

Scheduling incremental actions to build a comprehensive national protected area network for Papua New Guinea

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Abstract

Systematic conservation planning identifies priority areas to cost-effectively meet conservation targets. Yet, these tools rarely guide wholesale declaration of reserve systems in a single time step due to financial and implementation constraints. Rather, incremental scheduling of actions to progressively build reserve networks is required. To ensure this incremental action is guided by the original plan, and thus builds a reserve network that meets all conservation targets, strategic scheduling, and iterative planning is needed. We explore the issue of scheduling conservation actions using the national scale conservation plan for Papua New Guinea (PNG), commissioned by the PNG Conservation and Environment Protection Authority that identifies a comprehensive set of priority areas that meet conservation targets in both the land and sea. As part of the planning process a subset of areas were identified in collaboration as priorities for immediate action—termed areas of interest (AOIs). However, the extent to which targets are met if action stopped after implementing the AOIs is unknown. We test three possible implementation scenarios based on these priority areas to measure target achievement and shortfalls. We then consider how iterative planning would interact with scheduling actions to identify new long-term priorities that will meet missing targets. Our results show that while a large number of conservation targets are met within the AOIs there are shortfalls for protecting threatened and range restricted endemic species. Meeting targets for these would require an updated set of national priorities and an additional 13% of land area compared with if all areas identified in the original assessment were protected in a single time step. This provides important insights into the benefits of strategic scheduling of implementation, as well as the need for capacity to monitor action and update priorities as implementation proceeds.

KEYWORDS

implementation planning, land-sea connectivity, land-sea planning, marxan, systematic conservation planning

1 | INTRODUCTION

Papua New Guinea (PNG) occupies part of the island of New Guinea and 600 islands and atolls off its coast in the Southwest Pacific Ocean. It is home to the third largest tropical rainforest in the world, as well as swamps, lagoons, savannah grasslands, rivers, and deltas (Government of Papua New Guinea, 2009). The main island of New Guinea supports an estimated 5–9% of the world's terrestrial biodiversity in less than 1% of the land area (Bryan & Shearman, 2015). Similarly, the marine environment of PNG is highly diverse and productive; PNG waters are considered part of the Coral Triangle, the area of the world's highest known marine biological diversity. Between 1972 and 2002, 24% of the rainforests in PNG were lost due to logging and land clearing activities (Shearman et al., 2008). While clearing rates have declined since then, habitat loss, perpetuated by inadequate logging policies, is still a major threat to PNG's terrestrial species (Bryan & Shearman, 2015). Land conversion also results in pollutants into water ways and increased run-off that can cause widespread degradation of coral reef habitats, reducing species richness and reef habitat complexity (De'ath, Fabricius, Sweatman, & Puotinen, 2012).

Protected areas are a key conservation strategy to retain habitat and address threats such as land clearing and overfishing. However, only ~4% of land and 2% of sea are protected in PNG. In order to address this issue and meet its conservation commitments, the PNG government recently commissioned a national land-sea conservation assessment (Adams et al., 2016). The assessment identified priority areas that would increase the level of protection of the country's land and sea to a level in line with Aichi Target 11 of the Convention on Biological Diversity, which aimed to protect at least 17% of terrestrial and inland water, and 10% of coastal and marine areas, by 2020 (CBD, 2010).

Ideally, protection of all areas identified in the land-sea conservation plan would be implemented immediately. However, many factors can affect the timing and feasibility of protection such as acquisition or management costs, engaging with local communities, degradation of identified habitat, conflicts of interest (e.g., mining), and political will (McBride, Wilson,

Bode, & Possingham, 2007; Pressey, Mills, Weeks, & Day, 2013). The land-sea conservation assessment identified vast areas of PNG for protection (~20% of land and sea) making it impractical and perhaps impossible to fully implement in a short period of time. Instead, implementation of areas will occur in a step-wise fashion over a period of time. Therefore, scheduling conservation actions is important to ensure that these incremental increases in protection of land over time still result in a network that meets conservation objectives, such as representation of habitats and ecoregions within reserve networks (Pressey, Cabeza, Watts, Cowling, & Wilson, 2007).

