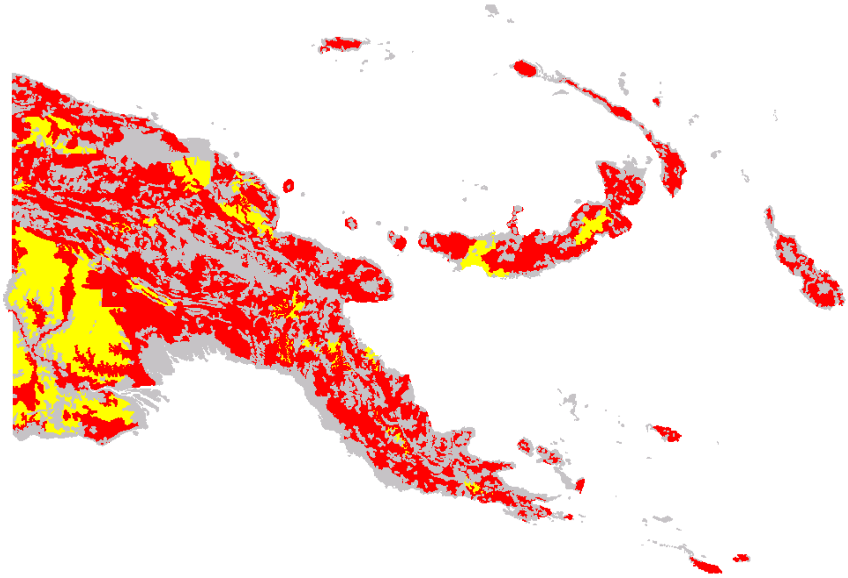
Figure 3. Black and red areas (RMUs) are those in which Queen Alexandra's Birdwing Butterfly, has been recorded and the red areas are those RMUs contained in the selected priority set (green designates all other priority areas).

Figure 4. Each map shows the current best set of priority areas, with priority set areas assigned colours to indicate key values for decision-making factors. Green areas in each case are remaining priority areas.
a) relative complementarity values of the priority areas (yellow is highest category, followed by orange, then purple).
b) must-have areas (orange) in order to achieve the 10%-based target
c) all priority areas having more than half their area in the highest PNGRIS land use intensity class (orange)
d) priority areas having highest ratings for timber volume (yellow is highest category, followed by orange, then purple).

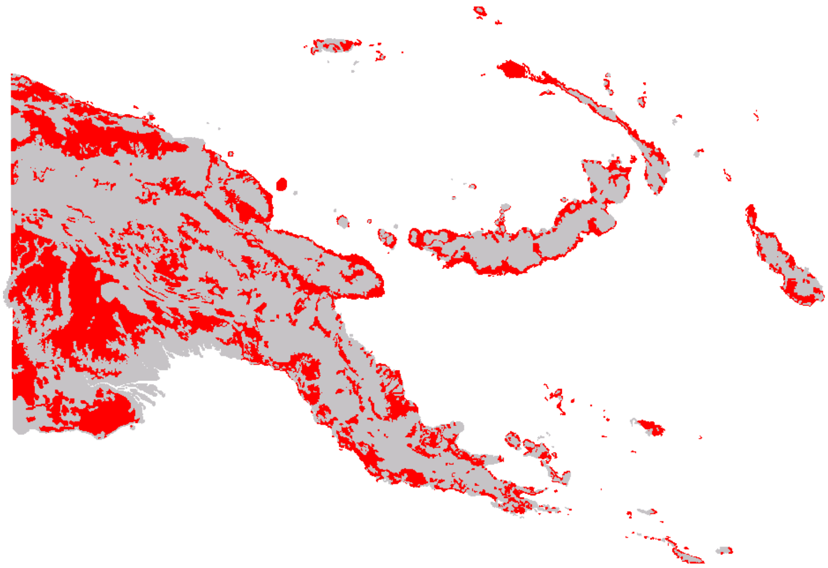
Figure 5. An expanded map of northeast PNG to show areas having high timber volume per unit area, and their substitute areas.
a) 50 areas (white) are in the priority set, among all those areas (black and white) that have high timber volume per unit area.
b) six priority areas with very high timber volume per unit area (white) and the three areas (blue) that could replace these (while still reaching the target). Other areas having high timber volume per unit area are shown as brown.

