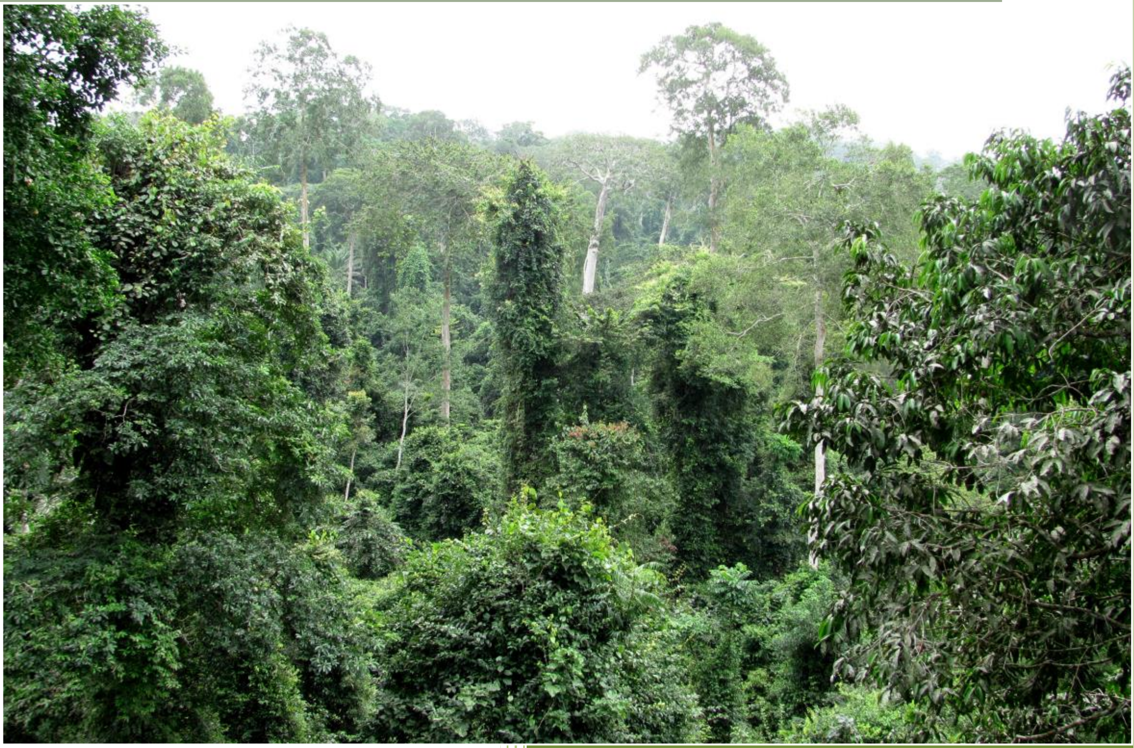
Protected Areas Resilient to Climate Change, PARCC West Africa

2015

West Africa Gap Analysis and Spatial Conservation Prioritisation



ENGLISH

Robert J Smith

DICE, University of Kent

2015

The United Nations Environment Programme World Conservation Monitoring Centre (UNEP-WCMC) is the specialist biodiversity assessment centre of the United Nations Environment Programme (UNEP), the world's foremost intergovernmental environmental organisation. The Centre has been in operation for over 30 years, combining scientific research with practical policy advice.

UNEP WCMC

West Africa Gap Analysis and Spatial Conservation Prioritisation, prepared by Robert Smith, with funding from Global Environment Facility (GEF) via UNEP.

Citation: Robert J. Smith 2015. West Africa Gap Analysis and Spatial Conservation Prioritisation. *UNEP-WCMC technical report*.

Available From: UNEP-World Conservation Monitoring Centre (UNEP-WCMC)
219 Huntingdon Road, Cambridge CB3 0DL, UK
Tel: +44 1223 277314; Fax: +44 1223 277136
Email: protectedareas@unep-wcmc.org
URL: http://www.unep-wcmc.org

Photo cover: Kakum National Park, Ghana. *Copyright: Elise Belle.*

Table of Contents

LIST OF FIGURES 4
LIST OF TABLES 5
EXECUTIVE SUMMARY 6
LIST OF ABBREVIATIONS 10
ACKNOWLEDGEMENTS 11
INTRODUCTION 12
METHODOLOGY 15
Study region 15
Setting targets 17
Producing the Conservation Planning Systems 19
Gap analysis 21
Calibrating the Marxan parameters 21
RESULTS 22
Conservation feature details and gap analysis 22
Systematic conservation assessment 28
DISCUSSION 30
Gap analysis 31
Identifying priority areas 32
RECOMMENDATIONS 33
Implementing the results 33
Improving the conservation planning system 34
REFERENCES 35

List of figures

Figure 1: Schematic representation of the outputs from Marxan. (A) shows the distribution of three species in four planning units. (B) shows the results of running Marxan twice and the resultant two different portfolios, where the selected planning units are shown in magenta. Both portfolios meet the target that at least one population of each species should be protected. (C) shows the selection frequency output, which counts how often each planning unit was selected in the two portfolios: the red planning unit is always selected because it contains the only population of the fish; one of the yellow planning units is needed to meet the target for the toad but neither is irreplaceable because it could be swapped with the other. 14

Figure 2: The West Africa planning region used in the analysis, showing national boundaries and capital cities. 15

Figure 3: The WWF Ecoregion map of West Africa, where ecoregion type is based on species richness, endemism and higher taxonomic uniqueness (Olson et al, 2001). 16

Figure 4: The approach used to set species targets based on their global ranges. This is based on a methodology developed by Rodrigues et al (2004) but each target is capped to 20% because the PARCC analyses used data with a relatively fine spatial scale. 18

Figure 5: Details of planning units produced by combining a regular hexagon layer, the layer of protected area boundaries and the layer of Important Bird and Biodiversity Areas. It shows that each planning unit is a hexagon unless it is found at the boundary of the planning region or is part of an existing PA or IBA 20

Figure 6: Map of West Africa showing major cities, administrative boundaries, Protected Areas, Important Bird and Biodiversity Areas and planning unit cost data. 22

Figure 7: Maps for West Africa showing (A) the status of the planning units used in Marxan and (B) the conservation feature richness, where the richness values range from 1 to 1456. 23

Figure 8: Percentage of amphibian, bird and mammal species for which the set target (i.e. proportion of their current distribution range to be protected) is met by the existing Protected Area (PA) network and Important Bird and Biodiversity Areas (IBAs). 26

Figure 9: Percentage of threatened amphibian, bird and mammal species for which the set target (i.e. proportion of their current distribution range to be protected) is met by the existing Protected Area (PA) network and Important Bird and Biodiversity Areas (IBAs). 27

Figure 10: Percentage of amphibian, bird and mammal species for which the set target (i.e. the proportion of their future predicted distribution range for the 2010-2039 time period to be protected) is met by the existing Protected Area (PA) network and Important Bird and Biodiversity Areas (IBAs). 27

Figure 11: Percentage of threatened amphibian, bird and mammal species for which the set target (i.e. the proportion of their future predicted distribution range for the 2010-2039 time period to be protected) is met by the existing Protected Area (PA) network and Important Bird and Biodiversity Areas (IBAs). 28

Figure 12: Selection frequency scores for West Africa based on the Marxan analysis. Areas in red were selected in every portfolio identified by the software, based on meeting targets whilst reducing costs and maintaining connectivity. 29

Figure 13: The four best portfolios identified by Marxan for meeting the conservation feature targets for West Africa whilst minimising costs. The total area is the combined area of the existing PAs, the unprotected IBAs and the additional priority areas selected by Marxan to meet the targets whilst minimising costs. 30

List of tables

Table 1. Details of how well each country is meeting their national Aichi target 11 PA coverage targets. The percentage target met can be more than 100% if the amount protected is higher than the target set. 23

Table 2: Details of the ecoregions used as conservation features in the West Africa conservation planning system and showing targets capped at 20% of the total distribution. 25

Table 3: Details of the elevation zones and vegetation types used as conservation features in the West Africa conservation planning system. Targets were set at 10% of the area of the elevation zones and vegetation types. 26

Table 4: Details of the area of planning units in West Africa grouped by their selection frequency scores. 28

Executive Summary

The importance of protected areas (PAs) for reducing biodiversity loss is widely recognised. This is why parties to the Convention on Biological Diversity (CBD) have agreed to implement Aichi target 11, which involves increasing the global coverage of terrestrial PAs to 17% and marine PAs to 10% by 2020. In addition, Aichi target 11 commits these countries to develop PA networks that include “areas of particular importance for biodiversity and ecosystem services” and are “ecologically representative and well connected systems”. Currently most national PA networks fail to achieve this target and so there is an urgent need to modify and expand these PA systems to improve their value for biodiversity conservation.

Systematic conservation planning is the most widely used approach for designing PA networks. It involves producing a list of important species, habitats and ecological processes (collectively known as conservation features), mapping their distributions and setting targets for how much of each conservation feature should be protected. These data are then used to carry out a gap analysis, which measures the extent to which the existing PA system meets these targets, and a spatial conservation prioritisation, which identifies priority areas for filling any target shortfalls.

PA networks also need to be robust to the impacts of climate change, as the distributions of the conservation features are likely to shift in response to changes in temperature, rainfall and sea levels. Systematic conservation planning can be used to address this problem by identifying priority areas for conservation that protect the predicted future distributions of important species, as well as their current distributions.

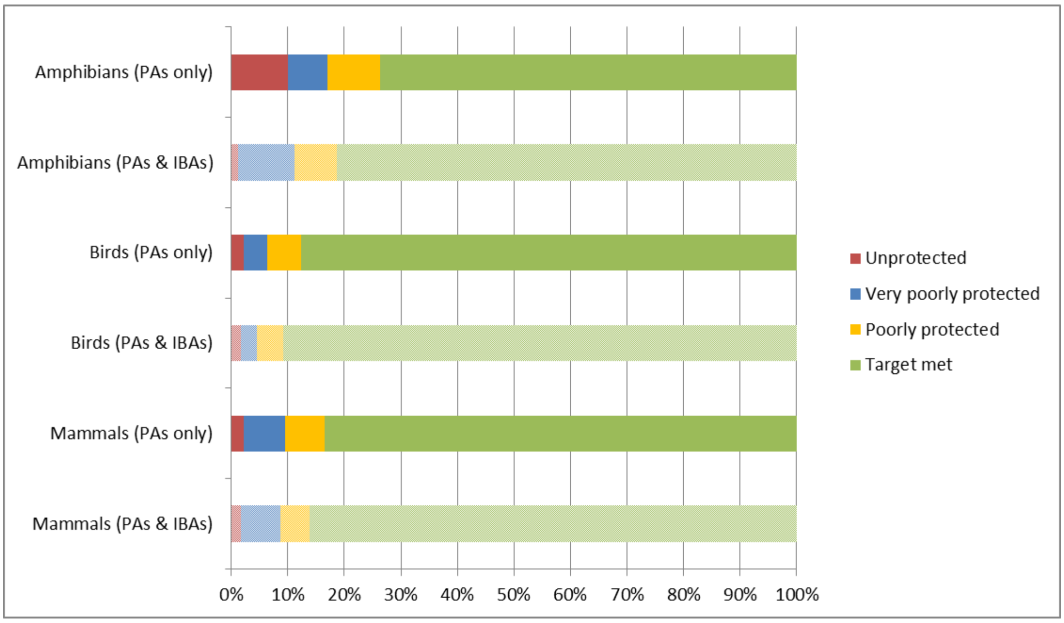
As part of the PARCC West Africa project, we carried out a gap analysis and spatial conservation prioritisation for the West African region and the five project countries: Chad, Gambia, Mali, Sierra Leone and Togo. This involved producing one regional and five national systematic conservation planning systems. We then used these systems to help identify ways in which PA networks could be improved to conserve biodiversity both now and in the future, taking into consideration future climate projections. This report presents results from the analysis of the West African region.