Approaches to scheduling incremental conservation action generally fall under two approaches: (1) prioritizing areas that are under greatest threat of loss (Margules & Pressey, 2000) or (2) prioritizing areas where the greatest opportunity to act exists (Knight, Cowling, Difford, & Campbell, 2010; Knight, Sarkar, Smith, Strange, & Wilson, 2011; Moon et al., 2014; Sacre, Bode, Weeks, & Pressey, 2019). Funding cycles often influence scheduling of actions. Even with well-planned incremental implementation, there are risks that progress may halt along the way such that conservation objectives are not met. For example, as governments change so do their priorities, which may cause certain policies to be removed or defunded. Thus, it is critical to know the extent to which different schedules of action may achieve conservation targets if progress is halted at varying stages. Furthermore, scheduling actions will inherently require updated spatial priorities as actions are taken which may deviate from the initial plan and as human dominated and natural landscapes change (Pressey et al., 2013).

We explore these issues of incremental implementation in the context of PNG and the national conservation plan (Adams et al., 2016). We first describe the collaborative approach taken to identifying a subset of the national priorities for immediate action—termed areas of interest (AOIs). Spatial actions that may be used for conservation in PNG include national parks with strict levels of protection, to areas managed by customary landowners such as Wildlife Management Areas, as well as areas of special spiritual significance called “tambu” (Leverington et al., 2017). We then define three implementation scenarios based on these

TABLE 1 Description of conservation features, associated dataset, and targets for terrestrial and marine ecosystems

Terrestrial			
Type	Description	Number features	Target
Land systems	Abiotic land systems (81) stratified by ecoregions (9)	359	A 10% target was set for each abiotic land system class, stratified by each ecoregion.
Vegetation	Natural vegetation types (61 total: 36 forests, 6 woodland, 3 savanna, 3 scrub, 11 grasslands, 1 mangrove, and 6 non vegetation types) stratified by percentage disturbed and by ecoregion.	954	A 10% target was set for any natural vegetation type (e.g., forested, grassland, and so forth) in keeping with the previous POWPA, stratified by each ecoregion. No targets were set for developed classes (e.g., bare, oil palm, timber plantation).
Fauna—restricted range endemic species	Restricted range endemic species including Bird of Paradise (10), Tree Kangaroos (12), Reptiles and Amphibians (123), Mammals (25)	170	Recognizing that restricted range endemic species are only found at a single site, these species were given 50% targets.
Fauna—critically endangered and endangered terrestrial species	IUCN red list critically endangered and endangered terrestrial species ranges including mammals (27) and amphibians (1).	28	Given the coarse resolution of this data and large spatial extent for most of these features we applied a 5% target. Given the large ranges, sensitivity tests for these features revealed most met their representation targets in the prioritizations without requiring actual targets to be set.
Climate refugia	Climate refugia	1	We used a threshold approach, where planning units with a probability of less than 0.25 (>25% chance of acting as a climate refugia) were targeted 5%. The lower target reflects the larger extent of this feature across the PNG land area.
Marine			
Biophysical habitat data	Habitat conservation features (oceanic geomorphological features (19), depth class (7), coastal mangroves (1), non-reef shallow shelf (1), coral reefs (169)) stratified by marine bioregion and ecoregion.	1,575	We set a goal of 10% for all habitat conservation features stratified by marine bioregion and ecoregion. This reflects the CBD target of 10% protection for marine habitats.
Fauna	Areas important for shorebirds and seabirds (Beck's petrel, streaked shearwater, Heinroth's shearwater, red-necked phalarope, Brown and Black Noddy, greater sand plover), blue whale critical breeding sites, sperm whale historical catches, Green turtle nesting sites, leatherback turtle nesting sites	10	A 20% target was set for each of these special features.
Reef fish spawning aggregation sites	Reef fish spawning aggregation sites	34	A 50% target was set for all reef fish spawning aggregations.

AOIs. We provide a gap analysis of the targets PNG will meet under each implementation scenario and what shortfalls will remain if no further action occurred in

the remaining priority areas. Finally, we ask where and by how much spatial priorities change as action is taken.