Figure 6. The yellow areas are those areas in a modified best set, building on the previous current best set, but only allowing must-haves and existing protected areas in New Britain to be retained. The additional areas shown as green then would be needed in order to reach the 10%-based target.

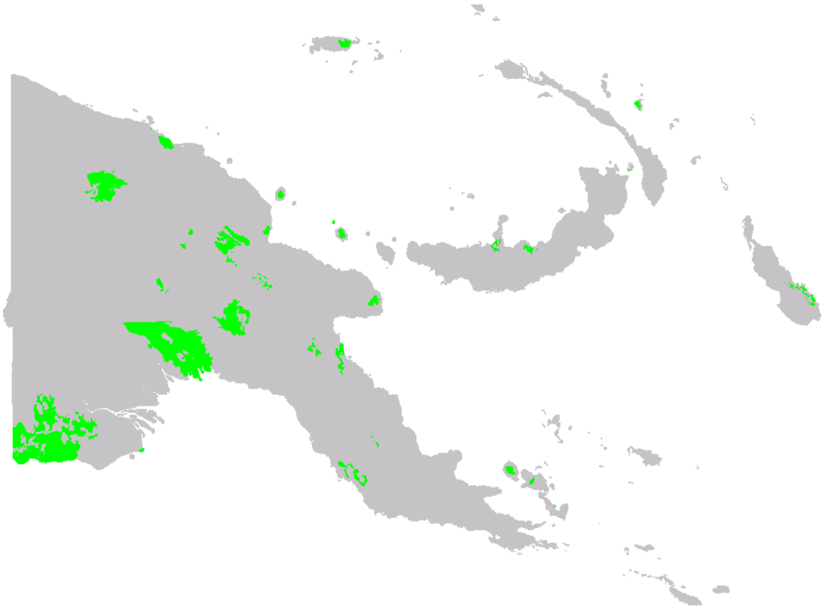
FIGURE 1



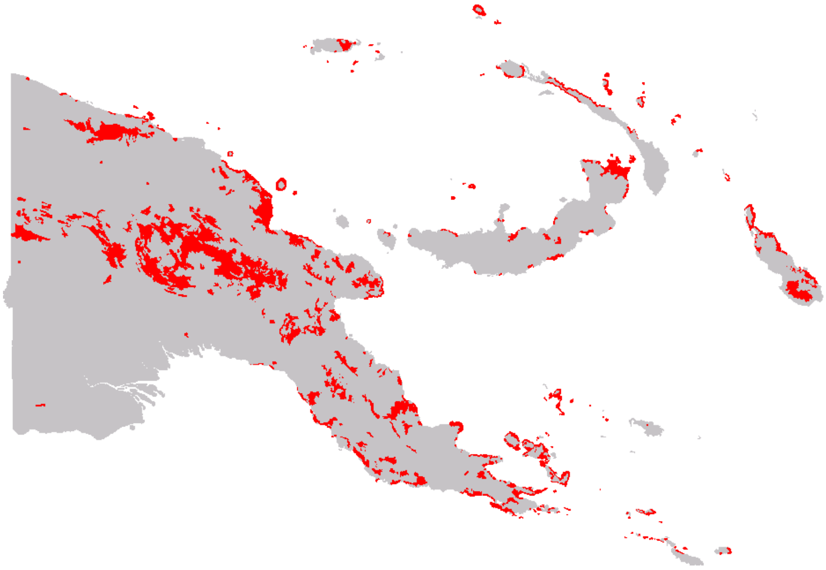
a)



