Some future prospects for systematic biodiversity planning in Papua New Guinea – and for biodiversity planning in general

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Abstract

We describe three challenges for biodiversity planning, which arise from a study in Papua New Guinea, but apply equally to biodiversity planning in general. These are 1. the best use of available data for providing biodiversity surrogate information, 2. the integration of representativeness and persistence goals into the area prioritisation process, and 3. implications for the implementation of a conservation plan over time. Each of these problems is linked to the effective use of complementarity. Further, we find that a probabilistic framework for calculating persistence-based complementarity values over time can contribute to resolving each challenge. Probabilities allow for the exploration of a range of possible complementarity values over different planning scenarios, and provide a way to evaluate biodiversity surrogates.

The integration of representativeness and persistence goals, via estimated probabilities of persistence, facilitates the crediting of partial protection provided by sympathetic management. For the selection of priority areas and land-use allocation, partial protection may be a "given" or implied by an allocated land use. Such an integration also allows the incorporation of vulnerability/threat information at the level of attributes or areas, incorporating persistence values that may depend on reserve design. As an example of the use of persistence probabilities, we derive an alternative proposed priority area set for PNG. This is based on 1) a goal of 0.99 probability of persistence of all biodiversity surrogate attributes used in the study, 2) an assumption of a 0.10 probability of persistence in the absence of any form of formal protection, and 3) a 0.90 probability of persistence for surrogate attributes in proposed priority areas, assuming formal protection is afforded to them.

The calculus of persistence also leads to a proposed system of environmental levies based on biodiversity complementarity values. The assigned levy for an area may change to reflect its changing complementarity value in light of changes to protection status of other areas. We also propose a number of complementarity-based options for a carbon credits framework. These address required principles of additionality and collateral benefits from biodiversity protection. A related biodiversity credits scheme, also based on complementarity, encourages investments in those areas that make greatest ongoing contributions to regional biodiversity representation and persistence. All these new methods point to a new "systematic conservation planning" that is not focused only on selecting sets of areas but utilizes complementarity values and changes in probabilities of persistence for a range of decision-making processes. The cornerstone of biodiversity planning, complementarity, no longer reflects only relative amounts of biodiversity but also relative probabilities of persistence.

INTRODUCTION: PNG BIODIVERSITY PLANNING ISSUES

The Papua New Guinea (PNG) conservation planning study using the current BioRap toolbox (Nix *et al*. 2000; Faith *et al*. 2001a,b) raised the natural questions of what might have been done differently, and what might be done next. An example of the former is the question of the quality of our nominated biodiversity surrogates – specifically whether we have made the best-possible use of available biotic data for biodiversity surrogate information. An example of the latter is the whole question of the practical implementation over time of a conservation plan. In between the two are other issues relating to the ongoing prioritization process, including the integration of the partial protection that might be afforded to some biodiversity features by areas used primarily for production activities. Partial protection is related to the broader problem of integrating representativeness and persistence/viability goals in prioritising areas.

All of these questions and issues are linked to the effective use of complementarity. A probabilistic framework for calculating persistence-based complementarity values over time can contribute potential solutions to each problem. The first section below focuses on appropriate methods and later sections explore applications.

INTEGRATION OF PERSISTENCE AND REPRESENTATIVENESS

The PNG study addressed persistence in only an *ad hoc* way, through the discounting of small areas and small surrogate attribute occurrences (Faith *et al.* 2001a,b). If attribute occurrences of less than 1 km^2 had been counted towards representation in the course of selecting areas, the total cost to represent all biodiversity attributes would have been markedly less. So, a simple “counting-up” of biodiversity represented, ignoring viability, might be tempting. However, such seemingly successful trade-offs, and apparent regional sustainability, would be meaningless unless proposed protected areas actually had the capacity to protect biodiversity.

With no proper integration of representation and persistence, protected areas could sample/represent lots of biodiversity, but none of it might be secure with any real probability of persistence. Alternatively, the protected areas could have high security – high probability of persistence – but not represent much biodiversity. In the PNG study (as in other conservation plans focusing primarily on the representation of patterns) it was implied, though never explicitly stated as an assumption, that members of the priority area set would persist, while for other areas there was an implication that they probably would not persist unaided. In an extreme case, an assumption might be made that any sampling, however small, counts as a successful representation that implies that the sample area is capable of providing “protection”. But the “protected” status of an area means persistence only if the area is adequate in size, for example. Acknowledging that persistence is not an all-or-nothing thing has another implication as well. An integrated calculus of representativeness and persistence allows us to credit current land use with partial protection (and even allocate land uses providing partial protection; Faith 1995a).

Can we integrate biodiversity representation and persistence assessment so that we can characterize a region’s land use allocations in terms of overall persistence of biodiversity? This question reflects the need to better integrate two separate paradigms of biodiversity conservation. As suggested above, conservation planning as it has mostly been practiced to date (for review, see Margules and Pressey 2000) focuses primarily on the representation problem. On the other hand, PVA (population viability analysis) and related methods focus primarily on the viability of known biodiversity features (usually species). Except in an *ad hoc* way, planning methods do not currently build in a consideration of implied biodiversity viability when an area is selected using a representation algorithm. Margules and Pressey (2000) observed that “planning for both the representation of patterns and persistence of species and natural processes requires planners to compare apples and oranges.” Mace *et al.* (2000) state that “systematic prioritization focuses on patterns of species”, arguing that there is a failure “to address the conservation of key ... processes which maintain those patterns”. Peres and Terborgh (1995), Faith (1995a,b), Faith and Walker (1996a), Pressey (1997) and Cowling *et al.* (1999) address some requirements for the integration of representation and persistence. Given the magnitude of the threat to biodiversity globally, it is hard to imagine a more urgent biodiversity research problem.

We take as a starting point some basic probabilistic strategies for expressing biodiversity persistence and vulnerability in a planning framework (Faith 1995a; Faith and Walker 1996a, 1997). Similar use of probabilities for biodiversity persistence, in a phylogenetic context, is found in Weitzman (1992). While not explored in our PNG study, the BioRap toolbox (Faith and Walker 1996b,c) provides a framework for using probabilities of persistence for biodiversity attributes contained in geographic areas. Complementarity values are defined as before, except the complementary contribution of an area is the implied incremental gain it provides in the overall probability of persistence of all components of biodiversity in the country or region.

What does a probability of persistence mean? A 0.50 probability of persistence assigned to an area could reflect a management regime providing some partial protection of biodiversity attributes, and so be viewed as a desirable gain (over some smaller previous probability). Alternatively, a 0.50 probability of persistence could reflect current threat/vulnerability of the area (say, due to likely loss of habitat), and argue for priority of the area for greater protection. Such threat scenarios suggest that we also have to consider how probabilities of persistence relate to opportunity costs, given that the attractiveness of an area for alternative uses, for example, logging, can be viewed as an opportunity cost of conservation, or as a threat implying a low current probability of persistence. A simple example (Table 1) highlights these issues. Suppose that protection means a probability of extinction (of its attributes/species) of 0.10. Suppose that no protection, but no current land-use threat, means a probability of extinction of 0.50, and a threatening land use, say, commercial logging, means a probability of extinction of 0.90. In Table 1a, suppose that area I has species a, b, and c with current-status persistence probabilities of 0.50. Suppose that area II has only two species, d and e, and that the high attractiveness of that area for intensive logging means a current-status probability of extinction of these two species in the area of 0.90 (probability of persistence of 0.10). Suppose that species a-e are currently partially protected to an equal extent elsewhere, and only one of these two areas can be selected for formal protection, which would provide a 0.90 probability of persistence to its member species. The persistence-based complementarity for area II is greatest (the new probability of extinction over all five species is least; Table 1a), so area II would be preferred for protection.