The systematic conservation planning system for West Africa contained data on the following conservation features found in the region: 17 natural vegetation types, 28 ecoregions, 171 amphibian species, 884 bird species, 230 mammal species and the future predicted distributions under climate change of 316 amphibian, bird and mammals species. The predicted distributions were for species that are listed as Threatened on the IUCN Red List and/or have been assessed as being vulnerable to the predicted impacts of climate change, based on Species Distribution Models (SDMs) for the time period 2010-2039.

The West Africa planning region has an area of 7,311,000 km^2 and 12.6% of this falls within existing PAs, while another 1.1% falls within unprotected Important Bird and Biodiversity Areas (IBAs) that have been identified by BirdLife International and their local partners.

The West Africa planning region consists of 16 countries and the percentage of each country that falls within PAs or unprotected IBAs ranges from 1.1% for Mauritania to 34.8% for Guinea-Bissau. Only six of these countries meet their Aichi 11 targets, based on their current PA and unprotected IBA networks. This regional network of PAs and IBAs meets targets for 15 of the 28 ecoregions, but fails to conserve any of the East Saharan montane xeric woodland or Mandara Plateau mosaic ecoregion.

The combined network of PAs and IBAs meets targets for 74.5% of all conservation features. Conservation targets are met for 79.3% of amphibian species, 75.0% of bird species and 78.0% of mammal species and for 46.2% of the SDMs in 2010-2039. However, 7.4% of these features are completely missing from this network and this percentage is even lower when considering threatened species, where 12.5% are currently unprotected.

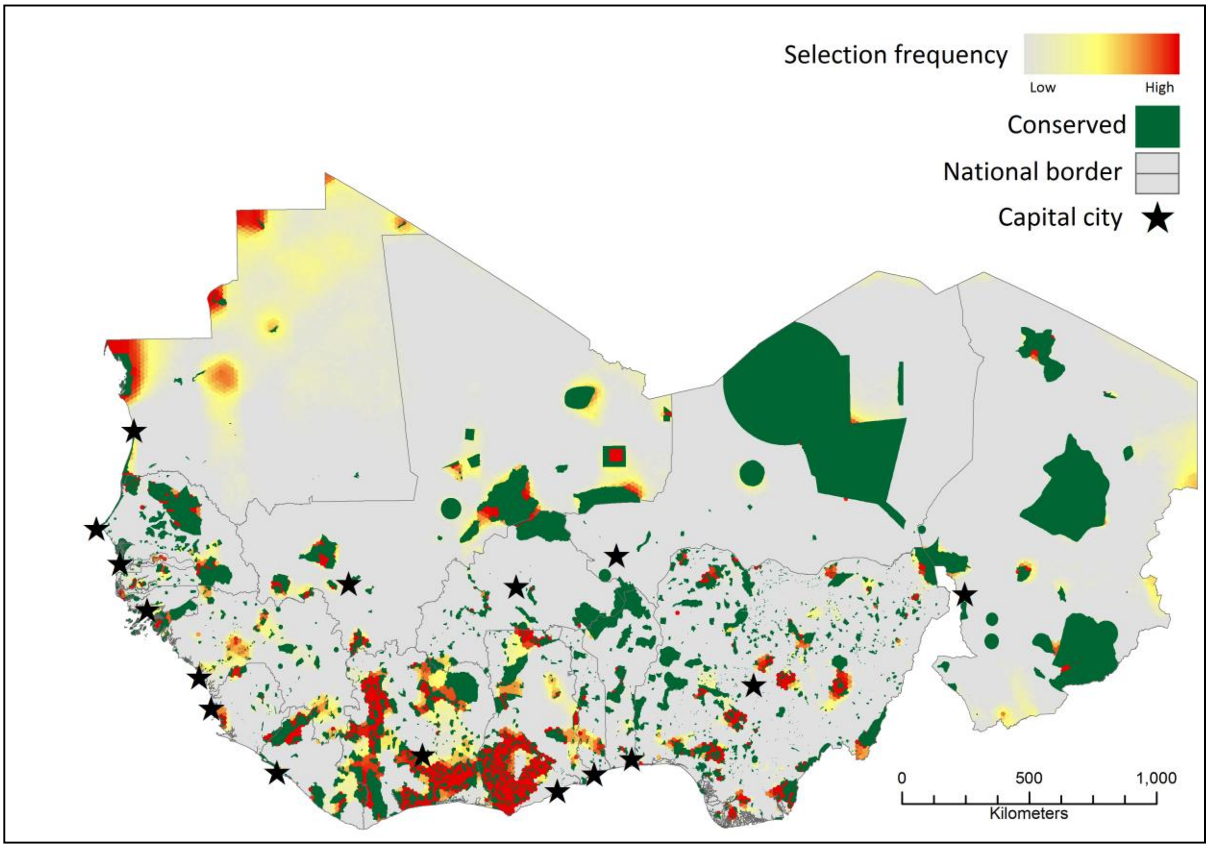


Percentage of amphibian, bird and mammal species for which the set target (i.e. proportion of their current distribution range to be protected) is met by the existing Protected Area (PA) network and Important Bird and Biodiversity Areas (IBAs).

The PA and IBA network is more effective at meeting targets for the future predicted distribution of species in 2010-2039, although 0.81% species of birds and 0.25% of mammals are completely unprotected. In contrast to the findings for the current distribution of species, the future distributions of threatened species are better protected than non-threatened species

We used the Marxan conservation planning software to identify priority areas for meeting the conservation targets. The analysis was designed to avoid areas of high human population density, where possible, and to identify priority areas that extend existing PAs or are large enough to be ecologically viable. We found that meeting all the targets required an additional 384,765 km^2 to be added to the PA network, so that 21.6% of the region needs protection to achieve all the targets.

The priority areas that were most consistently identified by Marxan were scattered throughout the region, but the most extensive areas were in Côte d'Ivoire, Ghana and Mauritania. For Côte d'Ivoire and Ghana, this was because they contained important biodiversity, but also because they contained many small existing PAs that Marxan sought to link. For Mauritania, this was because the PA coverage in the country is relatively low and so some ecoregions needed higher levels of protection to meet the specified targets.



Priority conservation areas for West Africa. Areas shown in red were the ones selected most frequently by Marxan.

The results from the gap analysis and the spatial conservation prioritisation provide a wealth of data that can be used to inform conservation policy and practice in West Africa. However, caution is needed when implementing the results because most of the distribution data were based on range maps that include some unsuitable habitats. Thus, the first step in implementing these results is to carry out literature reviews and field surveys to check that each priority area is definitely important for the conservation features for which it was selected.

It is also important to recognise that the West Africa conservation planning system only contained data on three groups of vertebrates and did not include data on a range of factors that might influence implementation, such as ecosystem services, opportunity costs from agriculture or land-use plans from other sectors. Thus, it is important that national and international researchers and conservation practitioners continue to improve the planning system by updating and adding new data.

List of abbreviations

asl	above sea level
BLM	Boundary Length Modifier
CBD	Convention on Biological Diversity
CPS	Conservation Planning System
GRUMP	Global Rural-Urban Mapping Project
IBA	Important Bird and Biodiversity Area
IUCN	International Union for Conservation of Nature
PA	Protected Area
SDM	Species Distribution Model
SPF	Species Penalty Factor
WDPA	World Database on Protected Areas
WWF-US	World Wildlife Fund – United States

Acknowledgements

We are deeply grateful to the Global Environment Facility (GEF), who funded the PARCC West Africa project, including this component.

We are grateful to the many individuals and organizations who contribute to the IUCN Red List of Threatened Species, the World Database on Protected Areas and the database on Important Bird and Biodiversity Areas. We are also grateful to the IUCN Species Survival Commission, UNEP-WCMC and BirdLife International for providing us with these data and advice on its use. Many thanks to all the experts from Burkina Faso, Chad, Côte d'Ivoire, the Gambia, Ghana, Mali, Sierra Leone and Togo for their help with the systematic conservation planning process, especially in identifying the relevant conservation features and setting targets. Thanks also to all the PARCC National Liaison Officers of the project.

We are extremely grateful to Rachel Sykes for helping run the Marxan analyses and producing the data and to Moreno di Marco for providing invaluable comments on earlier drafts of this report. Thanks also to the members of the PARCC Technical Advisory Group for providing advice and data. In particular thanks to David Baker and Steve Willis from the University of Durham, Andy Hartley from the UK Met Office, Stu Butchart from BirdLife International and Jamie Carr from the IUCN SSC Climate Change Specialist Group. Finally, we would like to thank the core members of the PARCC team. Thanks to Bora Masumbuko for all her help with organising project logistics and support and Luc Qemal for helping organise the workshops. Thanks also to Neil Burgess for his guidance and advice and to Elise Belle for her tireless work and support in producing this work.

Introduction

Biodiversity is in decline and protected area (PAs) are seen as a key approach for stemming this loss (Butchart et al, 2015). This is why the 196 countries that are signatories to the Convention on Biological Diversity (CBD) have committed through Aichi target 11 to increase the global extent of the PA network to 17% of the terrestrial realm and 10% of the marine realm by 2020 (CBD, 2010). However, there is an increasing recognition that simply increasing the extent of the global PA network will not be enough to reduce biodiversity loss. This is because PAs have traditionally been located in areas with little economic value, which has resulted in networks that fail to represent a wide range of species and habitats and are particularly poor at protecting threatened species (Venter et al, 2014). Thus, Aichi target 11 also stresses that PAs should be located in areas of particular importance for biodiversity and ecosystem services and PA systems should be ecologically representative and well-connected systems. In addition, it is widely recognised that PAs should play a major role in achieving Aichi target 12, which states that “By 2020, the extinction of known threatened species has been prevented and their conservation status, particularly of those most in decline, has been improved and sustained”.

Meeting Aichi targets 11 and 12 will require expanding the current PA networks so that they adequately represent and protect a much wider range of species and ecosystems (Butchart et al, 2015). However, nature is not static and it is also important that these PAs continue to protect these conservation features in the future. In particular, PAs need to take into account how biodiversity is likely to respond to climate change, as species are likely to shift their distributions in response to changes in temperature and rainfall patterns (Willis et al, 2015). Thus, there is a real need for research on how climate change will impact species distributions to inform the management actions of PA managers and conservation planners. The PARCC project has identified which species are most likely to be vulnerable to the impacts of climate change (Carr et al, 2014) and which PAs are likely to experience the highest levels of species turnover (Baker et al, 2015). The final research component of PARCC investigates how well the current West African PA system is conserving the current and future distributions of biodiversity and identifies priority areas for filling any gaps. This report describes the results from the West African regional analysis.

We adopted a systematic conservation planning approach to measure how well the current PA system protects the current and future distributions of biodiversity in West Africa. Systematic conservation planning was designed to be flexible enough to be applied in a range of contexts (Margules and Pressey, 2000) but it generally involves the following steps: (1) Identifying and involving key stakeholders; (2) Identifying broad goals for the conservation planning exercise; (3)

Identifying the species, habitats and ecological processes, collectively known as conservation features, to be used in the analyses; (4) Gathering and evaluating the available data on these conservation features, as well as data on socio-economic and implementation-relevant factors; (5) Formulating targets for each conservation feature; (6) Conducting a gap analysis to review how well the existing PAs meet the conservation feature targets; (7) Selecting additional conservation areas through a conservation assessment; (8) Implementing conservation action in selected areas, and (9) Maintaining and monitoring established conservation areas.