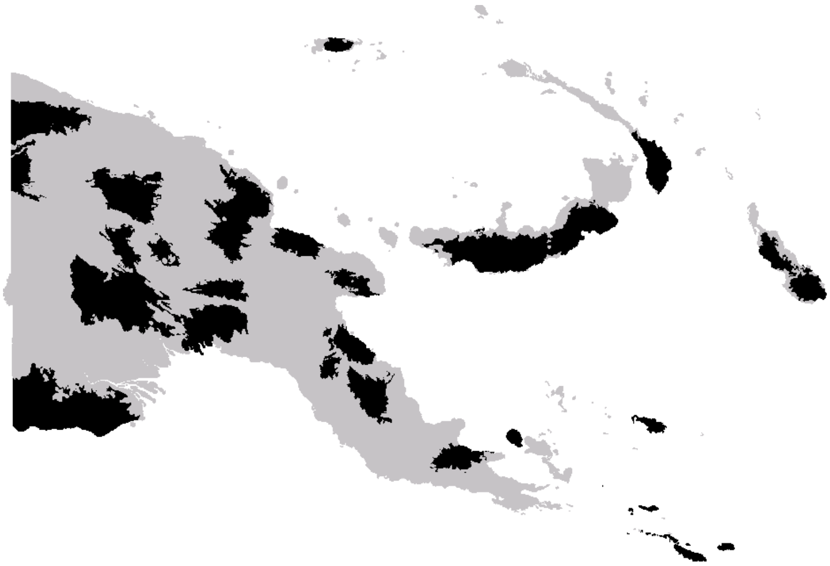
b)



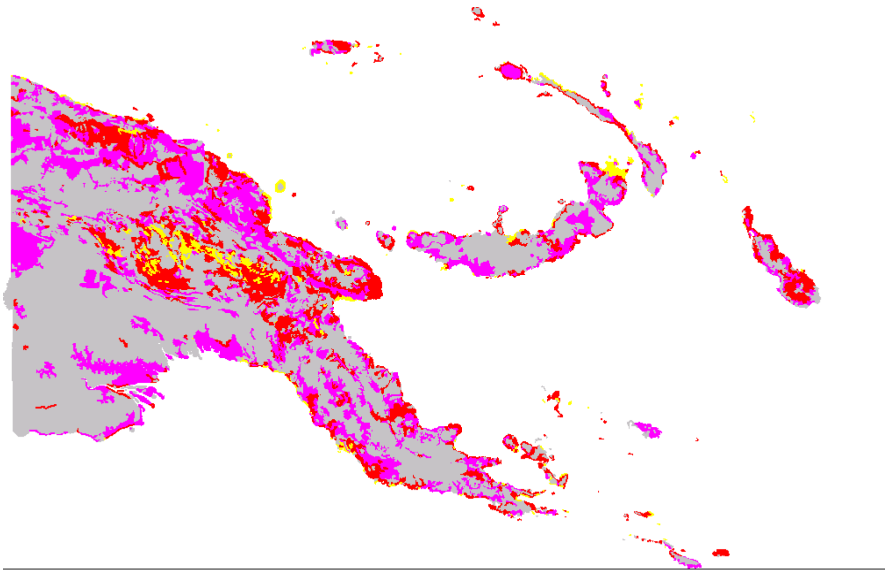
c)



d)