Now consider an alternative interpretation (Table 1b) where attractiveness for logging reflects a competing opportunity relative to biodiversity protection. In this case, it does not imply the high extinction probability that would make protection of area II appear to produce a big gain in biodiversity protection. In fact, protecting area I best increases the overall probability of persistence of all species. This preference is even more dramatic if the area not protected is then allocated to forestry production, providing only 0.10 probability of persistence for member species (Table 1c). Clearly, protecting area I and logging area II provides highest net benefits – highest overall probability of species persistence and highest forestry opportunity.

We advocate using current-status probabilities of persistence primarily to reflect those threats that do not imply the taking-up of an optional land-use opportunity that may be best considered in a trade-offs analysis. A probability of persistence reflecting a land use opportunity generally will not apply in analyses which consider land use allocation to the area. What might be thought of as a low probability of persistence (a high vulnerability) reflecting a perceived likelihood of logging can be interpreted as a degree of threat implying urgency for some trade-offs decision to be made on land use for the area. Faith *et al*. (2001a) further contrast the trade-offs approach with others (see Margules and Pressey 2000) that would give high priority for protection to areas that are attractive for other land uses.

We now present an example analysis, for PNG, using such baseline or current-status persistence probabilities. Suppose that each area (and its constituent attributes) has a notional 0.50 probability of persistence prior to any change in protected status, and a 0.90 probability of persistence if protected. The regional goal for each attribute is a 0.99 probability of persistence (a regional probability of extinction equal to 0.01). The regional probability of persistence of an attribute is one minus its probability of extinction, equal to the product of extinction probabilities for individual areas. Thus, allocating an area to protection increases the probability of persistence of its member attributes.

We used TARGET to find the set of areas that reaches this regional goal, while minimizing opportunity costs equated with forgone timber volume (Fig. 1). While the analysis is similar, it is not directly comparable to that in Faith *et al.* (2001b), because it does not include existing protected areas as given.

In general, such a TARGET analysis can nominate a different base ("current status") level of persistence and a different target level of persistence for each biodiversity attribute. Similarly, the target level of persistence may be varied for the different attributes. These capabilities are relevant also to the analysis of environmental levies and carbon offsets, as discussed below.

The level of persistence assumed for biodiversity priority areas in the above example was 0.90. In practice, a sympathetic management regime might be allocated, with some lower level of persistence, to other areas (Faith 1995a; Faith and Walker 1996c). Walker *et al.* (unpublished data) use this approach to allocate areas to tourism and explore scenarios where these areas make some partial contribution to biodiversity protection. Of course, formal protection in a protected area such as a national park does not by itself deserve an assumption of 90-100% persistence probabilities. Future work will explore how the level of persistence for the components of biodiversity found in a protected area may vary according to biodiversity persistence models relating to such things as shape and size of the geographic area that has been sampled. These new approaches to "biodiversity viability analysis" (BVA; Faith and Carter in prep) parallel methods used in population viability analysis (PVA: see e.g., Morris *et al.* 1999). We employ models that generate a continuum of hypothetical species (avoiding any bias due to application of persistence probabilities to an arbitrary number of types or attributes). Models linking species to environmental variables imply that each hypothetical species forms geographic fragments of predicted speciespresence that can then be associated with different probabilities of persistence. For example, Faith *et al.* (unpublished data) use species-area curve models to assess persistence ratings for the different sized fragments of species distributions found in a given selected polygon. BVA combines persistence probabilities from different places in ways that parallel PVA's methods (e.g., Morris *et al.* 1999).

In the above analyses we may never have definitive values for probabilites of persistence, but a persistence-probability framework nevertheless provides a mechanism for exploring scenarios and setting priorites as part of a biodiversity risk analysis. A strong role is anticipated when biodiversity priority area sets are not yet implemented and risk analysis assessemnt is needed to determine which areas might imply a high loss of biodiversity protection if lost. We nominate an indicative baseline probablity (that can be updated as information changes) and calculate the complementarity value of the area, indicating the current estimated loss if its contribution fell to 0. The next sections make use of these complementarity calculations for more general policy mechanisms including environmental levies, subsidies, and offsets.

IMPLEMENTATION PROBLEMS AND PROSPECTS

Sustainability in PNG has often been interpreted to mean a continuous flow of timber, and recent policy frameworks (for discussion see Filer and Sekhran 1998) continue to subscribe to this notion of sustainability. Arguing that the ongoing logging of forests provides motivation for their protection makes a link from continuous flow of timber to biodiversity protection.

A new Forestry and Conservation project for PNG, funded by donor agencies, is being designed to encourage monitoring of sustainable forest management and the promotion of decision-making on the part of land-owners to avoid “unsustainable” management (Filer and Sekhran 1998). The project includes a Conservation Trust Fund and possible strengthening of the Department of Environment and Conservation. Filer and Sekhran (1998) interpret the Trust Fund as a way to open the door to carbon offsets schemes that would provide payments to not clear land.

It would be unfortunate if this project is one in which “sustainability” monitoring, carbon offsets, and other policy strategies are seen as applying to single areas independent of a regional context. That is, the status of an area was not regarded as depending on that of other areas. This may satisfy a within-area version of the sustainable development requirement of “development that meets the needs of the present without compromising the ability of future generations to meet their own needs” (The World Commission on Environment and Development 1987). However, we see advantages in a regional or whole-country perspective on sustainability and planning (as in “regional sustainability”; Faith 1995a), and agree with Filer and Sekhran’s (1998) call for “fundamental changes to methods of determining the use of customary land” and an “integrated land use strategy” rather than simple non-integrated incentives schemes (see also Sekhran 1997).

Regional planning approaches for biodiversity and sustainability are timely. For example, WWF (2000) proposes a goal in PNG to: “redraw existing maps to identify areas where industrial logging would be inappropriate in terms of nationally or locally determined constraints such as biodiversity values, landscape sensitivity and community requests for alternative uses or conservation." Such efforts would fall also under the broad goals of the "ecosystem approach" to "seek a balance between biodiversity conservation and sustainable use of natural resources" (IUCN 2000a). Filer and Sekhran (1998) point out that, although PNG's conservation policy broadly is based on the goal of a representative system of reserves, "legal and institutional mechanisms…have proven to be unwieldy and ineffective" and that "biodiversity values are almost entirely confined to customary land, and there is no prospect of this land being alienated by the state for purposes of conservation". The recent report, "A future for our forests" (National Research Institute 2000; see also Hunt and Filer 2000) claims that "areas proposed for conservation reserves are routinely included in logging permits, as are areas of high biodiversity priority", suggesting that government controls may not always benefit biodiversity in any case.

Incentives approaches may not always work well in PNG (Filer and Sekhran 1998), but limitations to top-down controls suggest an ongoing role of well–targeted incentives based on regional planning. Incentives measures – broadly interpreted as any economic or legal instruments "designed to encourage beneficial activity" (UNEP 2000) - are seen as essential elements in any country's development of effective approaches to meeting its obligations under the Biodiversity Convention. IUCN (2000b) links these to the "eco-system approach", which seeks a balance, at national, regional and local levels, between biodiversity conservation and the use of resources. However, in spite of the theoretical work on incentives and biodiversity (e.g., OECD 1997), there has been concern about the low-level of response by countries to calls by

COP for case studies on incentives measures (UNEP 2000). This suggests that much work remains to be done on design and implementation of incentives.