This means that systematic conservation planning is a long-term process based around working with stakeholders to collaboratively develop and deliver an implementation strategy (Knight et al. 2006a). However, there are two key short-term technical aspects to this process. The first is a gap analysis (step 6 listed above) which involves measuring how well the current PA network meets biodiversity targets. The second is a conservation assessment, also known as a spatial conservation prioritisation (step 7 listed above), which involves identifying priority areas for conservation to fill any of these gaps (Knight et al. 2006a).

The spatial conservation prioritisation is the most technical part of this process and consists of: (i) Dividing the planning region into a number of planning units; (ii) Listing the abundance of each conservation feature in each planning unit; (iii) Setting representation targets for each conservation feature; (iv) Assigning a cost value for each planning unit; (v) Measuring the effectiveness of the present PA system, and; (vi) Using computer software to identify new planning units to be incorporated into the system based on complementarity. We used the Marxan software package to undertake the spatial conservation prioritisation. Marxan has been designed to identify sets of priority areas that meet conservation targets, minimise costs and maintain connectivity and is the most widely used systematic conservation planning software package (Ball et al. 2009).

Marxan uses an approach named simulated annealing to identify the priority areas, which involves running the software a number of times to identify a near-optimal set of planning units each time, where each of these sets of planning units is known as a portfolio. The results of each run tend to be slightly different, so Marxan produces two main outputs: (1) the ‘best’ solution which is the portfolio with the lowest overall cost; and, (2) a ‘selection frequency’ output which counts the number of times each planning unit appears in the different portfolios (**Figure 1**).

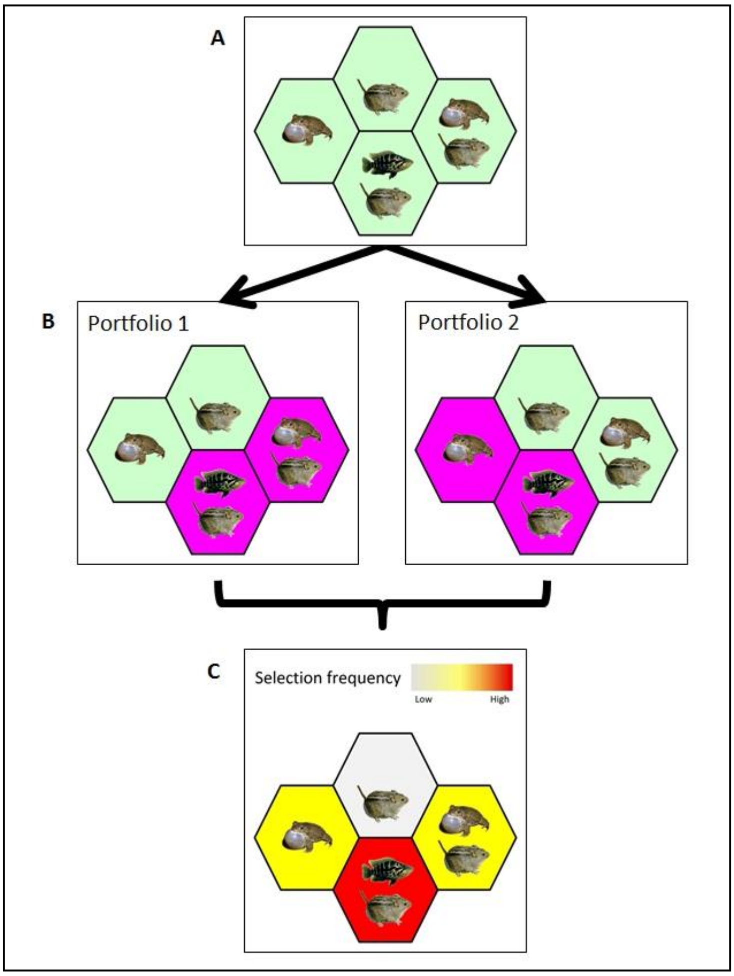


Figure 1: Schematic representation of the outputs from Marxan. (A) shows the distribution of three species in four planning units. (B) shows the results of running Marxan twice and the resultant two different portfolios, where the selected planning units are shown in magenta. Both portfolios meet the target that at least one population of each species should be protected. (C) shows the selection frequency output, which counts how often each planning unit was selected in the two portfolios: the red planning unit is always selected because it contains the only population of the fish; one of the yellow planning units is needed to meet the target for the toad but neither is irreplaceable because it could be swapped with the other.

In this report, when reporting the Marxan results we focus most on the selection frequency output, as this identifies priority areas without being too prescriptive about exactly which areas should be protected. In addition, to illustrate the range of options identified by Marxan we analysed the four best portfolios (the four portfolios with the lowest cost) to measure the total area needed to meet the targets and maintain connectivity. The decision to show the four best portfolios is based on balancing the need to illustrate the variation in the results without swamping the reader with information. So here we describe results from a gap analysis and Marxan spatial conservation prioritisation for West Africa. The next section details how the systematic conservation planning system was developed. This is followed by the results from the gap analysis and spatial prioritisation. The final section discusses the results and then lists a number of recommendations for implementing the results and improving the conservation planning system.

Methodology

Study region

The West Africa study region is defined as the 16 countries of Benin, Burkina Faso, Chad, Côte d'Ivoire, Gambia, Ghana, Guinea, Guinea-Bissau, Liberia, Mali, Mauritania, Niger, Nigeria, Senegal, Sierra Leone and Togo (**Figure 2**). The region shows strong climatic and biogeographic patterns: from north to south it consists of the Sahara desert, the semi-arid Sahel, a savanna zone and then a more tropical zone nearer the coast containing extensive wetlands and patches of rainforest. These forests are particularly rich in species and their global importance has been recognised as forming the Guinean Forest of West Africa biodiversity hotspot (Myers et al, 2000). The region is also home to 360 million people, many of whom rely on agriculture for their livelihood.

Figure 2: The West Africa planning region used in the analysis, showing national boundaries and capital cities.

Selecting and mapping the conservation features

We selected three types of conservation feature, with the aim of: (A) representing broad elements of biodiversity; (B) conserving the current distribution of particular species, and (C) conserving the future distribution of species that may be vulnerable to climate change. Details on how we selected and mapped these different types of conservation feature are given below.

A) Broad biodiversity elements and national commitments

The first set of conservation features sought to represent a broad range of biodiversity by including vegetation types, ecoregion types and elevation zones, as elevation is known to drive patterns of biodiversity. For the vegetation types we used the GlobCover dataset which has mapped the global distribution of 22 landcover types with a resolution of 300 m (Bicheron et al, 2008). This map was based on MERIS satellite imagery that was recorded between 2005 and 2006. The ecoregion type map was produced by WWF-US (Olson et al, 1998) and divided the terrestrial realm into 825 ecoregions based on species richness, endemism and higher taxonomic uniqueness (**Figure 3**). We produced the elevation zone map by reclassifying a 1 km resolution Digital Elevation Model that was provided by the Hadley Centre into three classes, which were 0 – 500 m above sea level (asl), 500 – 1000 m asl and > 1000 m asl. We selected these elevation zone classes based on a literature review and an initial assessment of mean annual temperatures at different elevation levels. We also set each country as a conservation feature so that we could set targets based on the national CBD commitments made as part of Aichi target 11.

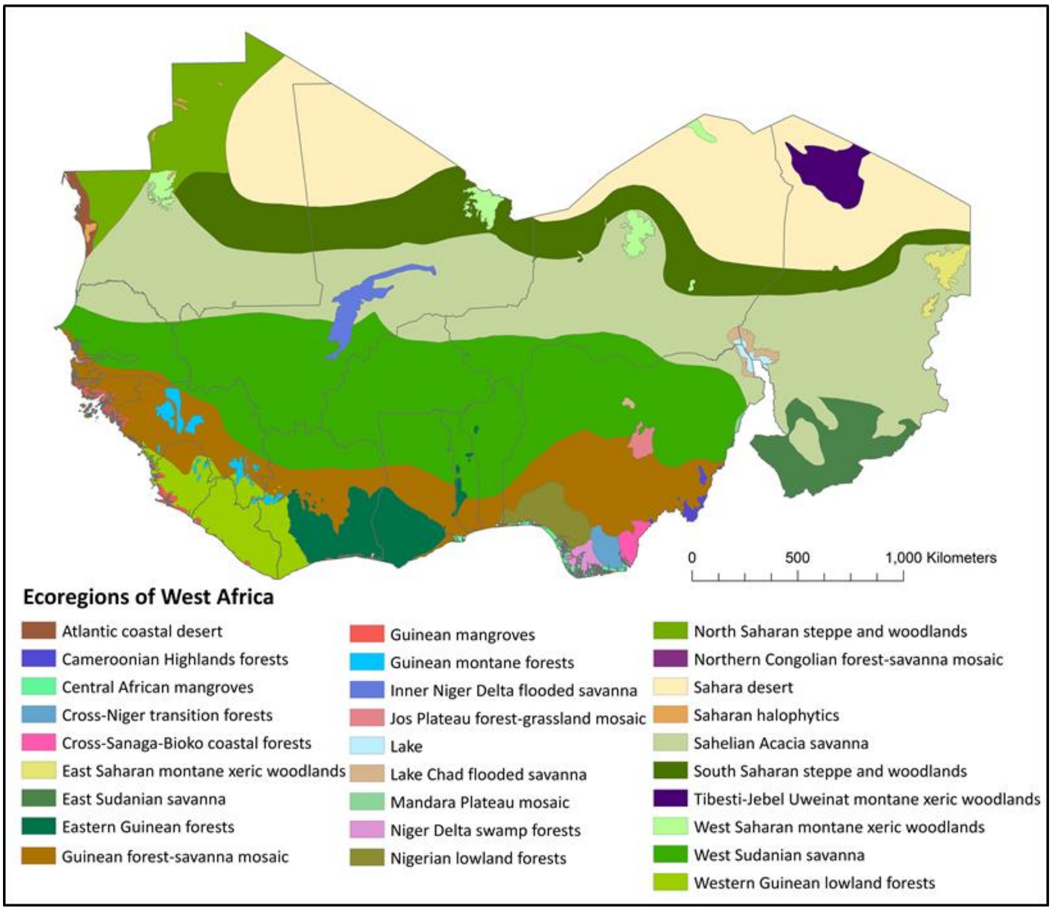


Figure 3: The WWF Ecoregion map of West Africa, where ecoregion type is based on species richness, endemism and higher taxonomic uniqueness (Olson et al, 2001).

B) Current species distributions

We selected all amphibians, birds and mammal species as our conservation features, except those that are listed in the IUCN Red List as Data Deficient. We did not include data on other species in our analyses, either because there was insufficient data on their distributions or because they were freshwater taxa, which generally need to be managed by improving management of the water catchment rather than establishing new PAs. We used the 2014 IUCN Red List range maps for each of these amphibians, birds and mammal species. For birds we also used separate data on their breeding and non-breeding range where appropriate.