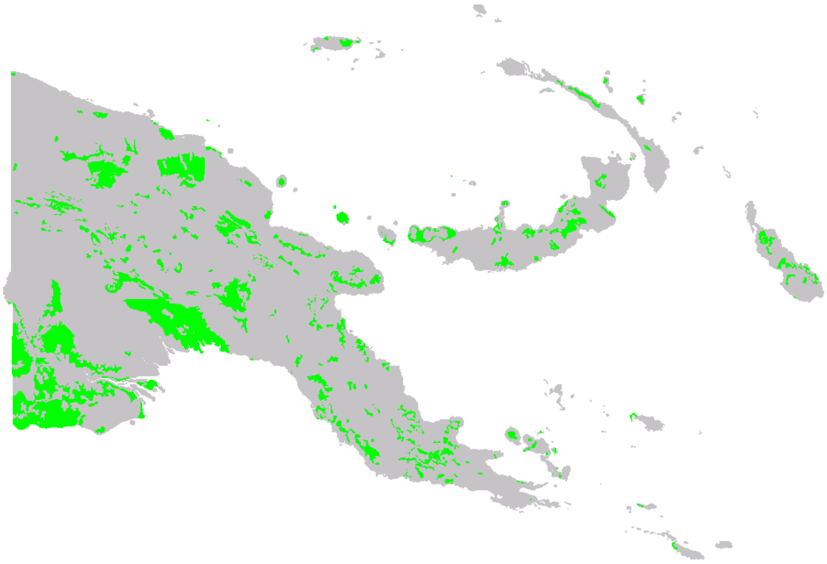


e)

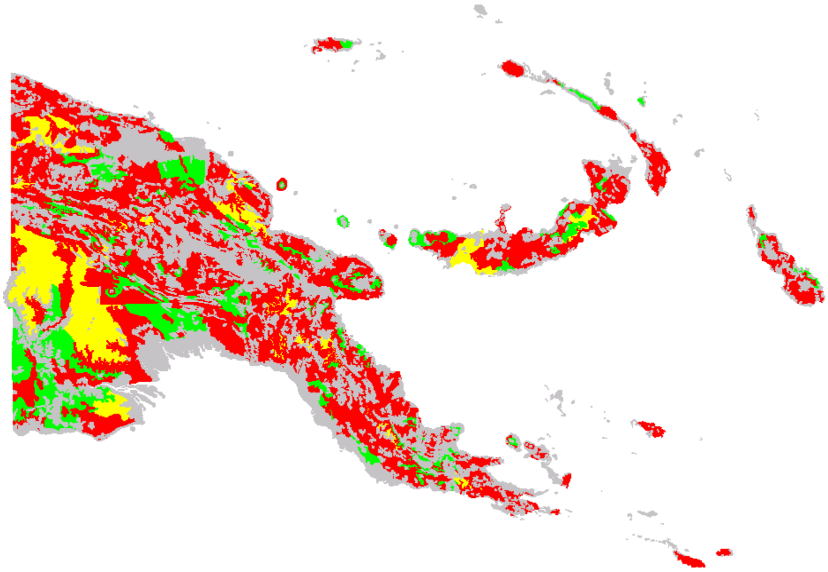


f)