UNEP (2000) outlines steps to implementing incentives programs, including attention to national biodiversity priorities and “valuation studies” to determine potential biodiversity benefits from incentives programs. There appears to be no link yet made between valuations of areas in their regional context and the principle of complementarity – the essence of the biodiversity value of an area in the regional context. The usual economic approaches to incentives (e.g., Young *et al.* 1996) all would seem to apply to any value inherent to an area, not depending on what is achieved in other areas. Yet the biodiversity value of an area depends on complementarity (Faith *et al.* 2001a,b), which is context sensitive, suggesting that special context-sensitive regional incentives methods are needed. This is an important, and often unrecognized, special feature of biodiversity. Many of the standard economic mechanisms that apply to area-specific biodiversity values can have a strong regional perspective when they are complementarity based. Theoretical examples describe incentives approaches (Faith 1997) where changing priorities on areas reflect changes in their complementarity values. We explore related environmental levies, subsidies, carbon offsets and biodiversity credits below, and suggest ways they might be useful in PNG.

Environmental levies

The prospective use of environmental levies in PNG (Diwai 1998) provides an important potential mechanism for conservation. In a levies system, resource users provide funds that may be used to promote biodiversity protection either in the areas currently being exploited, or in other areas. Management agreements and covenants may not achieve permanent protection, and the use of levies in effect provides a regulatory function. This allows for a two-pronged approach of incentives/agreements when combined with regulatory constraints.

Here we propose an initial framework for determining levies based on biodiversity contributions (see also Faith *et al.* 1999). We also provide a framework for ongoing decision support. Proposed levies depend on the biodiversity loss that an area may suffer when its status is changed and this in turn depends on the context – what else is protected.

As a first step, a levies system may be proposed for the period preceding implementation of biodiversity protected areas. For those areas that are "must-haves" if the biodiversity target is to be met (Faith *et al.* 2001a,b), the levy may be set so high that forestry production is excluded. An "infinite levy" may be assigned to any nominated priority areas in order to "close the door" on prescribed forms of forestry production. The 'ransom" effect (Filer and Sekhran 1998), in which forestry remains a threat, might be reduced under this strategy.

Why not assign all members of the proposed set (Fig. 2 in Faith *et al.* 2001b) a very high levy from the outset? The reason is that substitute areas exist for many of the nominated priority areas – a very high levy would unfairly foreclose landowner decisions in some cases to allow logging. A system of levies is needed that does not assume that the current best set is exactly the one that will be implemented. We use the probabilistic framework illustrated above (Fig. 1; see also Faith and Walker 1996a,b) with variations in target persistence probabilities, variations in the base probabilities of persistence and variations in probabilities of persistence in areas formally protected. Other partial protection probabilities could be introduced as well.

In the maps in Figure 2, low to high levies are indicated by green, brown, blue, red, turquoise. This order reflects a constant scale over all maps. Turquoise areas are those that would imply a very high loss in biodiversity protection under the simple levies model outlined here. In the model for Figure 2a, it is assumed optimistically that biodiversity attributes in all areas, in the absence of any land use changes, currently have a 0.50 probability of persistence, over N generations. This is the base or current probability of persistence. The overall regional target for any biodiversity attribute is taken to be a 0.99 probability of persistence. Relative to this target, the actual realized regional probabilities of persistence are simple functions of the probabilities for individual areas (Faith and Walker 1996a,b). In the simplest case, the regional probability of persistence of an attribute is one minus its regional probability of extinction, equal to the product of extinction probabilities for individual areas. The regional probability of persistence over all attributes is one minus the product of regional extinction probabilities over individual attributes.

The complementarity value of an area at any stage is calculated as the total loss in regional persistence of that area’s biodiversity attributes that would occur if that particular area (in this example) made a 0.00 probability contribution to the persistence of its constituent attributes. Levy values are then a function of these complementarity values. In Figure 2b, the current (base) probability of persistence is

0.20 and in Figure 2c the current probability is just 0.1. Note how in Fig. 2b followed by 2c, the levies for many areas increase in magnitude. In Figure 2d, the areas that are must-haves (Faith *et al*. 2001a,b) are also assigned the highest levy. These areas did not necessarily have high complementarity, but would have non-zero complementarity even if all other areas were protected to a high degree of persistence, reflecting the fact that each area has one or more attributes found only in that area. More generally, a highest possible levy may be assigned to an area when a low probability of persistence for its attributes would imply that one or more of those attributes was now below some minimum threshold value in its overall regional persistence probability.

The levies system shares with the probabilistic reserve selection algorithm (Fig. 1) the property that geographically extensive attributes require less additional protection (unless they are assigned smaller base probabilities). A novel property of the levies framework proposed here is that the levy associated with an area changes over time to reflect changes in the degree to which the contribution the area makes to achieving the biodiversity goal complements other areas in the region. If areas within the proposed priority set are given up to logging, other areas may become “must-haves” and acquire the highest biodiversity levy.

This system does not assume at this stage that the proposed set of biodiversity priority areas is actually protected. When a stage is reached where the priority set (or a modification of it) is regarded as well-protected and the biodiversity representation target is met, the levies would be re-calculated taking this into account. If a set of protected areas is implemented that reaches an agreed target, then the levies based on that target drop dramatically, reflecting the lower complementarity values that arise when formal protection implies (say) an assumed 0.90 probability of persistence (Fig. 2e).

The system of levies from the outset may have been those defined under the higher 15%-based target (Fig. 2f). These complementarity values (for a base persistence of 0.10 and a 0.999 target persistence) were those used above for assessing congruence with the areas previously identified by experts as conservation priority areas (see below). The levies are higher, even when the proposed 10%-based set is protected, if the number of attributes is taken to be that defined by the 15%-based target (Fig. 2g). We return to that scenario below in discussing subsidies for "eco-forestry" and carbon offsets.

Subsidies for small-scale forestry

A recent report (WWF 2000) notes that forest policies in PNG have focused almost exclusively on large-scale industrial logging while the small-scale forestry sector has long been overlooked. The report calls on the Government to support small-scale forestry, from which landowners, it is argued, can obtain greater cash benefits compared with large-scale industrial logging.

Such small scale forestry is a form of "eco-forestry" because it can avoid industrial logging and agricultural impacts. The WWF report claims that sustainability gains are made in areas where eco-forestry is established. But how does this relate to "regional sustainability"? There appears to be little work on how biodiversity protection arising from subsidized eco-forestry can be placed within a broad regional or whole-country framework. Both the regional notion of biodiversity values and the need for subsidies (and consequent importance of donor agencies) argue for a regional perspective for maximum effect. Recent work in PNG on subsidies for eco-forestry (Salafsky 2000) has no apparent overall regional perspective.

We suggest that biodiversity and other benefits from eco-forestry will be greatest if linked to the sorts of complementarity based planning methods explored in our PNG study. One possibility is that our priority areas be priority candidates for some eco-forestry within their boundaries. This may be appropriate given the large size of some of the map units identified as priority areas, allowing for the possibility for a range of management strategies to be implemented within them.

A critical issue is whether biodiversity protection provided from eco-forestry is permanent. If subsidies are needed only to get started, and economic benefits then flow continuously, the ransom effect referred to earlier would be reduced and protection for biodiversity would persist. Otherwise (perhaps in any case) one may view protection as providing no guarantee of long-term status, and so see eco-forestry as complementary, not directly contributing, to a central biodiversity goal of 10%- or 15%-based targets.

We can link the role for eco-forestry to complementarities and probabilities of persistence. Eco-forestry may not contribute to the crediting of progress towards the 10%-based target, but used to extend biodiversity protection beyond that level. We would give high priority funding to eco-forestry in those areas that would imply a large loss of representativeness/persistence if their persistence level were to go from some base level to zero. These would correspond to the same areas that would be assigned a high levy (Fig. 2) for logging or other uses.