C) Future species distributions

To map future distributions we used the species distribution models (SDMs) produced by the PARCC project (Baker et al, 2015). These predicted the distribution for a number of amphibian, bird and mammal species based on mean temperature of the warmest month, mean temperature of the coldest month, precipitation seasonality and an aridity index. The nature of this approach meant it was not possible to model the distribution of species with very narrow ranges, as they had too few distribution records to analyse (Platts et al, 2014). The SDMs have a resolution of 0.44°, which is approximately 50 km x 50 km at the equator. The original study produced 100 future different models for each species for the time periods 2010-2039, 2040-2069 and 2070-2099. However, including all this information would have been unwise for three reasons. First, there is a high uncertainty in these models that predicted the distribution of species for 2040-2069 and 2070-2099 (Baker et al, 2015). Second, the systematic conservation planning software is unable to analyse all the data because the files sizes are too large. Third, as part of the analysis we needed to run the systems during expert workshops, and to investigate the impacts of using different targets and analysis parameters we needed the datasets to be small enough to make this feasible.

We therefore reduced the size of the dataset in the following ways: (i) we only used SDMs based on climate models for the 2010-2039 time period, as these had relatively low levels of uncertainty; (ii) we condensed the 100 SDMs for each species into five, where each of these new SDMs represented the different regional climate modelling climate projections; (iii) we only included data in the analysis on species that are currently listed as Threatened (IUCN Red List status of Vulnerable, Endangered or Critically Endangered) and/or were identified as vulnerable to climate change in a previous PARCC study (Carr et al, 2014) based on their ‘exposure’, 'sensitivity' and 'adaptive capacity' to climate change and its impacts, and (iv) we only used data on those species where the predicted overlap in the current and future distribution by 2010-2039 was less than 90%, in order to focus on species that are most likely to affected by climate change. These four steps ensured we used the most reliable data on species that are likely to be most susceptible to the impacts of climate change

We used two different approaches when setting initial targets. For the vegetation types and elevation zones we set targets as 10% of their total area in the country. We used this relatively low target because, although we wanted to ensure the priority areas were representative of biodiversity, previous research has shown that setting high targets for broad-scale biodiversity surrogates is an inefficient at conserving narrow-range or threatened species (Venter et al, 2014).

For the ecoregion types and species, we based our approach on a widely used methodology for setting species targets in global analyses (Rodrigues et al, 2004). This method is based on global range data and sets targets that decrease from 100% for species with distributions <1,000 km^2 to 10% for species with distributions >250,000 km^2, and linearly interpolated on a log-linear scale between these two thresholds (**Figure 4**). However, this method was developed for analyses with a coarse spatial scale based on the recognition that some of the priority regions selected would contain unsuitable habitat. In our analysis, we assumed that our priority areas should directly inform the location of new PAs because our planning units were smaller and our analysis included higher resolution data. This more spatially detailed information came from the 300 m resolution GlobCover landcover dataset, which we used to both exclude planning units that were highly transformed and to map and set targets for natural vegetation types. Thus, our analysis was much less likely to select highly transformed planning units and so we decided to cap these targets at 20% of the total range of each species. This also ensured the total extent of the priority areas would be closer to the national coverage targets set by each country as part of their CBD commitments.

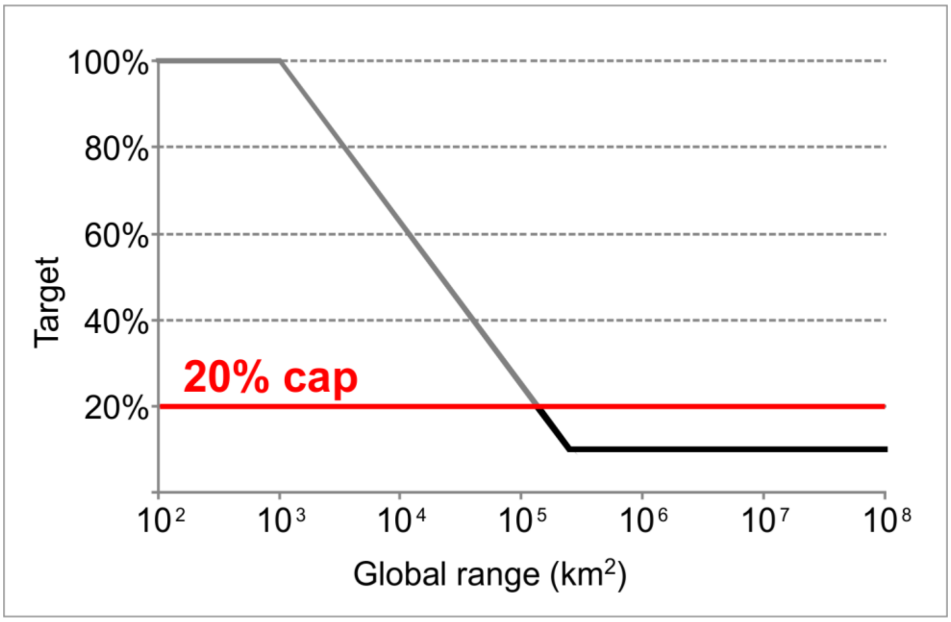


Figure 4: The approach used to set species targets based on their global ranges. This is based on a methodology developed by Rodrigues et al (2004) but each target is capped to 20% because the PARCC analyses used data with a relatively fine spatial scale.

Thus, our initial target for each species and ecoregion was calculated based on determining the total range of the conservation feature, that is to say the global range for the ecoregions and current species distributions and the total area that had been modelled for the SDMs (which covered Africa and the Mediterranean region). For each species we then worked out the percentage of the range that should be conserved based on the Rodrigues et al (2004) approach and then capped this at 20%.

Producing the Conservation Planning Systems

The first step in developing a conservation planning system (CPS) is to define the planning region, which in our case was West Africa. We then divided the region into a number of planning units, which were based on a layer of hexagons, clipping this to the planning region boundary and then combining this with the PA and IBA boundary layers. We set the hexagon sizes as 250 km^2, as we wanted to balance the need for the results to have a fine enough spatial resolution while having a small enough number of planning units to ensure that Marxan could produce efficient results. This meant the final system contained 48,534 planning units.

The PA boundary data were extracted from the World Database on Protected Areas (WDPA) (IUCN and UNEP-WCMC 2015) and the IBA boundary data were provided by BirdLife International. The WDPA boundary data consisted of polygons for most PAs, but in some cases we only had data showing the centroid of the polygon and the total area of the PA. For the point data we used buffers to represent each PA as a circle around the centroid with the PA area. Combining the data in this way produced planning units that were regular hexagons or sections of hexagons wherever they were split by a PA or IBA boundary or clipped by the national boundary (**Figure 5**).

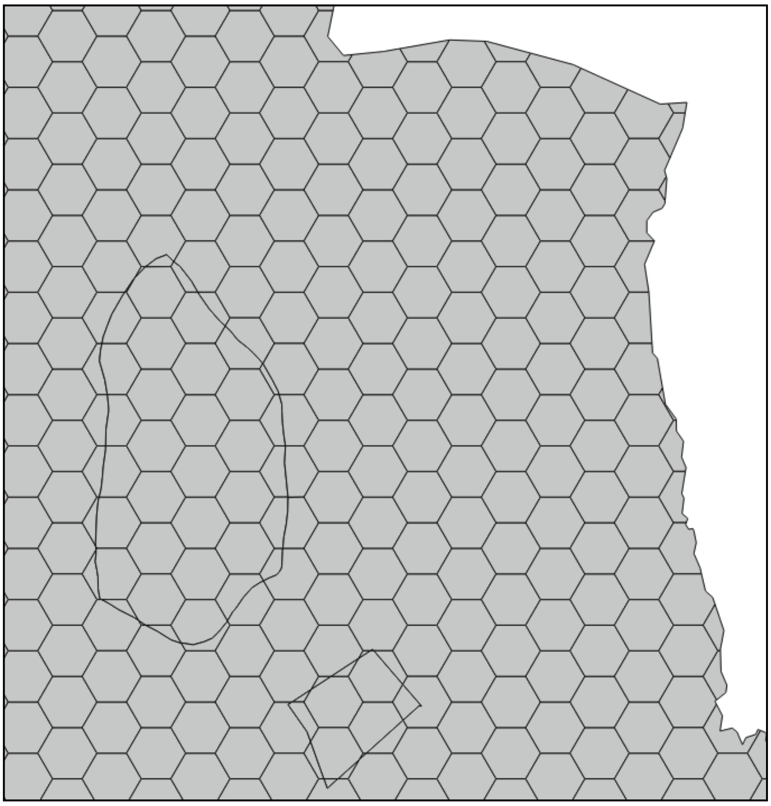


Figure 5: Details of planning units produced by combining a regular hexagon layer, the layer of protected area boundaries and the layer of Important Bird and Biodiversity Areas. It shows that each planning unit is a hexagon unless it is found at the boundary of the planning region or is part of an existing PA or IBA

The next step was to calculate the cost of each planning unit and we decided to base this on the human population size, so that Marxan would avoid selecting areas with a high population density where possible. Agricultural opportunity cost data are also available at a global scale (Naidoo and Iwamura, 2007) but we decided not to use this in our analysis, as it risks selecting areas of subsistence agriculture that have low economic value but are important for poor people's livelihoods (Butchart et al, 2015). Instead, we used the 1-km resolution Global Rural-Urban Mapping Project (GRUMPv1) dataset (CIESIN et al, 2011) dataset and used ArcGIS to calculate the number of inhabitants per planning unit. However, the human population per planning unit varies by more than three orders of magnitude from north to south and this makes it difficult for Marxan to produce results that balance efficiency and ecological viability throughout the region. Thus we produced a modified planning unit cost, which reduced the large differences but still gave an effective relative cost, based on the following formula: Planning unit cost = $\log_{10}$(planning unit human population size + 1) + 0.1

We then imported all of the data into the CLUZ plugin for QGIS. This involved specifying the planning unit layer and producing a table that listed every conservation feature and its target. We then imported the conservation feature distribution data into CLUZ, which we had already extracted from the vegetation, ecoregion, elevation zone, IUCN range maps and PARCC SDMs.

Finally, we set the status of each planning unit, based on whether it is “Conserved” (i.e. if it is already part of a PA) and should always be included in the priority areas selected by Marxan, or whether it is “Excluded” and should never be selected by Marxan (for example, because it has a very high human population and would not make a suitable PA). We set the status of every planning unit that fell within a PA or unprotected IBA as Conserved, following the example from previous studies (Butchart et al, 2015) and the national analyses that we undertook as part of PARCC. We used this approach in the national analyses based on feedback from local experts, who argued that IBAs should be treated in the same way as PAs, as they had been identified as globally important by BirdLife International and had similar or higher levels of conservation management than many PAs. We set the Excluded planning units based on their human population density and the proportion of their area under unsuitable landcover types (defined as irrigated cropland, rainfed crops and artificial surfaces). Based on feedback that we received during workshops to develop the national conservation planning systems, we selected 250 inhabitants per km^2 as the human population density threshold and 75% as the unsuitable landcover threshold.

Gap analysis

By importing the distribution of each conservation feature into CLUZ, setting their targets and setting the status of each planning unit, we automatically calculated the percentage of each target met by the PA and IBA systems. This provided the data for the gap analysis and we recorded for each conservation feature whether the percentage of its target met fell into one of the following four categories: 0% – 2% (referred to as “Unprotected”), >2 – 50% (referred to as “Very poorly protected”), >50% - 98% (referred to as “Poorly protected”) or >98% (referred to as “Target met”). The categories were adapted from the approach used by Butchart et al (2015) and allowed for the imprecision in the boundaries of the IUCN species distribution range maps, some of which were developed at a relatively coarse spatial scale. This imprecision means that a species may appear to have a protection value that is a few percentage points above or below the actual value, so we defined any species as unprotected if its target percentage was 2% or less and defined it as having its targets met if the target percentage was 98% or more.