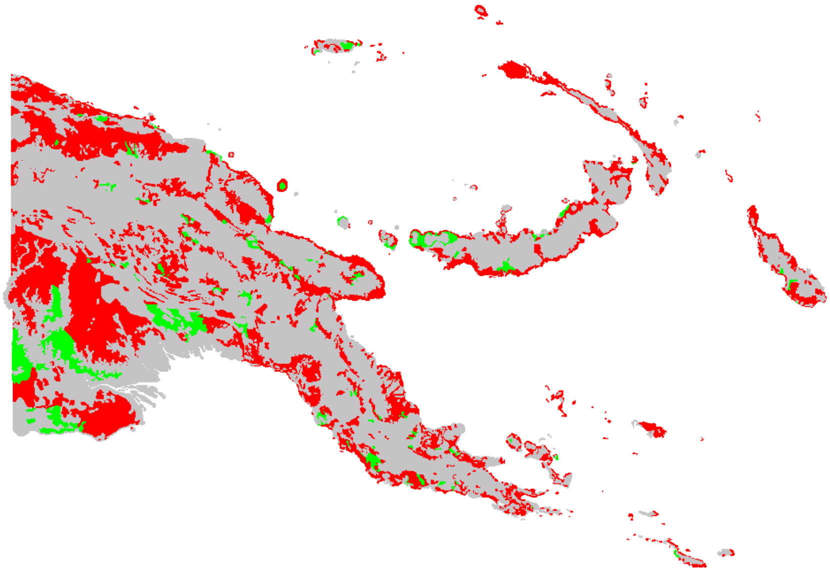
figure 2



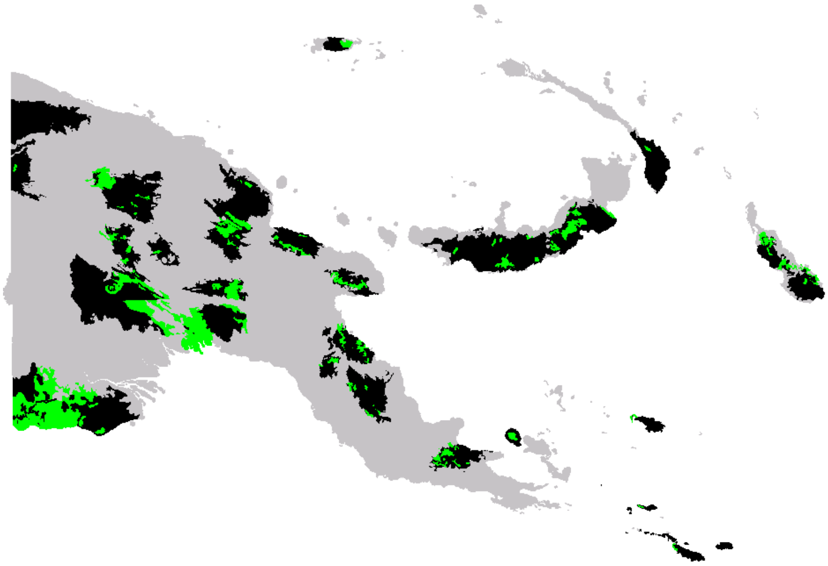
a)



b)



c)



d)

FIGURE 3