We can also look at this problem less as concern about loss of current biodiversity protection and more positively as identification of areas where eco-forestry would contribute well to increased biodiversity protection. High priority areas then will be those that have a high complementarity differential when assigned a persistence probability gained through eco-forestry, as compared to a scenario where the area had 0.0 probability persistence of its biodiversity under more intense logging or land clearance. A map of a set of such preferred areas would be produced in a way similar to that in Figure 1 (the selection of priority areas providing not 0.90 probability of persistence but some smaller value), with up-dating as areas were acquired for eco-forestry, so contributing more to overall biodiversity protection.

A priority set of areas for eco-forestry funding may take "timber costs" (Fig. 1a in Faith *et al.* 2001b) into account in addition to biodiversity contributions. But areas would be assigned a *high* priority if those "costs" were high, because those costs reflect forestry opportunities to be captured by eco-forestry. The set of priority areas would be the one that achieves a nominated level of biodiversity representation/persistence with a maximum timber-volume-based estimate of forestry production opportunity. Thus, timber volume values would not then be an opportunity cost but an opportunity benefit, given that they represent the economic gain made by eco-forestry programs, assuming that eco-forestry can match the gains provided normally by industrial logging (WWF 2000).

Carbon offsets

The 1997 Kyoto Protocol to the United Nations Framework Convention on Climate Change set targets for reductions in emissions of greenhouse gases, and the Kyoto Protocol "mechanisms" include the Clean Development Mechanism, which is linked to carbon offsets strategies. A carbon offset is a payment that leads to a reduction of carbon emissions so as to offset other carbon emissions. Carbon sequestration by forests is one aspect of such offsets and was considered as a benefit in recent proposals in PNG for conversion of areas currently designated for logging to permanent conservation (Hunt and Filer 2000).

Conservation of biodiversity requires resources, including resources from overseas. It would seem to follow then that directing carbon offset funding to areas that could serve not only carbon sequestration but also protection of biodiversity would be an effective use of limited resources. Carbon offsets guidelines (refs) indeed call for "collateral benefits" of biodiversity protection. But benefits of carbon offsets sometimes exclude the "option values" of biodiversity simply because they cannot be put into dollar values (e.g., Kremen *et al.* 2000). Complementarity calculations overcome that problem.

In principle, any of PNG's areas might be nominated for carbon offsets – either achieving protection of one of the biodiversity priority areas or subsidizing eco-forestry in an area that is not in the priority set. However, we see advantages in approaches (see also Faith *et al.* 1999) that are integrated over the entire country.

These strategies for identifying offsets are based on the links between biodiversity complementarity values, regional planning, and carbon offset funding.

Our current best set of priority areas (Faith *et al.* 2001b) might be judged as suitable for carbon offsets funding in that they provide carbon sequestration combined with a high level of biodiversity protection. That funding in practice might feed into a larger trust fund for implementing protected status for these areas. One potential barrier to such a strategy is that criteria for permissible carbon offsets programs appear to exclude projects that are not “additional” to other efforts. However, offsets projects in Costa Rica may provide a precedent where areas previously nominated as national parks were apparently deemed appropriate for offsets, as no other funding for actual park establishment had been identified.

One way to strengthen the degree of “additionality” may be to regard those particular areas from the priority set that have high forestry opportunity (Fig. 1a in Faith *et al.* 2001b) as particularly appropriate for offset funding. Given the realities of land-owner decision-making powers in PNG, logging often will be the land use selected by land owners even when high biodiversity values are present (for discussion see Filer and Sekhran 1998). Offsets funding therefore satisfies the additionality criterion for such areas.

The carbon offset funding tied to those priority areas having high forestry opportunity might be married with the infinite levy discussed above. These funds could provide ongoing compensation to owners. This strategy would avoid the transient biodiversity protection (and transient carbon sequestration) that would be associated with "ransom" payments (referred to above).

Carbon offsets funding may be justified in another way that could also assist the implementation of the biodiversity priority set. Among all sets of areas that achieve the biodiversity target, this one has a larger total area (about 16.8% of the country) in order to minimize conflict with forestry opportunities. A set with smaller total area might well imply greater forgone forestry opportunities. But the larger set does have an additional cost related to the greater amount of compensation and so on for land owners (where total compensation reflects amount of land rather than forestry opportunities). Carbon offsets funding could make up the extra funding needed to implement the strategy that allows for greater net benefits. The amount of funding, reflecting additionality, would be roughly proportional to the extra total protected area needed to implement the net benefits solution.

It may be desirable to initiate a carbon offset, which is additional to the entire protected areas program, if that program is assumed to be already separately funded by a conservation trust fund (however unlikely that would ever be). Targeted areas may still be those that are expected to make biodiversity contributions, but they reflect biodiversity targets greater than those of the current proposed program. Offset funding might be applied to those additional "must-have" areas (Fig. 5 in Faith *et al.* 2001a) that correspond to the higher 15%-based attributes, together with those (see Figure 2f,g), that have a high complementarity value even when the proposed set is assumed protected.

A more extreme view of offsets as essentially additional to other programs is to regard those areas having *high* forestry opportunity and *low* biodiversity complementarity as the strong candidates for offsets. In figure 3, black areas have “zero” contribution to biodiversity (in the context of the nominated 10%-level target) if other areas are assumed protected. At the same time, these areas fall into the top two classes for timber volume (Fig. 1a in Faith *et al.* 2001b). Offset strategies, in response to landowner’s wishes, that exclude logging in these areas (perhaps using the same exclusion mechanisms as for biodiversity priority areas) clearly can be justified as above-and-beyond the priority set programs for biodiversity.

A variation on this approach would expand forest opportunities in the above strategy to include any areas vulnerable to land clearance (see also Pressey 1997). This may be modeled in PNG through PNGRIS information about land use suitabilities.

Under these schemes, there might be an incentive, in the PNG case, for the environment department (OEC) to help achieve true protection of the proposed priority set in order to establish the low complementarity values for these other areas and so open them up to offsets. In a similar vein, PNGFA has an incentive to encourage establishment of formal protection of the proposed biodiversity priority set in order to reduce biodiversity levies in remaining areas attractive for logging.

In summary, the application of carbon offsets to the proposed priority set has appeal in providing “collateral” benefits and may be inexpensive in conjunction with a trust fund. But it may be more difficult to justify with respect to “additionality”. The possibility of biodiversity gains down the track may increase this additionality while maintaining collateral benefits. At the extreme, application to areas highly suitable for logging but not providing biodiversity gains may maximize additionality but without much “collateral” gain beyond that implied by alignment with land owners’ wishes. The Lak experience (see Stuart and Sekhran 1996) in trying to implement a form of carbon swap illustrated how landowners may not wish to forgo other benefits, and may change their minds at any time down the track. That problem may again argue for the top-down levies associated with the nomination of protected areas. A weakness of many of these proposals is that there may be “leakage”; land clearance may happen at a greater pace at alternative locations.

Biodiversity offsets

A biodiversity offset amounts to a payment to support protection of biodiversity in a designated area. Clearly, the calculus of carbon offsets (see also Faith *et al.* 1999) is relevant also to this problem, with a focus on biodiversity as a principal rather than a collateral benefit. As was the case for environmental levies, the magnitude of the complementarity value of an area determines the payment required (for example, based on complementarity values calculated as in Figure 2). While an environmental levy is a mechanism for providing permission for land uses in that same area, the biodiversity offset payment compensates for permission to use other areas. We noted that the levy payment changes as the complementarity of the area changes. What happens to a biodiversity offset payment for an area? If these offsets are based on ongoing payments (say, year to year), then the payment surely must increase if the complementarity increases. But a danger then is that areas requiring higher payments may be abandoned.