Calibrating the Marxan parameters

Marxan is a systematic conservation planning software package that identifies near-optimal portfolios of planning units that meet conservation feature targets, whilst minimising costs and reducing fragmentation levels. The user can influence the fragmentation levels by adjusting the Boundary Length Modifier (BLM) value. Selecting a higher BLM creates a higher cost for having fragmented portfolios and, as a consequence, Marxan selects larger patches of planning units to reduce this cost. After running some sensitivity analyses we decided that a BLM value of 0.004 produced efficient results that were not overly fragmented. The user can also determine the importance of meeting each target by setting a “species penalty factor” (SPF), which is multiplied by the estimated cost of meeting any target shortfall. We used a SPF value of 10 for each feature in order to ensure that each target was met but was not so large that it would mask the trade-off between the combined planning unit cost and boundary cost.

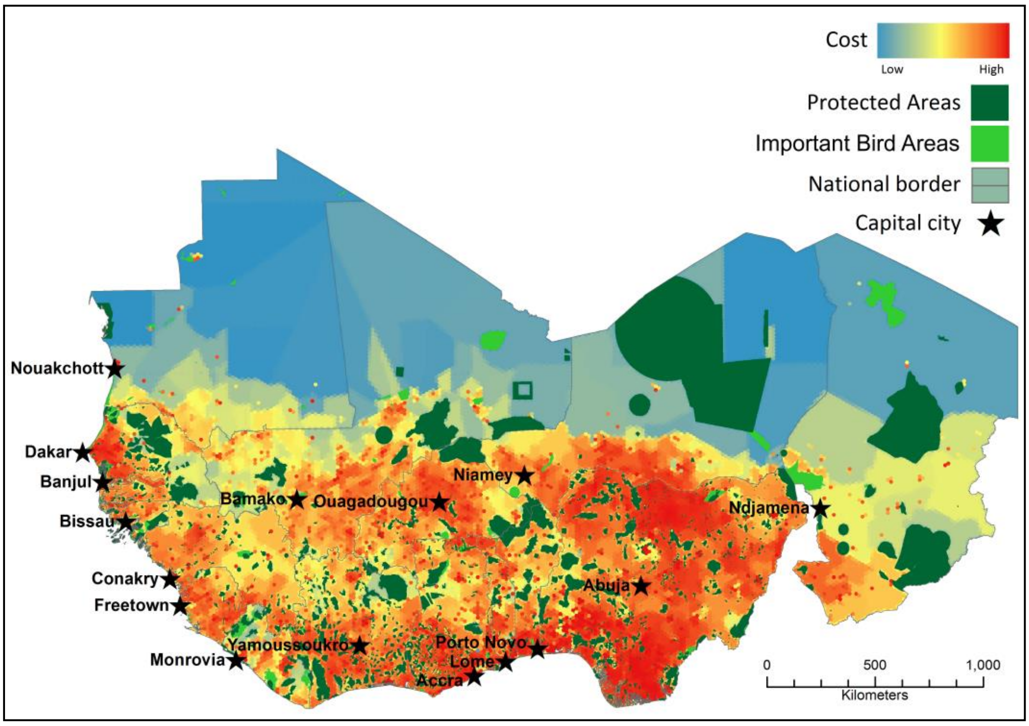


Figure 6: Map of West Africa showing major cities, administrative boundaries, Protected Areas, Important Bird and Biodiversity Areas and planning unit cost data.

Results

Conservation feature details and gap analysis

The West Africa conservation planning system classified 921,433 km^2 (12.6%) as already being in PAs and 84,033 km^2 (1.1%) as already being in currently unprotected IBAs (**Figure 7**A). The percentage of each country with PA or unprotected IBA status varied between 1.1% for Mauritania and 34.8% for Guinea-Bissau (**Table 1**). The planning system contains data on 17 natural vegetation types, 28 ecoregions, 171 amphibian species, 884 bird species, 230 mammal species and SDMs for 316 species in 2010-2039. Conservation feature richness per planning unit varied between 1 and 1456, with a median richness of 608 (**Figure 7**B).

A)

B)

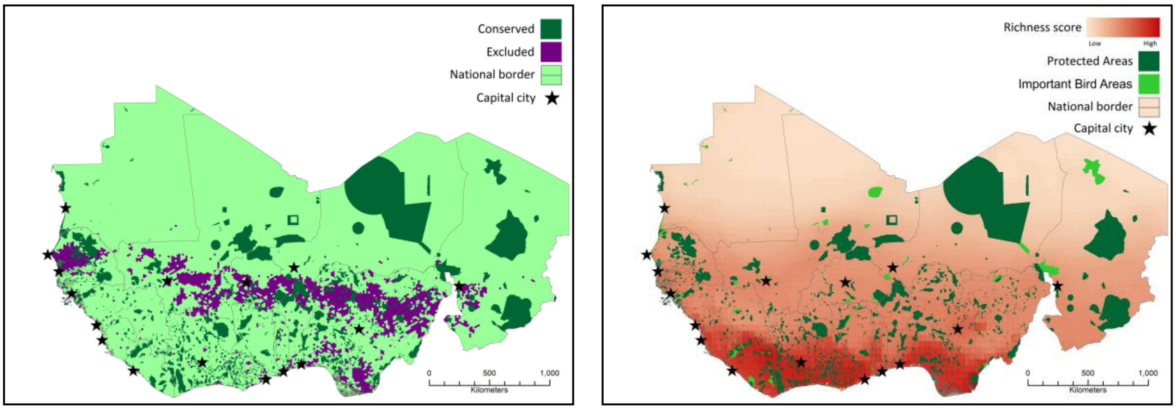


Figure 7: Maps for West Africa showing (A) the status of the planning units used in Marxan and (B) the conservation feature richness, where the richness values range from 1 to 1456.

The current PA network meets targets for 86.9% of the conservation features used in this project and meets targets for 89.5% when IBAs are included in the PA system. The PA and IBA network meet targets for 68.8% of the national targets, 72.9% of the broad biodiversity elements (ecoregions, elevation zones and vegetation types), 66.7% of the amphibians, 89.9% of the birds, 82.6% of the mammals and 94.0% of the SDMs predicting the distributions of threatened and climate change vulnerable species in 2010-2039.

However, with regards to the broad biodiversity elements, the existing PA network fails to conserve any of the East Saharan montane xeric woodland or Mandara Plateau mosaic ecoregion (Table 2). The PA network is also failing to protect any of the range of 20 amphibians, 23 birds and 6 mammals. This means that 3.5% of all of these species are absent from the current PA system, although this is reduced to 2.6% when the unprotected IBAs are included (**Figure 8**). This pattern is even stronger when only considering threatened species, where 5.7% of threatened species are absent from the PA system, which is reduced to 1.9% when the IBAs are included (**Figure 9**).

The PA and IBA network is better at meeting targets for the future predicted distribution of species, although 0.81% species of birds and 0.25% of mammals are completely unprotected (**Figure 10**). In contrast to the findings for the current distribution of species, the future distributions of the threatened species are better protected than non-threatened species (**Figure 11**).

Table 1. Details of how well each country is meeting their national Aichi target 11 PA coverage targets. The percentage target met can be more than 100% if the amount protected is higher than the target set.

Name	Total area (km^2)	Area in PAs (km^2)	Area in IBAs (km^2)	Target (km^2)	% target met by PAs & IBAs
Benin	115,205	27,181	629	19,585	142.0
Burkina Faso	273,985	39,685	2,013	46,578	89.5
Chad	1,270,797	158,850	30,335	190,620	99.3
Cote d'Ivoire	320,763	70,540	1,373	54,530	131.9

Gambia	10,623	441	220	1,593	41.5
Ghana	238,618	34,584	2,361	42,951	86.0
Guinea	244,701	13,298	1,680	36,705	40.8
Guinea-Bissau	33,737	9,203	2,536	5,735	204.7
Liberia	95,830	12,549	7,720	23,958	84.6
Mali	1,252,481	75,287	14,384	150,298	59.7
Mauritania	1,038,974	6,276	5,111	166,236	6.9
Niger	1,181,133	294,611	6,831	165,359	182.3
Nigeria	907,916	119,337	3,481	154,346	79.6
Senegal	195,258	49,288	4,682	33,194	162.6
Sierra Leone	72,326	4,079	512	12,295	37.3
Togo	56,658	6,221	166	7,932	80.5

Table 2: Details of the ecoregions used as conservation features in the West Africa conservation planning system and showing targets capped at 20% of the total distribution.

Name	Total area (km^2)	Area in PAs (km^2)	Area in IBAs (km^2)	Target (km^2)	% target met by PAs & IBAs
Atlantic coastal desert	16,913	5,299	338	3,383	166.6
Cameroonian Highlands forests	9,107	1,854	496	1,821	129.0
Central African mangroves	17,294	1,697	133	3,459	52.9
Cross-Niger transition forests	20,599	534	0	4,120	13.0
Cross-Sanaga-Bioko coastal forests	15,951	5,819	728	3,190	205.2
East Saharan montane xeric woodlands	25,713	0	0	5,143	0.0
East Sudanian savanna	172,654	46,893	11	17,265	271.7
Eastern Guinean forests	187,866	39,950	618	27,369	148.2
Guinean forest-savanna mosaic	660,433	71,402	4,990	66,043	115.7
Guinean mangroves	21,603	3,845	1,572	4,321	125.4
Guinean montane forests	30,924	3,359	244	6,185	58.3
Inner Niger Delta flooded savanna	45,868	5,083	526	9,174	61.1
Jos Plateau forest-grassland mosaic	13,281	1,199	5	2,656	45.3
Lake Chad flooded savanna	18,226	3,153	6,362	3,645	261.0
Mandara Plateau mosaic	1,800	0	0	360	0.0
Niger Delta swamp forests	14,078	1,121	0	2,816	39.8
Nigerian lowland forests	66,661	11,425	3	13,332	85.7
North Saharan steppe and woodlands	267,624	161	2,026	26,762	8.2
Northern Congolian forest-savanna mosaic	91	42	2	9	476.3
Sahara desert	1,199,021	74,877	251	119,902	62.7
Saharan halophytics	5,561	0	256	1,112	23.0
Sahelian Acacia savanna	1,832,359	255,233	14,216	183,236	147.1
South Saharan steppe and woodlands	684,750	142,818	8,025	68,475	220.3
Tibesti-Jebel Uweinat montane xeric woodlands	73,680	0	18,498	14,736	125.5
West Saharan montane xeric woodlands	59,980	20,486	389	5,998	348.0
West Sudanian savanna	1,631,655	189,255	12,108	163,166	123.4
Western Guinean lowland forests	203,790	30,961	8,731	27,097	146.5

Table 3: Details of the elevation zones and vegetation types used as conservation features in the West Africa conservation planning system. Targets were set at 10% of the area of the elevation zones and vegetation types.