2 | METHODS

2.1 | Identifying national conservation priorities and scheduling priority areas for immediate action

Our analyses are based upon the national land-sea conservation assessment we completed in 2016 (Tulloch et al., 2020; Adams et al., 2016), which was commissioned by the PNG Government to identify national conservation priorities. During the planning process of this assessment, a series of workshops (March, August, October, and November 2016) were conducted to identify conservation features (the things we want to protect, such as species distributions or different habitat types), associated spatial data, and conservation targets (Table 1). In total there were 1,512 terrestrial features, including vegetation types, ecoregions, and threatened and range restricted endemic (RRE) species. A total of 1,619 marine features were included, with features such as habitats, important bird areas, and spawning sites.

The spatial prioritization in this national assessment included asymmetric land-sea connectivity based on a linked land-sea runoff-dispersal model (Tulloch et al., 2020; Tulloch et al., 2016). The model provided fine-resolution spatial outputs of land erosion, as well as runoff, sediment discharge, and coastal dispersal of sediments from watersheds given existing land-use (e.g., forestry, mining). Outputs from the linked runoff-dispersal model were used to identify coastal regions least affected (best-off) and worst affected (worst-off) by runoff and associated sedimentation given current conditions.

Spatial priorities across the land and sea were identified in the assessment using a systematic conservation planning approach that includes connectivity (Tulloch et al., 2020) and the decision support tool Marxan (Ball, Watts, & Possingham, 2009). Important features of this assessment were the inclusion of climate refugia to ensure the identified priorities protect biodiversity both now and into the future, and inclusion of land-sea connections such that the national priorities embody a ridge-to-reef approach (for all technical details see Tulloch et al., 2020; Adams et al., 2016). The priority areas identified through the Marxan analysis were vetted and further refined in workshops (October 2016, November 2016) that included government and scientific expert representatives. A total of ~20% of land and sea in PNG was identified as conservation priorities in the assessment (Figure 1, see Table 1 for details of targets for each feature).

Once the spatial priorities were finalized in the land-sea prioritization and agreed upon through stakeholder consultation, the PNG government was asked to consider

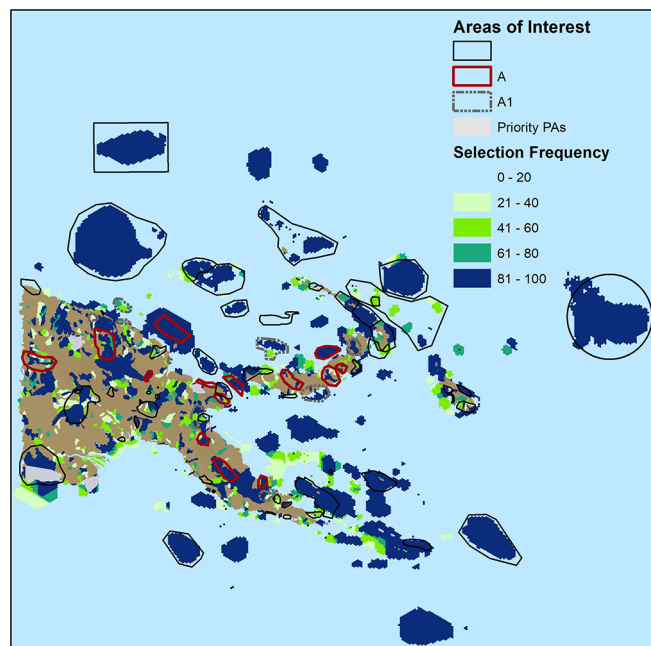


FIGURE 1 Conservation priorities identified in the Papua New Guinea National Conservation Priority Assessment. Selection frequency from the Marxan analysis indicates relative importance of planning units for meeting conservation targets. Areas identified for short and medium-term action are identified as areas of interest (general, schedule A and A1)

how the plan would be implemented. During this workshop, the concept of scheduling actions over time was introduced and how priority areas for scheduling would be identified was discussed. Key principles for scheduling actions related to feasibility—including aspects of financial support, community and stakeholder support, and political support—and threats—primarily from land clearing. Based on these principles, the workshop attendees identified a subset of the conservation priorities that should be targeted first for conservation investment (Figure 1, AOIs). These areas were identified for immediate action due to aspects such as overlapping with other policies and priorities (e.g., World Heritage Areas), or areas under immediate threat from developments (e.g., mining and palm oil on land and seismic exploration in the sea). In total 81 AOIs were mapped across the land and sea. The geographic delineation of each AOI was guided by using the “selection frequency” map from the Marxan outputs of the original conservation assessment. The selection frequency indicates how frequently a site is selected within the different solutions that Marxan finds, all of which meet the defined conservation objectives, and is an indicator of the site's priority for conservation. While clusters of planning units with high selection frequencies were used to broadly indicate conservation priority areas, final AOIs were hand drawn by workshop