Another, more likely, framework for such biodiversity offsets is that a large one-off offset payment is made, akin to a purchase of the land, for its protection for the foreseeable future. Scenarios where the complementarity of the area increases or decreases then have interesting implications. When the complementarity value goes up (say, because similar areas in the region are cleared for non-protective land uses), the value of the biodiversity protected through the offset payment goes up. That means that the offset credits are higher, and so the area could now attract a larger payment. The offsets may be sold-on for a higher price. As an investment strategy, an area that will show an increase in complementarity is sound, while one showing a decrease is less advantageous. Thus, areas that contain unique biodiversity attributes and/or contain attributes that are under threat elsewhere in the region, point to good biodiversity "futures" investments.

EVALUATION AND IMPROVEMENT OF BIODIVERSITY SURROGATES

Biodiversity credits strategies, such as that proposed above, will require good biodiversity surrogate information for the calculation of complementarity. During workshops and other discussions in the course of the PNG study, it was often suggested that a previous study, the Conservation Needs Assessment (CNA; Alcorn 1993; Beehler 1993) might have provided a useful "test" of biodiversity surrogates, if the CNA areas had not been used as a preference in the area selection process to identify the current best set of biodiversity priority areas. In other words, the extent to which CNA areas overlapped with areas chosen using the methods employed for the present study (Faith *et al*. 2001b) would indicate how well the surrogates we used matched 'expert opinion'. How should such an evaluation be carried out? We cannot simply compare the two using a new set of priority areas that achieves the same target level of representation as achieved in the present study but without using the CNA areas as preferences. Differences between that set and the CNA areas might variously reflect the fact that the selected set is one of many that could have been selected to met the target, that it is different simply because it deals with costs and constraints, that it is different because a different target level of representation was chosen from the (implicit) CNA one, and so on.

The evaluation and comparison of biodiversity surrogates focuses on the prediction of the complementarity values we would find if we could measure all of biodiversity (Faith 1996; Faith and Walker 1996d; Faith *et al.* 2001a). Two kinds of errors, analogous to type 1 and type 2 errors in hypothesis testing, can be made by predictions of complementarity based on surrogates. High complementarity may be observed when in fact complementarity over the components to be predicted (e.g., all of biodiversity) is low (call that error “type 1”). Alternatively, low complementarity may be observed when in fact actual complementarity is high (call that error “type 2”). Clearly both errors matter, and the context may determine which is most important. The use of trade-offs approaches as in our PNG BioRap study may mean that high complementarity areas are protected and low complementarity areas assigned to other land uses. A precautionary approach to biodiversity conservation would suggest that avoiding type 2 errors is critical.

To carry out such an evaluation of predicted complementarity for our surrogate data, we ideally would simulate many protected sets and generate many complementarity values for evaluation. Instead, as a simple alternative, we use an existing PNG analysis (Faith *et al.* 1999) in which complementarity values were calculated for all areas based on our surrogate data, in order to estimate values for proposed environmental levies. Figure 4 shows one of these analyses. As in our earlier applications of persistence probabilities, the complementarity of an area is the amount it contributes to overall biodiversity persistence. In this case, any occurrence of an attribute is assumed to contribute a 0.10 probability of persistence in the area in which it occurs, and the target is a 0.999 probability of persistence of all surrogates defined at the 15% level of heterogeneity (discussed above). Areas with high complementarity will be those with many attributes that are not represented in many other areas.

Do these areas, as "complementarity hotspots" (sensu Faith and Walker 1996d), correspond to the hotspots identified as CNA priority one areas? Figure 4a shows the map of all the highest complementarity areas ("complementarity hotspots") that fall within the CNA areas, while Figure 4b shows all of the highest complementarity areas that fall outside the CNA priority one areas. Figure 4c shows the map of the lowest complementarity areas ("complementarity coldspots") that fall outside the CNA areas, while Figure 4d shows the lowest complementarity areas that fall within the CNA areas.

Complementarity hotspots based on our PNG data fall within most CNA areas, but the degree of overlap is not different from that expected by chance. A total of 78 CNA areas fall within the 267 complementarity hotspots (29%) and 1163 CNA areas fall within all 4719 areas (25%) for PNG.

Complementarity coldspots based on our PNG data fall outside most CNA areas, but the degree of overlap with non-CNA areas is not different from that expected by chance. A total of 2062 non-CNA areas fall within the 2579 complementarity coldspots (80%) and 3556 non-CNA areas fall within all 4719 areas (75%) for PNG.

An important aspect of these comparisons should be noted. The CNA priority one areas were not defined taking complementarity into account. Thus, the "expert opinion" captured by the CNA process does not indicate how well one area is expected to complement another. The CNA priority one areas are therefore probably not an efficient way to represent biodiversity. Our strategy of using surrogates in a trade-offs framework and ensuring where possible that we also sample CNA priority one areas seems to be a sound strategy that builds on the CNA work.

Our comparisons here were based on a simplified version of the predicting complementarity approach. Proper comparisons of complementarity values for different surrogates, for a range of geographic regions, will be reported elsewhere (Faith, Oliver and Williams in prep). The "predicting complementarity" evaluation of surrogates is now implemented in the WORLDMAP software (Williams 2000).

Better use of Museum data

Inclusion or exclusion of the modeled species data (Faith *et al.* 2001a,b) as part of the total set of PNG surrogates for biodiversity had little effect on the results of our study. The reason probably was that the final 10 classes of species bio-climatic profile types each had such a broad range that they were represented as a matter of course in seeking any representation of all the other more restricted biodiversity surrogate attributes. Future work needs to consider more effective ways to integrate species data from museum/herbarium collections into the surrogate information used for broad-scale conservation planning. The primary problem with such data will continue to be the lack of comprehensive sampling over all areas (Margules and Austin 1994). Modeling species distributions using the same environmental data that contributes to the biodiversity surrogates may remove any independent signal the two sets could provide. Further, the set of modeled species may give undue weight to those taxa that happen to be numerous in the set. It would be better to somehow model all the species as a multivariate set, for example using constrained ordination models (Faith and Walker 1996d,e). In fact, such an approach is compatible with the conclusion (discussed in Faith *et al.* 2001a) that a continuous pattern for surrogates is more appropriate in setting and adjusting biodiversity goals than fixed classes. Complementarity can be calculated for an ordination space as the incremental gain in the representation of that space (e.g., using the p-median criterion as in the "ED" measure of Faith and Walker (1996e). The environmental data in effect fill in the gaps in the species data, while the species data in effect scale the environmental variation to make it more meaningful to turnover in biodiversity. A research problem is how to improve on constrained ordination methods to make them more robust to missing values in species collection data (Faith and Walker 1996d). An advantage of such a framework is that it will feed in to future work on "biodiversity viability analysis" (discussed above).

The other major gap in our use of biotic surrogate data concerns the historical biogeographic component. Concerns about this aspect prompted us to avoid using single species models to predict species occurrences and then use that information as a biodiversity surrogate. Two different biogeographic regions might appear the same in terms of our abiotic descriptors. This problem became apparent when we searched for substitute areas for logged-over areas of New Britain. Some of the substitute areas were on the main island, and the question remains as to whether these substitutes really would capture the same components of biodiversity. An example of the potential contrast between biodiversity complementarity values reflecting present day habitat versus historical processes is found in Moritz and Faith (1998). In that study, phylogenetically-based complementarities were calculated using a different module of DIVERSITY, also included within the BioRap toolbox. Future work should explore these and other ways to capture biodiversity patterns emerging from historical processes. Such new biodiversity information will be part of any ongoing refinement of the current best set of priority areas for PNG.