Name	Total area (km^2)	Area in PAs (km^2)	Area in IBAs (km^2)	Target (km^2)	% target met by PAs & IBAs
Elevation zones					
0-500 m elevation	6,004,838	704,967	54,495	600,484	126.5
500-1000 m elevation	1,100,542	189,081	9,631	110,054	180.6
>1000 m elevation	111,676	16,854	17,219	11,168	305.1
Vegetation types					
Mosaic vegetation	734,273	80,312	8,873	73,427	121.5
Closed open forest	196,918	45,984	8,177	19,692	275.3
Open forest woodland	392,668	91,945	2,794	39,267	241.3
Mosaic forest-shrubland grassland	295,371	66,658	2,309	29,537	233.5
Mosaic grassland forest-shrubland	43,028	9,506	171	4,303	225.0
Shrubland	711,665	88,368	4,329	71,166	130.3
Herbaceous vegetation	703,159	67,744	4,822	70,316	103.2
Sparse vegetation	101,361	13,331	1,983	10,136	151.1
Closed open flooded forest	5,397	1,408	302	540	317.2
Closed flooded forest	17,243	4,004	1,444	1,724	318.5
Closed flooded grassland woody vegetation	10,387	1,713	1,356	1,039	295.5
Bare areas	3,119,651	369,937	36,299	311,965	130.2
Water bodies	22,779	1,910	2,419	2,278	189.9

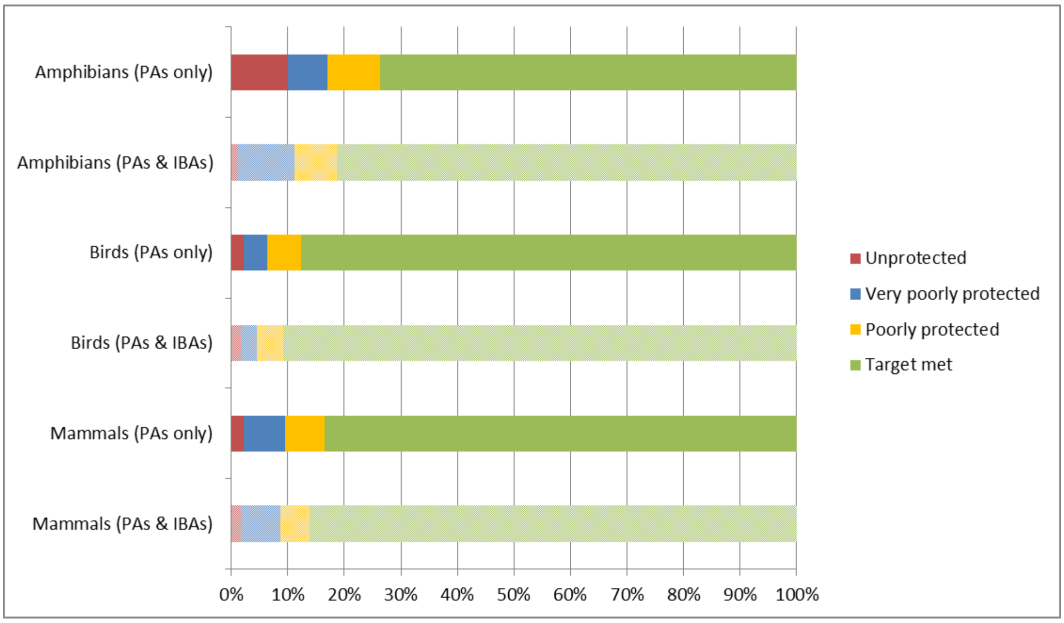


Figure 8: Percentage of amphibian, bird and mammal species for which the set target (i.e. proportion of their current distribution range to be protected) is met by the existing Protected Area (PA) network and Important Bird and Biodiversity Areas (IBAs).

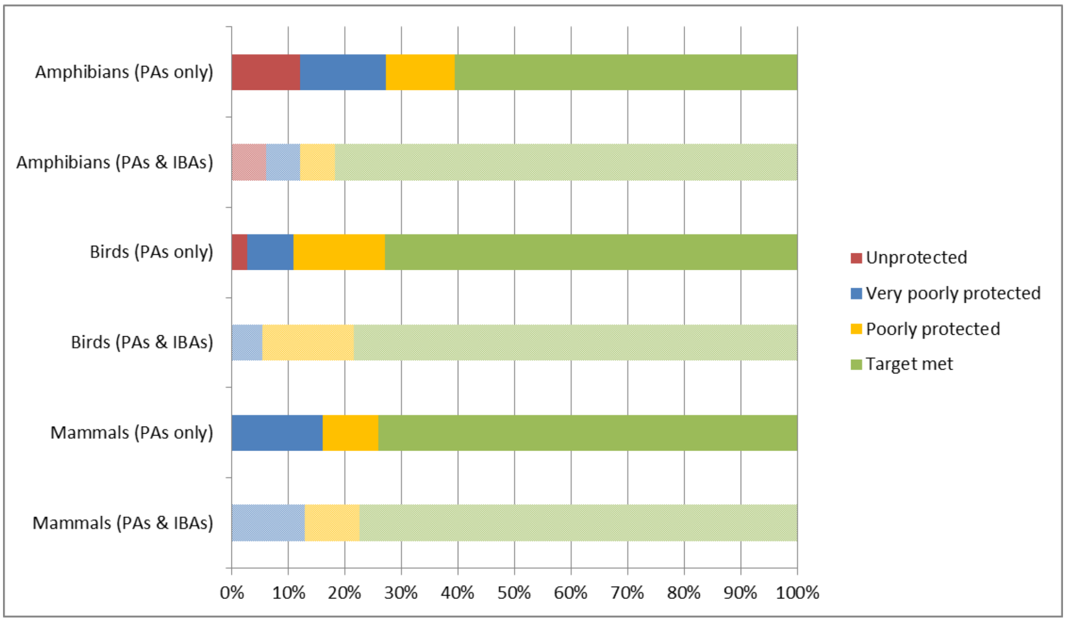


Figure 9: Percentage of threatened amphibian, bird and mammal species for which the set target (i.e. proportion of their current distribution range to be protected) is met by the existing Protected Area (PA) network and Important Bird and Biodiversity Areas (IBAs).

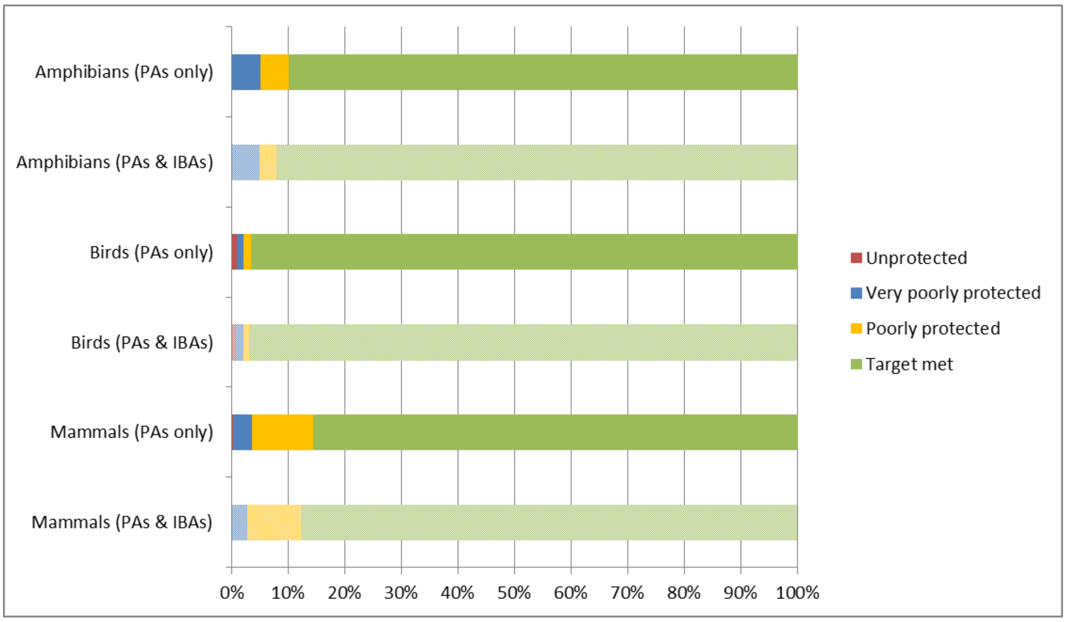


Figure 10: Percentage of amphibian, bird and mammal species for which the set target (i.e. the proportion of their future predicted distribution range for the 2010-2039 time period to be protected) is met by the existing Protected Area (PA) network and Important Bird and Biodiversity Areas (IBAs).

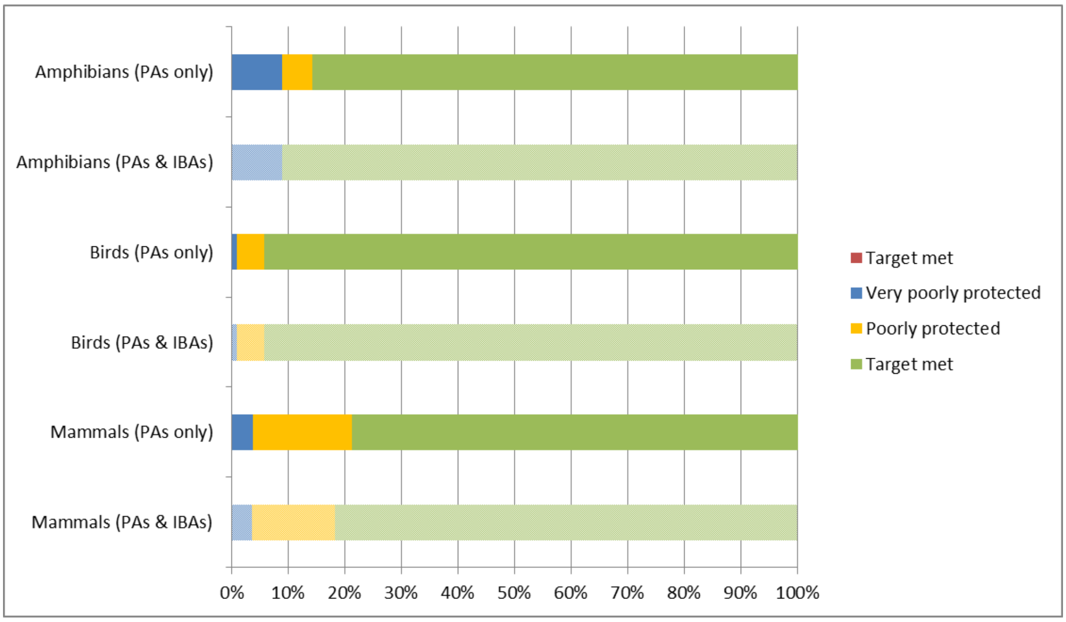


Figure 11: Percentage of threatened amphibian, bird and mammal species for which the set target (i.e. the proportion of their future predicted distribution range for the 2010-2039 time period to be protected) is met by the existing Protected Area (PA) network and Important Bird and Biodiversity Areas (IBAs).

Systematic conservation assessment

Most of the areas with high selection frequencies are found in Côte d'Ivoire, Ghana and Mauritania, with additional smaller patches in Nigeria. In addition, there are priority areas neighbouring existing PAs in many of the countries (**Figure 12**). The total area of planning units with very high selection frequency scores was 16.2% (**Table 4**, **Figure 12**) and the mean area of the four best portfolios was 1,577,341 km^2, which is 21.6% of the region (**Figure 13**). This means that the Marxan analysis suggests that an additional 7.9% of the region should be under conservation to meet all the conservation targets. The four best portfolios show that large parts of Côte d'Ivoire, Ghana and Mauritania are needed to meet targets. Some of these areas also have high selection frequency scores and would always be needed to meet the targets. However, some of the patches in Mauritania have low selection frequency values, showing that there is more flexibility when selecting areas to meet targets in that part of the planning region (**Figure 12** and **Figure 13**).

Table 4: Details of the area of planning units in West Africa grouped by their selection frequency scores.