participants to satisfy local considerations of size, shape and location to other activities. This is a common practice in conservation planning exercises with stakeholder consultation, and rarely (if ever) are outputs from conservation planning tools directly implemented. For example, even in marine cases where full reserve systems are implemented in a single time step, extensive stakeholder negotiations and shifts in priority areas take place following initial prioritization analysis (Adams et al., 2019; Fernandes et al., 2009; Gleason et al., 2010; Jumin et al., 2018).

A shortlist of AOIs was then selected for short-term action at the national scale (14 priorities—Schedule A) and provincial scale (10 priorities—Schedule A1). National priorities represent priorities that were considered to be under the domain of the national government to implement due to alignment with funding (e.g., international funding programs such as REDD+ or Global Environment Fund initiatives) or international obligations (e.g., World Heritage Areas). Provincial scale priorities were considered to be priorities that would require action by Provinces due to location or nature of priorities. The A and A1 list represents approximately one third of all AOIs and focus on the eight provinces that are the focus of Global Environmental Fund (GEF) 5 and 6 (East Sepik, West Sepik [Sundown], Madang, Morobe, Central, Oro, East New Britain, West New Britain) because there are funds or other forms of support for immediate action in these places.

2.2 | Implementation scenarios and gap analysis

It was noted that the A and A1 lists should be used to guide immediate action, but that opportunities across all AOIs should be kept in mind. It is therefore critical to understand which targets will be met if conservation is successfully implemented within the A and A1 AOIs, and for which targets there will be shortfalls that must be subsequently met through further conservation action at a later date. To address this, we develop three implementation scenarios to quantify the targets PNG will meet if (1) only the A and A1 subsets of AOIs were scheduled and successfully implemented (short-term), (2) the A and A1 subsets and key protected areas were successfully implemented (short to medium-term), and (3) all AOIs and key protected areas were successfully implemented (medium to long-term). We include key protected areas in scenarios 2 and 3 because the original conservation prioritization did not include any of the existing protected areas as there is uncertainty around the extent to which these protected areas are in fact protected or rather

are paper parks. Key protected areas are those protected areas most likely to be implemented or to be able to improve management (Hunstein, Kamali, Lake Kutubu, Libano, Mangalas, Maza, Mt Toricelli, Tonda, and Yus). Key protected areas were identified based on the management effectiveness evaluation (Leverington et al., 2017) and through further review by experts during workshops held in PNG.

While the conservation assessment identified both land and sea priorities, for the purpose of our gap analyses we focus on the terrestrial conservation targets only. We chose to do this because halting protection implementation on land poses a greater risk to loss of both terrestrial and downstream coastal and marine values. Furthermore, the focus was on terrestrial priorities as this is where there was immediate ability to influence implementation by the Conservation and Environmental Protection Agency (CEPA) and was thus of interest to them for scheduling actions. By contrast, there are other complementary conservation actions for marine protection, such as community tambu, areas regulated by fisheries, shipping lane management—all of which are implemented by other authorities. While we are prioritizing terrestrial areas for connected land-sea protection there may be many other unaccounted-for protection measures that effectively conserve linked downstream regions.