It is encouraging that PNG is now listed among the priority tropical wilderness areas for conservation as part of the "Critical Ecosystems" Program (Mittermeier *et al*. 1999; Myers *et al*. 2000). The strong focus of that program on acquisition of species-based data will provide opportunities to refine the biodiversity surrogates information used in future BioRap conservation planning for PNG.

DISCUSSION

Hunt and Filer (2000) have summarized the policy recommendations from a recent conference held in Port Moresby, PNG, called “Forest Policy for the New Millennium”. Their report highlights the fact that presently “there is no national biodiversity conservation plan to guide the Government, NGOs, landowners, or donor agencies in decision making.” The policy recommendations call for more transparent decision making at the national level, and funding to establish links to “connect local communities with regional, national, and international biodiversity conservation strategies.” Funding would provide incentives to landowners to opt for eco-forestry and conservation rather than large-scale commercial logging. The report notes that the financial costs of replacing logging with conservation would be substantial, including not just forgone royalties to landowners but loss of taxes and revenues to the government. Those needs appear to make the approach advocated in this study quite compelling. Regional sustainability – a balance between conflicting objectives for society – is achieved at two levels in our study. First, our planning approach minimizes forgone timber opportunities for a given biodiversity protection level. Second, the analysis framework facilitates eco-forestry as potentially replacing intensive logging, so that even those areas producing logging income contribute as well to biodiversity protection. More generally, the framework provides a way of targeting incentives expenditures for maximum net benefits.

All these processes depend on complementarity. Returning to the theme of prospects for biodiversity planning in general, our PNG study suggests that “systematic conservation planning” need no longer be restricted to methods for finding sets of areas. Using the calculus of complementarity in decision-making, there may be no protected *set* because degree of protection (persistence) occurs along a continuum.

Further, high complementarity of an area need not simply imply priority for protection but also, or instead, that the area is a target for levies, offsets, or other incentives mechanisms.

Complementarity itself is no longer just a measure of marginal biodiversity gain (not even in the broad pattern sense of Faith and Walker 1996d). We have illustrated how it can reflect, in an integrated calculus, the marginal gain in degree of expected persistence of biodiversity.

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Table 1. Probabilities of extinction under different protection scenarios. Bold extinction probabilities contrast a scenario reflecting logging threat (a) with a scenarios (b) and (c) reflecting logging opportunity.

Species	a	b	c	d	e	product of probabilities
a)						
current probability of extinction	.5	.5	.5	**.9**	**.9**	.0506
probabilities when area I is protected	.1	.1	.1	**.9**	**.9**	.0008
probabilities when area II is protected	.5	.5	.5	.1	.1	.0006
b)						
alternative initial probabilities of extinction	.5	.5	.5	**.5**	**.5**	.0155
alternative probabilities when area I is protected	.1	.1	.1	**.5**	**.5**	.0003
alternative probabilities when area II is protected	.5	.5	.5	.1	.1	.0006
c)						
alternative initial probabilities of extinction	.5	.5	.5	.5	.5	.0155
alternative probabilities when area I is protected, area II logged	.1	.1	.1	.9	.9	.0008
alternative probabilities when area II is protected, area I logged	.9	.9	.9	.1	.1	.0073

FIGURE LEGENDS

Figure 1.
The biodiversity components in each polygon have a notional 50% probability of persistence prior to any change in protected status, and a 90% probability if protected, while the regional goal for all attributes is 99% probability of persistence. The orange areas on the map are the set of areas that reach that regional persistence target while minimizing "timber volume" cost.

Figure 2. Low to high levies are indicated by green, brown, blue, red, turquoise. Cutoffs in complementarity values between colours are arbitrary but consistent over all maps.
a) a 0.990 probability of persistence goal for all attributes, with 0.50 current probability of persistence
b) a 0.990 probability of persistence goal for all attributes, with 0.20 current probability of persistence
c) a 0.990 probability of persistence goal for all attributes, with 0.10 current probability of persistence
d) a 0.990 probability of persistence goal for all attributes, with 0.10 current probability of persistence, and must-haves for 10%-based target also assigned highest levy
e) a 0.990 probability of persistence goal for all attributes, with 0.10 current probability of persistence, and assuming 0.90 probability of persistence for proposed protected set for the 10%-based target. Proposed areas are coloured grey and a levy is not calculated for these in this example.
f) analysis for a 15%-based target, assuming a 0.999 probability of persistence goal for all attributes, with 0.10 current probability of persistence, and must-haves also assigned highest levy
g) analysis for a 15%-based target, assuming a 0.999 probability of persistence goal for all attributes, with 0.10 current probability of persistence and assuming 0.90 probability of persistence for proposed protected set for the 10%-based target. Proposed areas are coloured grey and a levy is not calculated for these in this example.

Figure 3.
A strategy in which areas having high forestry opportunity and low biodiversity complementarity are strong candidates for offsets. Black areas have "zero" contribution to biodiversity if other areas are assumed protected, and also fall into the top two classes for timber volume.

Figure 4.
The complementarity of an area in these maps is the amount it contributes to overall biodiversity persistence. "High" as compared to "low" complementarity for these maps is based on arbitrary cut-offs along the continuum of values. For further information see text.
a) high complementarity areas (orange) that fall within the CNA priority one areas (green and orange).
b) high complementarity areas (orange) that fall outside the CNA priority one areas (green).

c) low complementarity areas (blue) that fall outside the CNA priority one areas (green).
d) low complementarity areas (blue) that fall within the CNA priority one areas (blue and green).

FIGURE 1

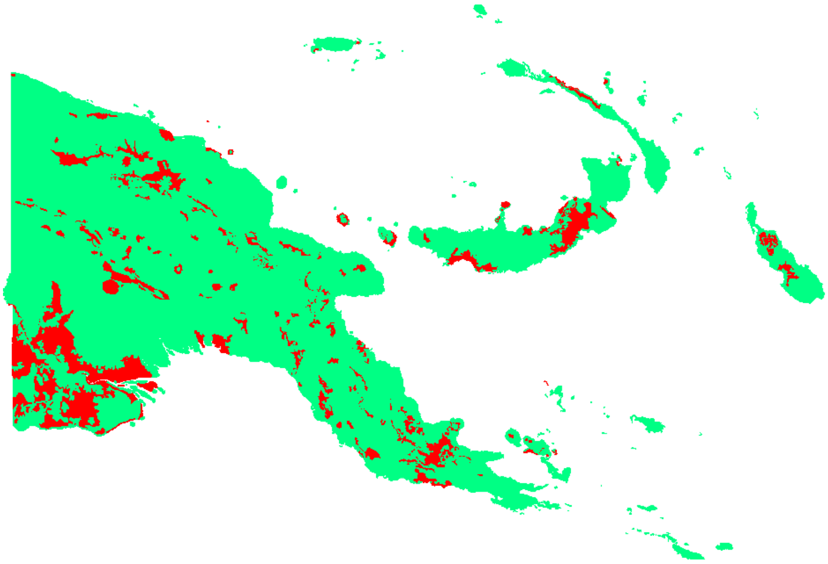
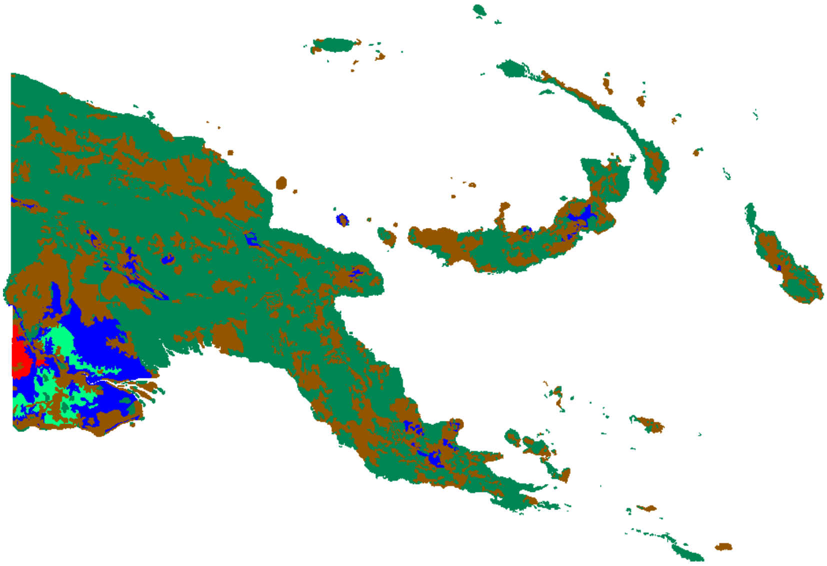