Selection frequency categories & values (number of times selected from 100 runs).	Area (km^2)	Percentage of region
Low (0 – 49)	5,885,822.26	80.51
Medium (50 -74)	118,415.54	1.62
High (75 – 89)	80,664.54	1.10
Very high (90 – 100)	1,226,100.94	16.77

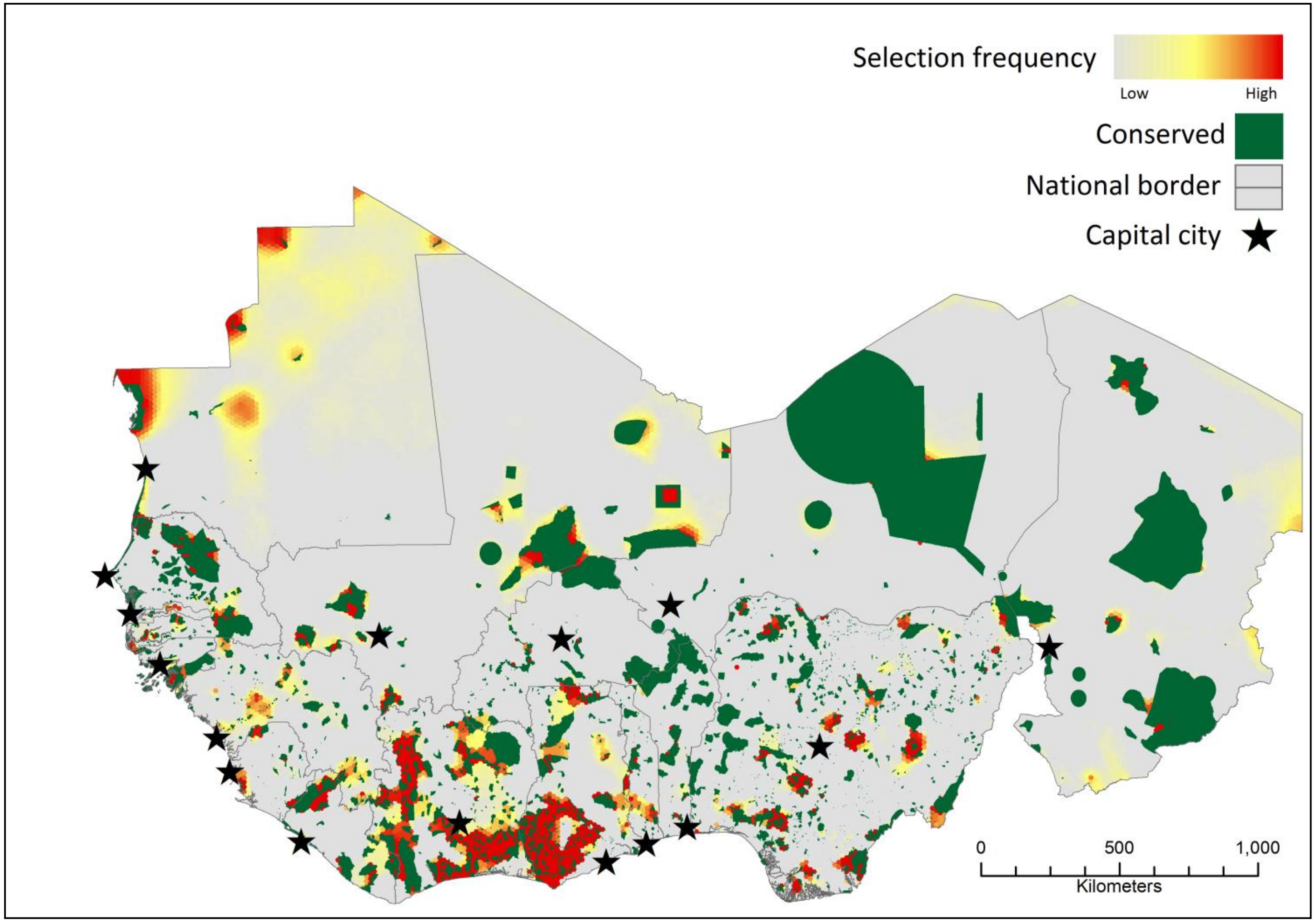
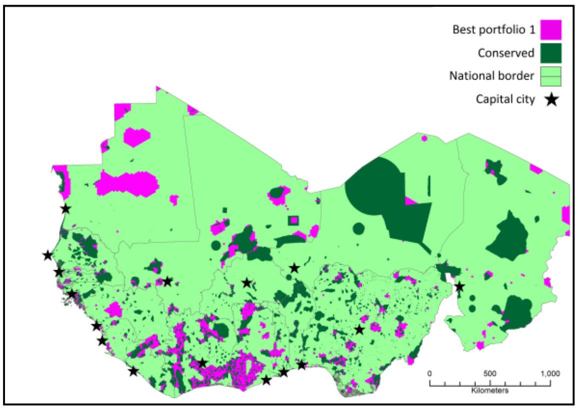
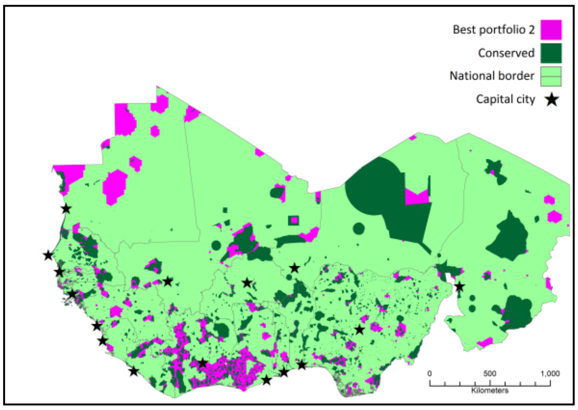


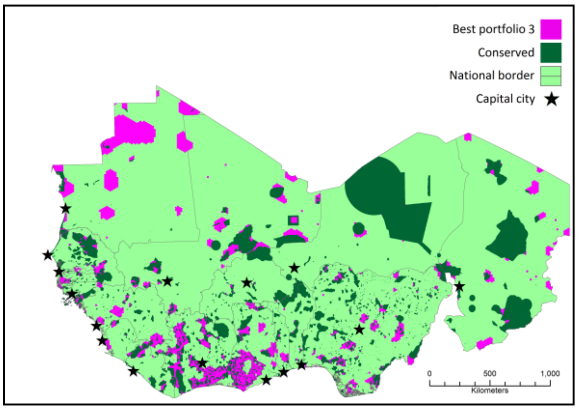
Figure 12: Selection frequency scores for West Africa based on the Marxan analysis. Areas in red were selected in every portfolio identified by the software, based on meeting targets whilst reducing costs and maintaining connectivity.



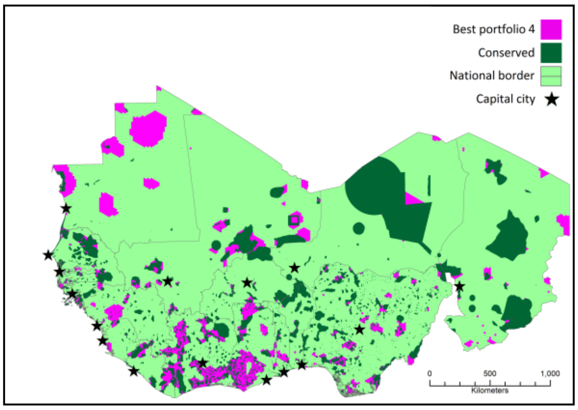
Portfolio 1: Total area = 1,564,892 km^2



Portfolio 2: Total area = 1,588,231 km^2



Portfolio 3: Total area = 1,584,251 km^2



Portfolio 4: Total area = 1,571,990 km^2

Figure 13: The four best portfolios identified by Marxan for meeting the conservation feature targets for West Africa whilst minimising costs. The total area is the combined area of the existing PAs, the unprotected IBAs and the additional priority areas selected by Marxan to meet the targets whilst minimising costs.

Discussion

Protected area networks are a key component of all national conservation strategies and their importance is recognised in the Convention on Biological Diversity. Therefore, it is vital that each country develops PA networks that, as defined in Aichi Target 11, contain "*areas of particular importance for biodiversity and ecosystem services*" and "*are conserved through effectively and equitably managed, ecologically representative and well connected systems of protected areas and other effective area-based conservation measures, and integrated into the wider landscapes and seascapes*". The process of developing such PA networks involves carrying out a gap analysis, to measure how well the existing PAs meet conservation targets, and spatial conservation prioritisations, to identify where new PAs and other conservation areas should be located to fill any target gaps. This report has carried out these analyses for West Africa and in this section we discuss the results, putting them in a broader context and identifying limitations with the analyses that need to be considered.

Gap analysis

The gap analysis showed that West Africa's current PA network meets the majority of the conservation targets and that is improved even further when the IBAs are included in the analysis. This suggests that the PAs and IBAs are generally covering the most important areas for biodiversity. This is a generally positive picture, but it should still be highlighted that the PAs and IBAs are failing to meet targets for 13% of the conservation features and that several ecoregions and species are completely unprotected. Perhaps unexpectedly, it is the ecoregions associated with the Sahara Desert and montane areas that are particularly poorly protected, despite being land of low economic potential. This may be because of logistical reasons or because these habitats are at low risk and so were not considered to be a priority for protection. However, there are arguments that such habitats need protection to produce a representative PA network, especially if these ecoregions contain specific habitats and species that are vulnerable or seen as important. This seems to be particularly relevant for the Mandara Plateau in northern Nigeria, which is known to be ecologically diverse but currently has no formal protection.

This regional analysis also showed that the predicted future distributions of the amphibians, birds and mammals in 2010-2039 are relatively well protected by the current PA and IBA network, and this is especially the case for threatened species. This was probably for a number of reasons. First, SDMs could only be produced for species with a relatively wide range, as species with small ranges did not provide sufficient sample points for the modelling process. This meant that many threatened species were not included in the analysis, as these types of species often have small ranges. Second, we only used SDMs for 2010-2039 as models for 2055 and 2085 had high levels of uncertainty, and most species had predicted ranges that changed relatively little and so strongly overlapped with their current ranges. Third, the SDMs have a relatively coarse resolution and so each species had a relatively large range as predicted by the SDMs, targets were therefore often set at 10%, and so easier to achieve.

It is also important to take into account the quality of the data and target-setting methodology when considering the results of the gap analysis. For the distribution data, the main issue is that the ecoregion and species maps show the range of each conservation feature. This means all these range maps include patches that have been transformed into agricultural or urban land. They also do not take into account the fact that most species are limited to a subset of natural vegetation types within this range. Thus, the gap analysis probably underestimates how well each feature is conserved, as they may be absent from much of the unprotected land within their range.

There are also potential issues over how the targets were set, as we used a relatively simple approach that does not account for each feature's threat status, biological characteristics or how much of its range is likely to contain suitable habitat (Pressey et al, 2003). Producing such feature-specific targets would have been ideal but was beyond the scope of this project. Instead, we used a well-established approach that has been used for over a decade (Rodrigues et al, 2004) and accounts for aspects of endemism and threat by seeking to conserve higher percentages of features with smaller ranges. However, in this study we capped these percentage targets to 20%, rather than using the 100% highest value from the original system. This was partly because our analysis used relatively small planning units that would mostly contain natural vegetation types, whereas the original method was developed for global analyses that used very large planning units based on the assumption that the priority areas identified would include transformed land that would be excluded from any eventual PAs. It was also a response to Aichi target 11, which aims to conserve 17% of the terrestrial realm by 2020, so that the amount of land identified as important for conservation would be relatively close to the 17% figure and so could help inform current planning (we did not cap targets at 17% because we wanted our results to guide action beyond 2020). This produces results that are more likely to influence policy but it should be recognised that the ecoregions and species with limited ranges probably need higher levels of protection in the medium- to long-term.