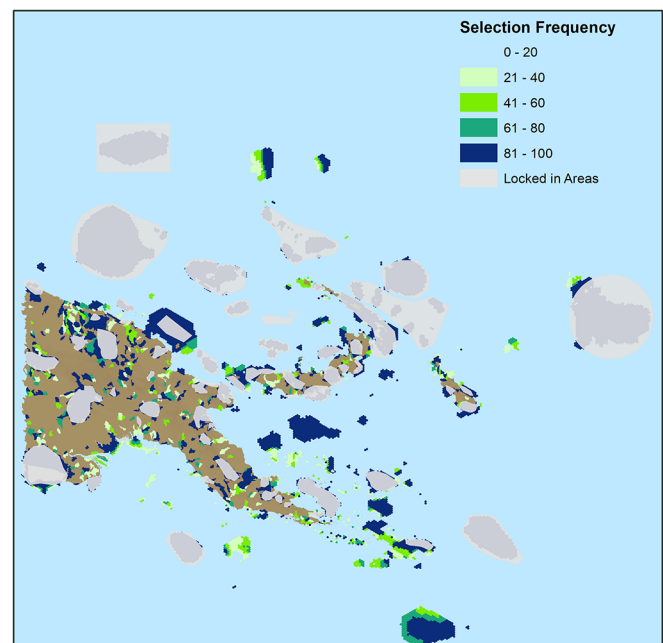


FIGURE 2 Selection frequency for updated land-sea Marxan analysis with all Areas of Interest plus 9 key protected areas locked-in. Areas with higher selection frequencies are a priority for meeting targets and ones that have been selected less often are more interchangeable

For each scenario we conducted a gap analysis using Marxan to measure the terrestrial conservation targets that would be met, and what shortfalls would remain if the priority areas in each implementation scenario were protected but subsequent action ceased. We did this by requiring Marxan to include the priority areas in solutions (termed “locked in”) and keeping all other parameters the same as in the original assessment. We assumed that all planning units within each AOI would be protected. We used the original conservation assessment spatial data and associated targets for the gap analysis (Table 1). For each feature (e.g., a single species, type of vegetation, and so forth), a target was considered as being met if >90% of the target area for that feature was under protection.

A key component of the conservation assessment was to guide conservation to meet the CBD Aichi 11 Target of 17% of terrestrial area protected, so we also considered the extent to which the three scenarios would meet this target by terrestrial ecoregion (Lipsett-Moore et al., 2010; Olson et al., 2001; Sheppard & Saxon, 2008). Ecoregional conservation was identified as a priority by stakeholders in previous national prioritizations, and during initial planning phases for this prioritization (Green et al., 2014; Lipsett-Moore et al., 2010). To this end, for each scenario we calculated the percentage of area protected by ecoregion.

2.3 | Identifying long-term spatial priorities

Given all implementation scenarios only considered a subset (AOIs) of all identified national conservation priority areas, further long-term action will be needed to meet all targets. Thus, to guide future conservation actions after priority areas (Scenario 3) are effectively

implemented, we considered which areas should be prioritized next. To do this we updated the full land-sea Marxan analysis from the original conservation assessment by conducting a new Marxan analysis that locked in all areas for Scenario 3 (All AOIs + Key Protected Areas), reflecting the assumption that they were all successfully protected (see Adams et al., 2016; Tulloch et al., 2020 for full Marxan methods). As in the gap analysis, we assumed all planning units within each AOI would be protected. We followed the exact calibrations and parameter setting as the national land-sea assessment and ran Marxan for 100 runs, changing only the configuration of locked versus available planning units. We mapped the best solution against RRE to visualize new priority areas that are selected to meet the land-sea assessment targets. To compare the extent to which the updated priorities differ from the original priorities, we compared the total area included in the best solutions and compared the selection frequency of the updated and original Marxan analyses using a difference map, subtracting the selection frequency of the reprioritization from the original conservation prioritization values for each planning unit.

3 | RESULTS

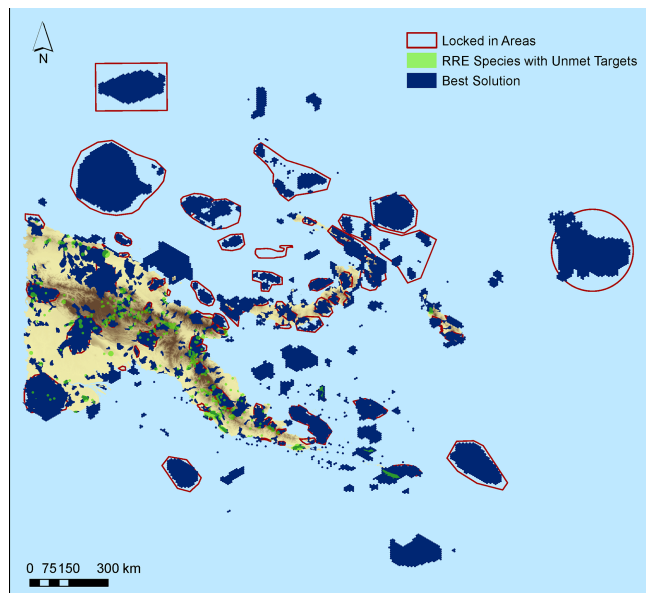
The results of the gap analysis are summarized in Table 2. We found that there were target shortfalls in all scenarios. However, as the area implemented increased under the different scenarios, the number of targets met increased from 31% of all targets in ($n = 1,152$, Table 1) Scenario 1 (A + A1) up to 58% in Scenario 3 (All AOIs + Key Protected Areas) (Table 2). There was large variability in the features whose targets were met. For example, all scenarios met the climate refugia target, but there were large shortfalls for RRE and Endangered and