FIGURE 2



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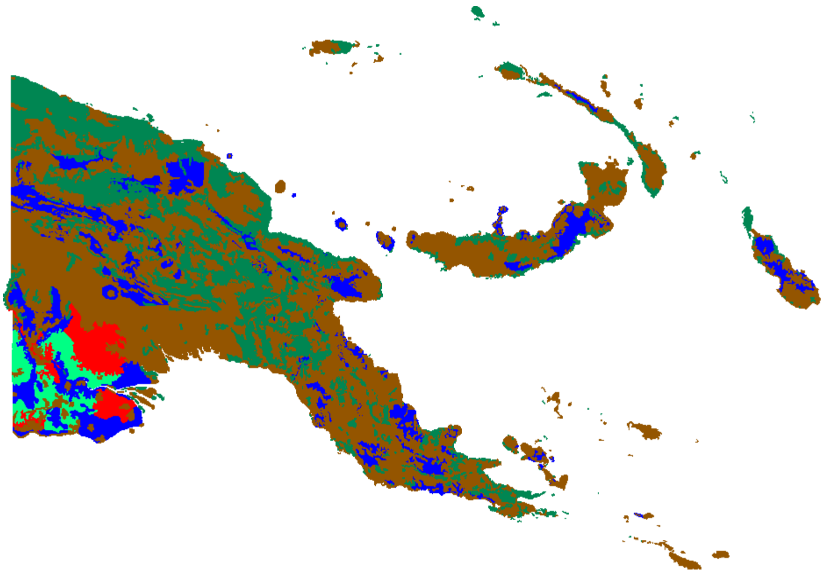

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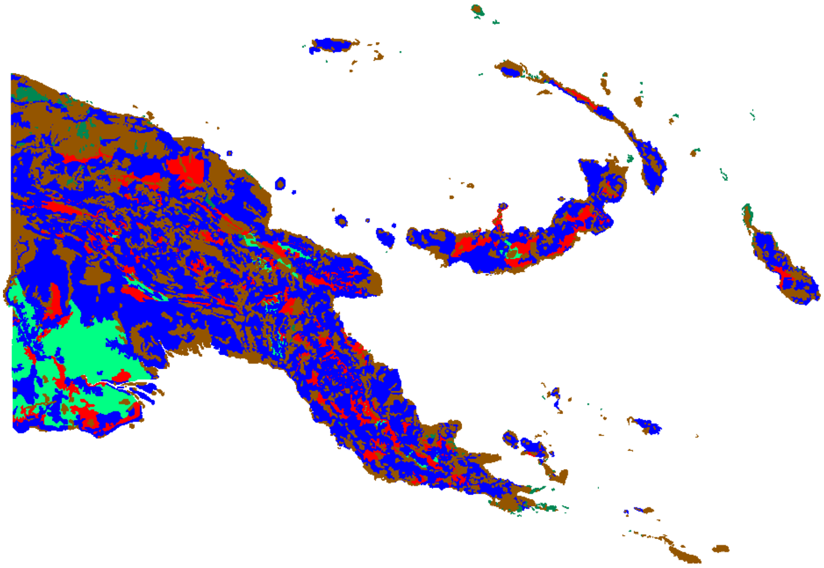

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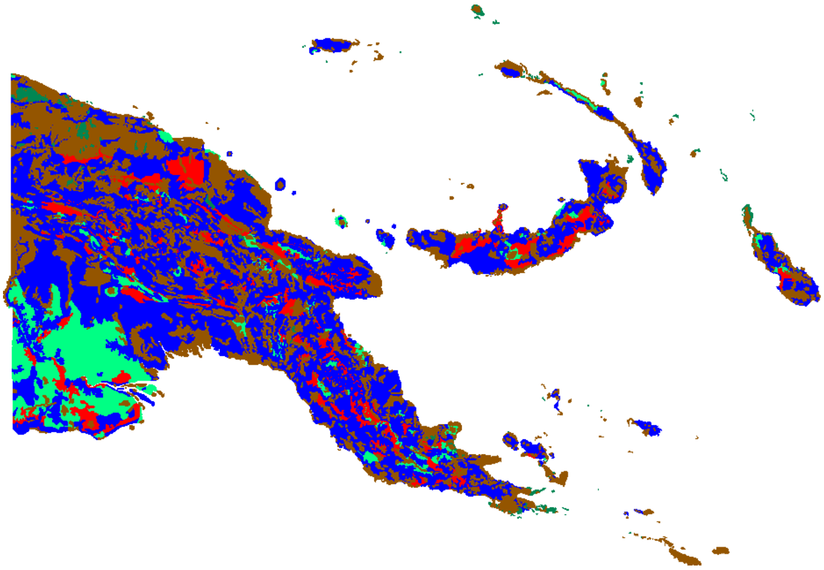

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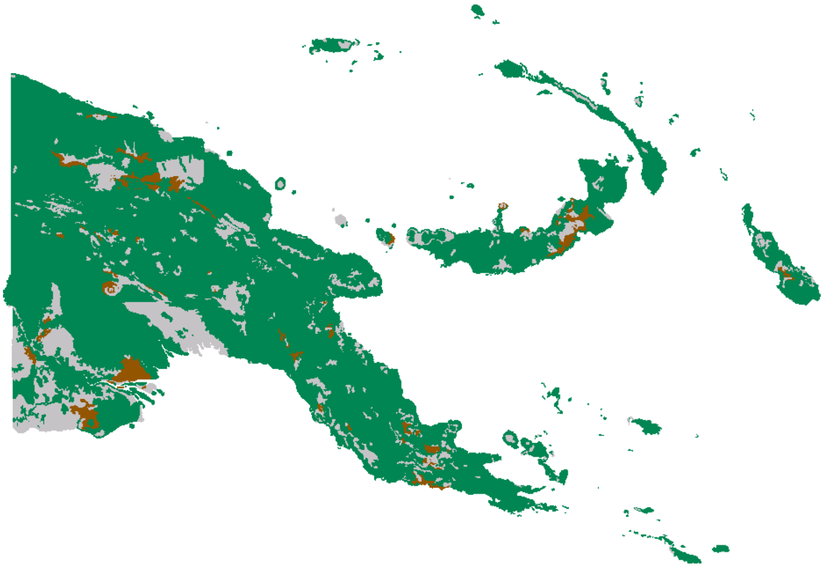