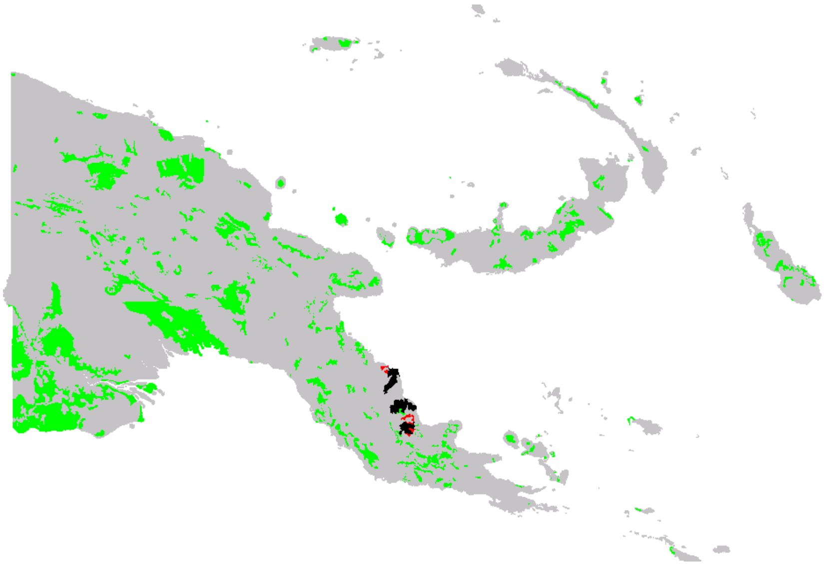
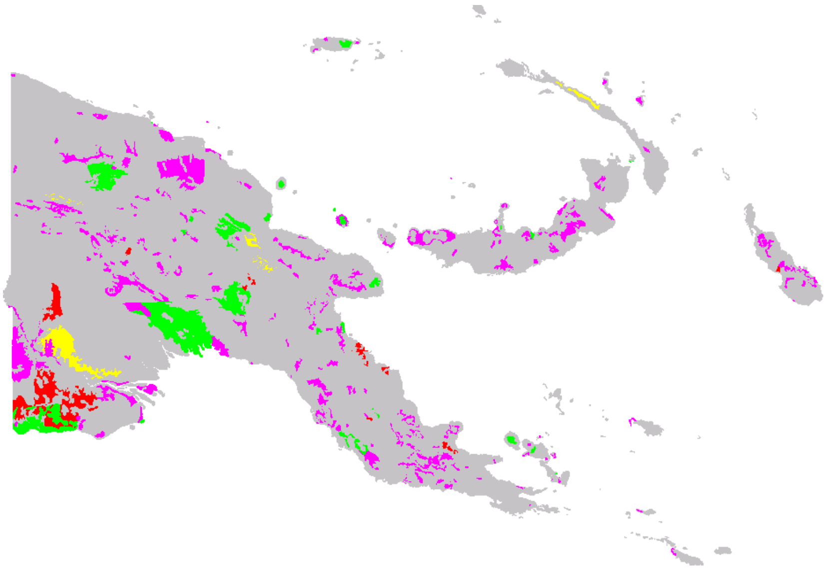
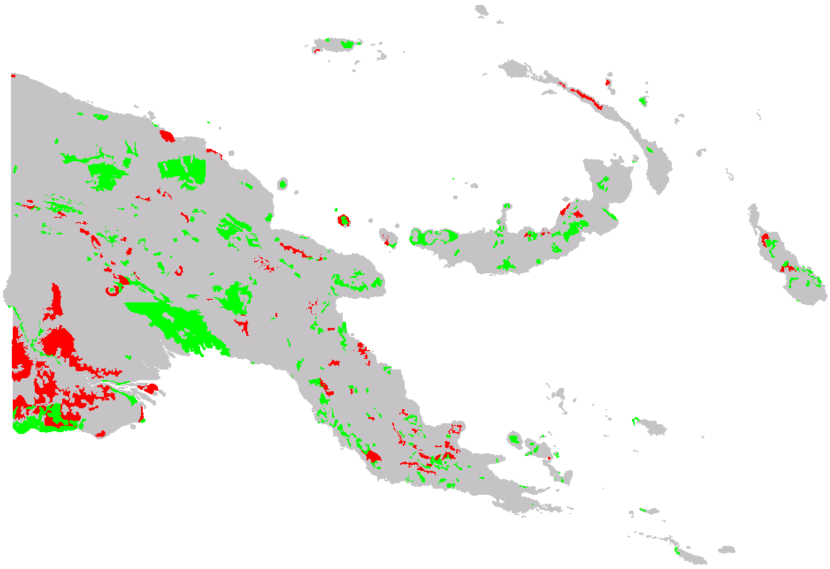