TABLE 2 Percent of features for which more than 90% of the target area are protected under each scenario

Category	Target	Percent of targets met (number of features met of total features targeted)		
		Scenario 1 (A + A1)	Scenario 2 (A + A1 + key protected areas)	Scenario 3 (all AOIs + key protected areas)
Climate Refugia	5%	100% (1 of 1)	100% (1 of 1)	100% (1 of 1)
Endangered and critically endangered Fauna	5%	32% (9 of 28)	43% (12 of 28)	43% (12 of 28)
Land systems	10%	35% (126 of 359)	52% (187 of 359)	76% (273 of 359)
Restricted range endemic Fauna	50%	13% (22 of 170)	29% (49 of 170)	29% (49 of 170)
Vegetation	10%	23% (217 of 945)	47% (444 of 945)	93% (878 of 945)
All features	n/a	31% (469 of 1,512)	40% (605 of 1,512)	58% (876 of 1,512)

TABLE 3 Percent of ecoregions protected under the three scenarios, and provinces that are contained within each ecoregion (“partial” identifies those provinces spread across several ecoregions)

Ecoregion	Provinces in ecoregion	Percent of ecoregions reserved		
		Scenario 1 (A + A1)	Scenario 2 (A + A1 + key protected areas)	Scenario 3 (all AOIs + key protected areas)
Admiralty Islands	Manus Island	0	0	100
Bougainville	Bougainville	0	0	30
Central range	Gulf (partial), Eastern Highlands, Southern Highlands, Western Highlands, Chimbu, West Sepik (partial), East Sepik (partial)	7	8	16
Northeastern Island	West New Britain, East New Britain, New Ireland	26	26	43
Northern New Guinea	Madang, Morobe (partial), West Sepik (partial), East Sepik (partial)	7	11	15
Southeast Peninsula	Central, Oro, Morobe (partial), Milne Bay (partial)	12	17	19
Southeastern Islands	Milne Bay (partial)	0	0	17
Southern New Guinea	Western, Gulf (partial)	0	4	18
Trobirand Islands	Milne Bay (partial)	0	0	91

**FIGURE 3** Best solution for updated land-sea Marxan analysis, including the distributions (ranges) of restricted range endemic species which have not met their conservation protection targets

Critically Endangered fauna (shortfalls in targets of 13–29% for RRE and 31–44% for endangered fauna, Table 2).

The scenarios performed variably in terms of ecoregion representation, reflecting the geographic biases in placement of A and A1 priorities to GEF priority provinces. For example, in Scenario 1 (A + A1) the only 17% ecoregion protection target met was for the Northeastern Island ecoregion. Scenario 2 (A + A1 + Key Protected areas) only met the 17% protection target for one additional ecoregion (Southeast Peninsula, Table 3). By contrast, Scenario 3 (All AOIs+Key Protected Areas) achieved representation targets for all ecoregions ($n = 9$).

To explore the extent to which spatial priorities changed as actions were taken, and what those changes in priorities were, the full land-sea Marxan analysis was run locking in all AOIs and Key Protected Areas (assuming Scenario 3 is fully implemented) (Figure 2). The updated Marxan best solution (the solution that meets all targets for the lowest cost) requires 33% of the total land area of PNG to be protected (Figure 3), compared with the original conservation assessment covering 20% of land area (Figure 1). The location of RRE fauna with shortfalls in targets are overlaid on the Marxan best solution (Figure 3) showing that the spatial solution of additional areas to be protected is driven by these narrowly distributed species.