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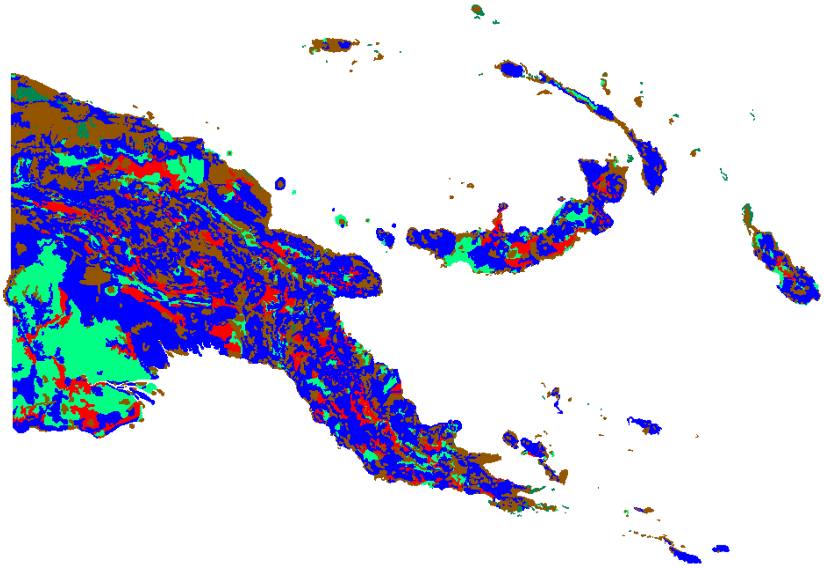

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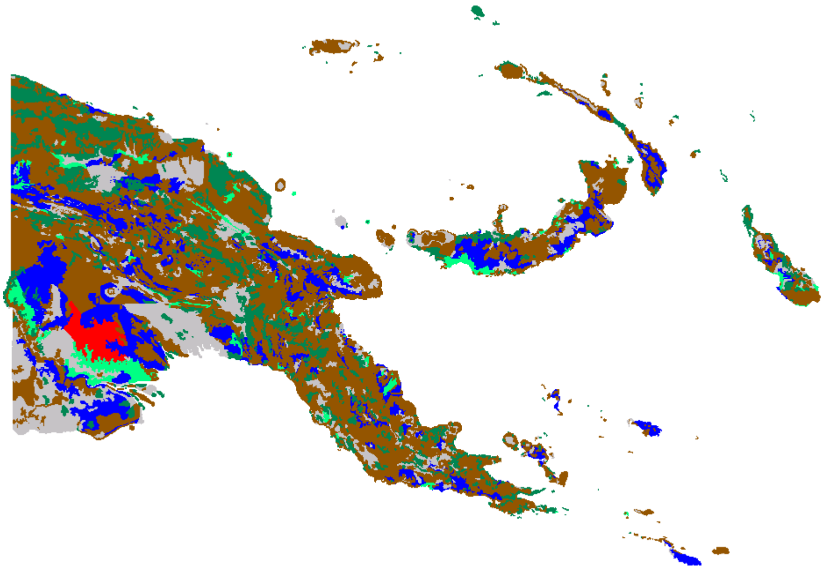
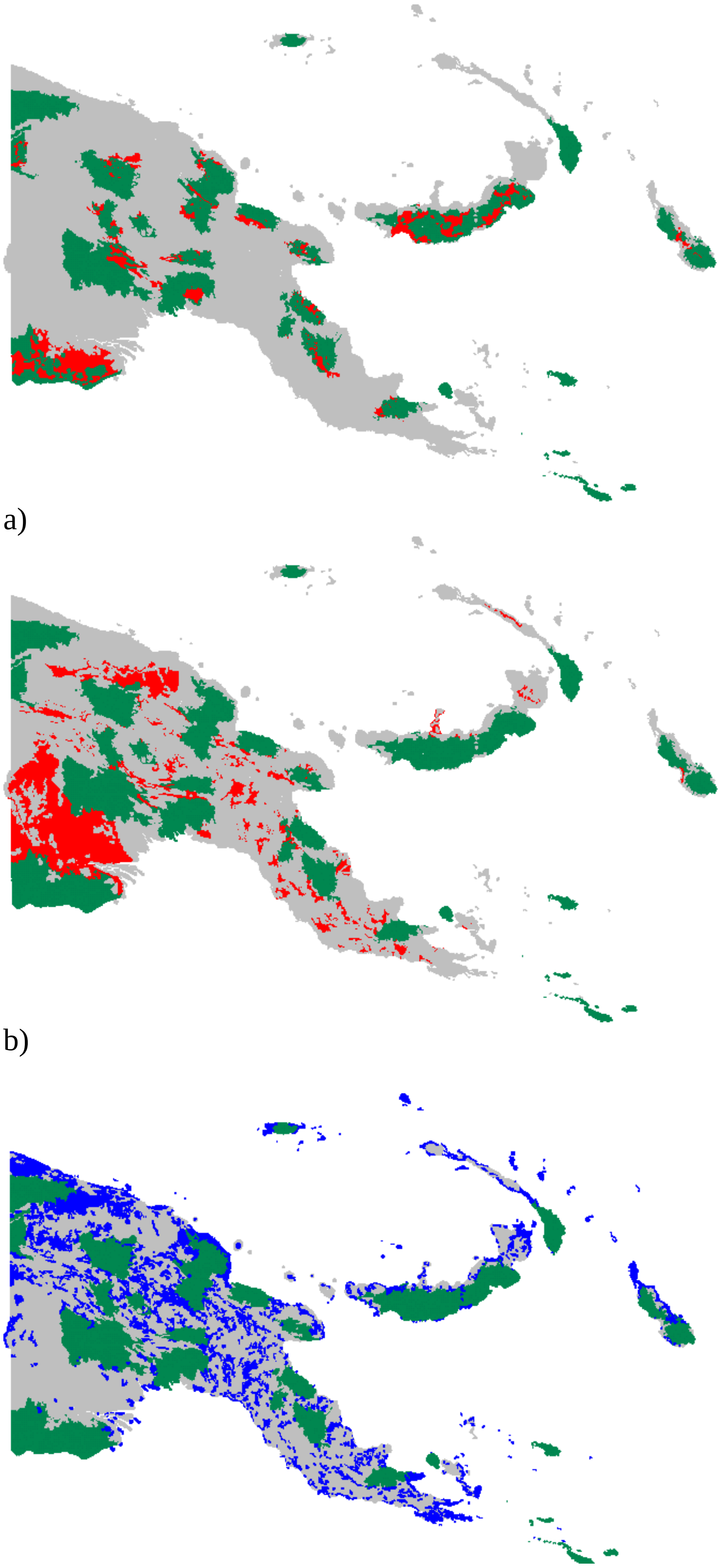


g)

FIGURE 3

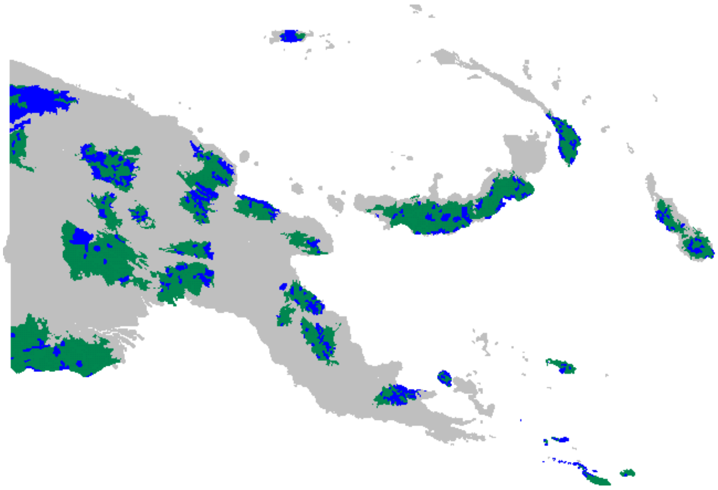
FIGURE 4



a)

b)

c)



d)