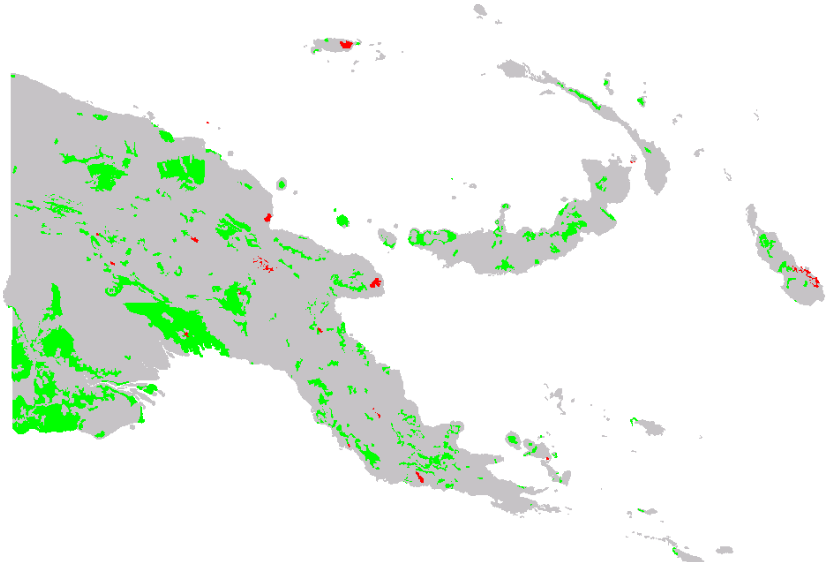
FIGURE 4



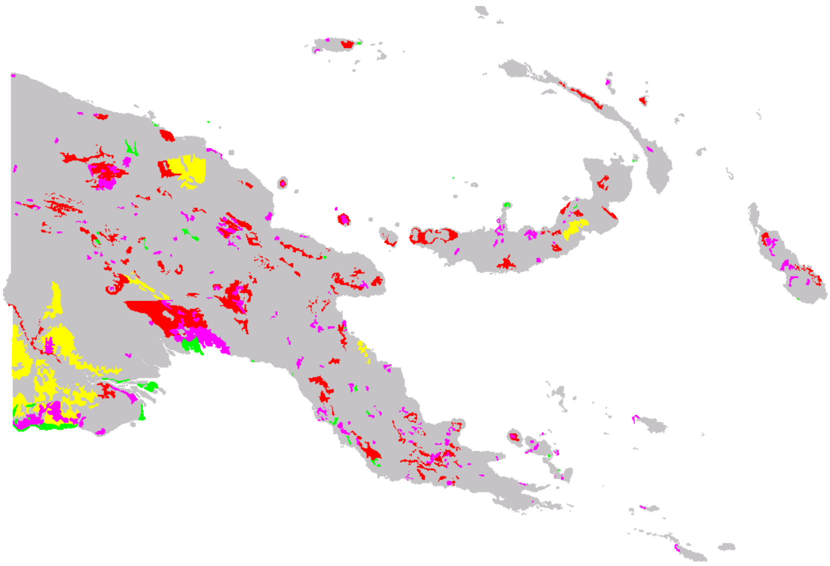
a)



b)

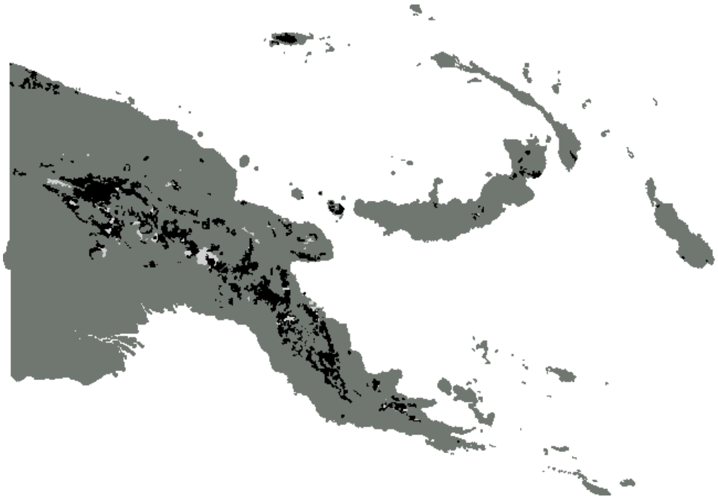


c)

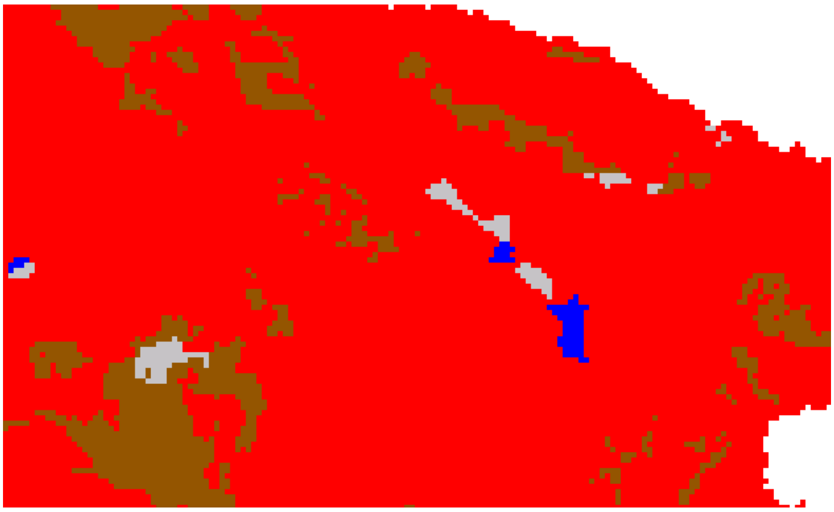


d)

FIGURE 5



a)



b)

FIGURE 6