The new priority areas from the updated Marxan “best solution” (the solution that meets all targets for the lowest cost) were prominently located in the highlands and in the

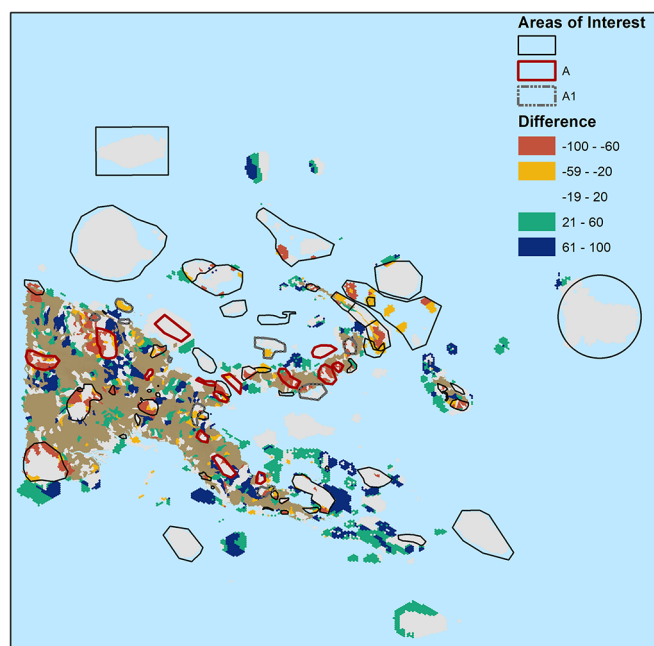


FIGURE 4 Difference in selection frequency from original conservation prioritization and the updated prioritization to identify long-term priorities after achieving scheduled actions in Scenario 3. Positive values indicate planning units more frequently selected in the original prioritization. Gray areas indicate priorities shared in both Marxan prioritizations. Negative values indicate planning units more frequently selected in the reprioritization locking-in all priorities in scheduling Scenario 3

downstream catchments (reflecting the land-sea connections incorporated in the prioritization) (Figure 2). Most marine priority areas were not influenced by scheduling as they were offshore and not connected to terrestrial regions. However, there was an exception for coastal priorities, which shifted in response to changes in protected terrestrial areas to maintain land-sea connections.

The changes observed in the updated priorities are due to the protection (“locking-in”) of planning units as part of AOIs that were not identified in the original priority sets. This results in higher selection within some AOIs compared with the original conservation assessment (Figure 4). As the conservation assessment approach includes land-sea connections, locking in the AOIs also results in a change in spatial clumping to include planning units adjoining locked in areas or downstream of these areas, thus shifting some coastal priorities (Figure 4).

4 | DISCUSSION

While systematic conservation planning, supported by decision support tools like Marxan, is common (Schwartz

et al., 2017), the full set of sites identified through such processes are rarely implemented in entirety, or in a single time-step. We are only aware of a single terrestrial example (Justus & Sarkar, 2002; Pressey, 2002) and limited marine examples (Adams et al., 2019) where a comprehensive reserve system was implemented at a single point in time. Rather, scheduling of actions and incremental action over time to build reserves is the norm (Sarkar et al., 2006). We present one approach to scheduling actions by identifying AOIs through systematic conservation planning and collaborative workshops in order to identify priority areas for immediate conservation investment and action (Figure 1).

Since these AOIs will guide conservation action by the PNG government, it is important to understand which species and habitats will be effectively conserved within them, and which fall short of meeting their conservation targets. We addressed this issue by carrying out a gap-analysis that considered three incremental scheduling scenarios. Furthermore, we provided an updated prioritization that demonstrates how spatial priorities shift as action is taken and how iterative planning can guide conservation action once all the identified AOIs have been protected. We found that if only the national (A) and provincial (A1) priorities were protected that most conservation features (mainly habitats and species) would not meet conservation targets—an exception is climate refugia, which met its target in all scenarios. The shortfalls in target achievement across most features demonstrates a real risk associated with incremental implementation—that the full extent of conservation targets will not be achieved due to delays or lack of implementation of the entire conservation plan. We found that even if all AOIs are protected (Scenario 3), substantial shortfalls remain, especially for RRE fauna.

Iterative planning that reprioritizes areas for action as progress is made towards plan implementation is clearly necessary to ensure that long-term action achieves all targets. Iterative updating of the plan and integration in a decision support tool, such as Marxan, may be required to further schedule actions to meet targets in the long-term in a cost effective manner (Meir, Andelman, & Possingham, 2004). Our analysis of an iterative update of the reserve design and long-term implementation based on scenario 3 demonstrates the potential inefficiencies of scheduling conservation action—the updated design would take ~13% more land area and risks shortfalls for RREs if action stopped in the short or medium-term. This is consistent with other studies that have assessed inefficiencies associated with incremental implementation (Stewart, Ball, & Possingham, 2007).

Another aspect of incremental implementation of reserves is whether design aspects, such as reserve size and spacing, are maintained. An important feature of the PNG national conservation assessment was consideration of climate change refugia and land-sea connections. These are

design features of the assessment that might be lost if areas are protected ad-hoc without iterative updating of the plan to ensure that ecological connections are maintained. Coincidentally, all scenarios achieve targets for protecting climate refugia, indicating that all identified regions important for protecting biodiversity under climate change (Game, Lipsett-Moore, Saxon, Peterson, & Sheppard, 2011) are contained within the A and A1 priority areas. However, land-sea connections are not necessarily preserved as areas are scheduled for action. Design features such as how areas are networked may be particularly challenging to maintain as implementation progresses (Álvarez-Romero et al., 2015; Álvarez-Romero, Pressey, Ban, & Brodie, 2015). For example, our updated Marxan analysis demonstrates how spatial priorities will shift if all AOIs and key protected areas (scenario 3) are achieved. Because the AOIs and key protected areas do not preserve the asymmetric connectivity of the original priority areas, the updated Marxan analysis shifts additional priorities to areas near the AOIs along with their connected downstream coastal zones (Figure 4).

Scheduling conservation actions is a reality. Understanding how much different priority areas contribute to target achievement, such as the analysis we present here, allows planners to implement actions incrementally while ensuring the objectives of the original plan are met. Thus, while an iterative planning process may, in the end, require more area to be protected than a planning process considering a single time-step, it will ensure that the original conservation targets and design principles are met—in this case, maintaining land-sea connections and protecting climate refugia.

Ideally, an iterative planning process would take into account new knowledge that will likely emerge after a suite of priority areas have been implemented, as well as new or variable threats to conservation features. For example, over the period of implementation there is likely to be changes in the distribution of land available (e.g., due to clearing), and conservation features (e.g., known or predicted locations of endangered species), as well as updated knowledge regarding these features (Meir et al., 2004). As we used the best available data in our planning processes, we were unable to incorporate the potential of “new” data in our analysis. Despite this, the scheduling process that we outline here demonstrates how iterative planning increases transparency and ensures that if action does stop that it is clear where action should resume in the future. Our analysis highlights the benefits of scheduling by demonstrating a transparent set of sequential actions to take and an analysis of what targets are met in each. Our Marxan analysis demonstrates one approach to sequential plan updates and highlights the technical capacity needed within governments to reanalyse priorities as they schedule and

implement action (Cheok et al., 2018; Pressey et al., 2013). Future research could include either updated or forecasted changes in knowledge to test how these will interact with iterative actions and planning.

Iterative planning and implementation is a challenge; staff capacity is a critical aspect of successful ongoing implementation of conservation priorities identified within this assessment (Adams et al., 2019; Pressey et al., 2013). Our analysis provides critical guidance to the PNG government about which targets will and will not be met as they advance implementation of their immediate priority areas. Furthermore, we provide a practical demonstration of what iterative planning might look like by integrating Marxan into a long-term iterative planning and acting cycle. Evaluating possible schedules of actions at the outset of plan implementation is one way to inform iterative planning and may ensure that agencies understand what targets have been achieved as they act and what targets remain.

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CONFLICT OF INTEREST

The authors declare no potential conflict of interest.

AUTHOR CONTRIBUTIONS

Vanessa M. Adams, Nadya Dimitrova, Caitlin D. Kuempel, Vivitskaia J. Tulloch and Hugh P. Possingham: conceived of the analyses. **Vanessa M. Adams and Nadya Dimitrova:** completed analyses. All authors interpreted the results. **Vanessa M. Adams and Nadya Dimitrova:** led the drafting of the article and all authors contributed to writing and editing.

ETHICS STATEMENT

No ethics review for animal handling or human subjects was necessary for the analyses reported in this article.

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