In addition, there is the issue of accuracy of the PA data that was used in this analysis. For this regional analysis we used data on all of the PAs recorded in the WDPA. However, some countries have not submitted the most recent updates of their PA networks to the WDPA. Furthermore, some officially established protected areas are actually not managed for conservation and have often been cleared of much of their natural vegetation through farming. Finally, PAs that are represented as point data in the WDPA were not included in the national systematic conservation planning exercises based on the advice of local experts. This meant that overall, this regional analysis contains more PAs than were included in five national analyses and this should be taken into account when comparing results between analyses.

Identifying priority areas

Marxan identifies priority areas based on meeting conservation targets, minimising costs and habitat fragmentation. Thus, there are two reasons why a priority area is selected. The first is if it is vital for meeting one or several targets. The second is if it helps meet one or several targets, has a low cost and/or helps join or expand an existing PA. None of the targets used in this analysis were more than 20% of each conservation feature's range, so there was generally a relatively high level of flexibility in where Marxan could select planning units to meet these targets. Thus, many of the identified priority areas were selected because they had relatively low human population density or were located near the existing PAs and IBAs. This explains why the selection frequency scores show that most of the priority areas were found around existing PAs. This was especially the case for Côte d'Ivoire and Ghana, in parts of the country where there are many small existing PAs. The only exceptions come from Mauritania, which has relatively few PAs and so contains several ecoregions that are poorly protected. The results from the four best portfolios also provide important insights into where new protected areas should be located. As expected given the gap analysis results, they identify large areas in Côte d'Ivoire, Ghana and Mauritania, as well as significant amounts of land in almost every one of the other countries. In general, similar priority areas were identified in each of the four portfolios, the exception was in Mauritania, where there is more flexibility in where new PAs could be located.

When considering these results, it is also important to be aware of the limitations of the conservation planning system. As with the gap analysis, it should be stressed that most of the conservation feature distribution data were based on range maps and the priority areas might therefore not contain the specific conservation features for which they were selected. However, it is likely that this problem was reduced in the spatial prioritisation compared to the gap analysis because Marxan was more likely to choose planning units with low population density and that met targets for natural vegetation types. Thus, we can be more confident that the priority maps contained untransformed habitat. Another limitation relates to the cost data, as the population density dataset used (GRUMP) only records human population size per large administrative district and therefore failed to distinguish between planning units in the same region. This is why selection frequency scores were relatively low in many areas, as many planning units appeared to have identical costs and could be swapped with similar planning units.

Despite the data limitations, the West Africa conservation planning system provides important information to guide conservation actions and help improve PA systems to better protect biodiversity now and under climate change. However, systematic conservation planning is not a static process and the results presented here should be seen as the beginning of a long-term set of activities. In particular, the results need to be discussed with local experts from a range of sectors. In addition, there is the need to see the gap analysis and conservation prioritisation as a continuous process that should be updated with better data when it becomes available.

Recommendations

Implementing the results

Identify priority sites for implementation. The spatial prioritisation identified many sites where new PAs should be established, based on the conservation targets and distribution data used in the analysis. The importance of these sites should be checked by consulting with local experts and carrying out field visits to check that each site is important for the conservation features for which it was selected. Any assessment should also consider the feasibility of protecting the site. If feasibility is low then the Marxan prioritisation should be rerun, with the site set as Excluded and with all the other priority areas set as Conserved. This will then identify alternative sites that complement the existing PAs, IBAs and priority areas identified in this study

Identify priority species and ecoregions for conservation implementation. The gap analysis identified species that are poorly represented in the current PA and IBA system in West Africa. These results should be checked by consulting with local experts and priority species for additional conservation management should be identified. In particular, there is a need to determine whether ecoregions associated with the Sahara desert need extra protection, as these ecoregions are poorly represented by the current PA system.

Build capacity and mainstream the planning system. Part of the PARCC project involved training experts from the five focal countries to use the Marxan and CLUZ conservation planning software. This training needs to be broadened to include more local practitioners and researchers from all of the West Africa range states so that the planning system can continue to be used and updated by national experts. The government conservation agencies should also work to include outputs from the planning system in their decision making processes and mainstream conservation planning into other sectors.

Improving the conservation planning system

Planning unit cost data. The global human population density dataset we used in the analysis had a coarse-spatial resolution for many of the countries in West Africa. This meant that planning units in the same region often had very similar cost values, making it difficult to distinguish between areas. If a more detailed population dataset is not available, one way to reduce this problem would be to develop a composite cost map that weighted values based on distance from roads, settlements or other forms of infrastructure.

Improve the WDPA data. We used two types of PA data in the planning system: polygons and points from the World Database on Protected Areas (WDPA). However, during our national workshops experts from the five project countries stated that some of this PA data was inaccurate. Thus, there is a need for national experts to revise these data and the government of each West African country should provide up-to-date information to the WDPA managers at UNEP-WCMC to ensure that the WDPA only contains accurate PA polygon data.

Improve the IBA polygon data. The IBA polygons had small boundary and projection issues that meant that they often did not perfectly match with country coastlines or with data on the same sites stored in the WDPA (some IBAs already have PA status). Therefore, there is a need for in-country experts to help BirdLife International update these spatial data.

Include a wider range of conservation features. We used a relatively narrow set of species as conservation features in the conservation planning system. In particular, there were no data yet included on the IUCN Red List on reptiles, invertebrates or plants. Future analyses would benefit from collecting and importing these data into the planning system. Notably, the imminent addition of the extinction risk of all West African species, assessed within the framework of the PARCC project, to the Red List should allow to add data on reptiles to the conservation planning system.

Include more data on planned developments. We were unable to include data on factors that relate to implementing the results of the spatial conservation prioritisation. In particular, we lacked data on where different sectors, such as agriculture, transport and mining, have plans to develop new projects. This is why we focused on the selection frequency results in our analysis, as these are less prescriptive and can be used to identify where priority areas for conservation and other sectors may overlap. However, ideally this implementation data should be included in the prioritisation process so that Marxan can, wherever possible, avoid selecting areas that are planned for development.

Improve the target-setting approach. We adopted a widely-used approach for setting targets for the different conservation features that is based on their global range. We then modified some of these targets following feedback from national experts. This was an effective way of setting targets for such a large group of conservation features, especially as little is known about many of these broad biodiversity elements and species. However, there is scope for revisiting these targets and modifying them based on the available data on threat and species population viability.

References

Baker, D. J., A. J. Hartley, N. D. Burgess, S. H. M. Butchart, D. J. Carr, R. J. Smith, E. Belle, and S. G. Willis. 2015. Assessing climate change impacts for vertebrate fauna across the West African protected area network using regionally appropriate climate projections. *Diversity and Distributions* **21** (9): 991–1003.

Ball, I. R., H. P. Possingham, and M. Watts. 2009. Marxan and relatives: software for spatial conservation prioritisation. In *Spatial conservation prioritisation: quantitative methods and computational tool*, eds Moilanen, A., K.A. Wilson, and H.P. Possingham. Oxford University Press.

Bicheron, P., M. Leroy, C. Brockmann, U. Krämer, B. Miras, M. Huc, F. Ninõ, P. Defourny, C. Vancutsem, O. Arino, F. Ranéra, D. Petit, V. Amberg, B. Berthelot, and D. Gross. 2006. Globcover: a 300m global land cover product for 2005 using ENVISAT MERIS time series. Universitat de Valencia, Valencia, Spain.

Brugiere, D. and P. Scholte. 2013. Biodiversity gap analysis of the protected area system in poorly-documented Chad. *Journal for Nature Conservation* **21**:286-293.

Butchart, S. H. M., M. Clarke, R. J. Smith, R. E. Sykes, J. P. W. Scharlemann, M. Harfoot, G. M. Buchanan, A. Angulo, Balmford, A., B. Bertzky, T. M. Brooks, K. E. Carpenter, M. T. Comeros-

Raynal, J. Cornell, G. F. Ficetola, L. D. C. Fishpool, R. A. Fuller, J. Geldmann, H. Harwell, C. Hilton-Taylor, M. Hoffmann, A. Joolia, L. Joppa, N. Kingston, I. May, A. Milam, B. Polidoro, G. Ralph, N. Richman, C. Rondinini, D. Segan, B. Skolnik, M. Spalding, S. N. Stuart, A. Symes, J. Taylor, P. Visconti, J. Watson, L. Wood, and N. D. Burgess. 2015. Shortfalls and solutions for meeting national and global conservation area targets. *Conservation Letters*, in press.

Carr, J. A., A. F. Hughes, and W. B. Foden. 2014. A climate change vulnerability assessment of West African species. UNEP-WCMC technical report.

Center for International Earth Science Information Network (CIESIN), Colombia University, International Food Policy Research Institute (IFPRI), The World Bank, and Centro Internacional de Agricultura Tropical (CIAT). 2011. Global Rural-Urban Mapping Project Version 1 (GRUMPv1): Urban Extents Grid.in N. S. D. a. A. C. (SEDAC), editor., Palisades, NY.

CBD 2010. Secretariat of the Convention on Biological Diversity, Strategic Plan for Biodiversity 2011-2020 and the Aichi Targets. Pages 1-2. United Nations Environment Programme, Montreal, Quebec, Canada.

IUCN and UNEP-WCMC. 2015. The World Database on Protected Areas (WDPA) [On-line], [May, 2014], Cambridge, UK: UNEP-WCMC. Available at: www.protectedplanet.net.

Knight, A. T., R. M. Cowling, and B. M. Campbell. 2006. An operational model for implementing conservation action. *Conservation Biology* **20**:408-419.

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

Naidoo, R. and Iwamura, T. 2007. Global-scale mapping of economic benefits from agricultural lands: implications for conservation priorities. *Biological Conservation*, **140**:40-49.

Olson, D. M., Dinerstein, E., Wikramanayake, E. D., Burgess, N. D., Powell, G. V., Underwood, E. C., D'amico, J.A, Itoua, I., Strand, H.E., Morrison, J.C, Loucks, C.J., Allnutt, T.F., Ricketts, T.H., Kura, Y., Lamoreux, J.F., Wettengel, W.W., Hedao, P. and Kassem, K. R. (2001). Terrestrial Ecoregions of the World: A New Map of Life on Earth A new global map of terrestrial ecoregions provides an innovative tool for conserving biodiversity. *BioScience* **51**: 933-938.

Platts, P. J., R. A. Garcia, C. Hof, W. Foden, L. A. Hansen, C. Rahbek, and N. D. Burgess. 2014. Conservation implications of omitting narrow-ranging taxa from species distribution models, now and in the future. *Diversity and Distributions* **20**:1307-1320.

Pressey, R. L., R. M. Cowling, and M. Rouget. 2003. Formulating conservation targets for biodiversity pattern and process in the Cape Floristic Region, South Africa. *Biological Conservation* **112**:99-127.

Rodrigues, A. S., H. R. Akcakaya, S. J. Andelman, M. I. Bakarr, L. Boitani, T. M. Brooks, J. S. Chanson, L. D. C. Fishpool, G. A. B. Da Fonseca, K. J. Gaston, M. Hoffmann, P. A. Marquet, J. D. Pilgrim, R. L. Pressey, J. Schipper, W. Sechrest, S. N. Stuart, L. G. Underhill, R. W. Waller, M. E. J. Watts, and X. Yan. 2004. Global gap analysis: Priority regions for expanding the global protected-area network. *Bioscience* **54**:1092-1100.

Venter, O., R. A. Fuller, D. B. Segan, J. Carwardine, T. Brooks, S. H. M. Butchart, M. Di Marco, T. Iwamura, L. Joseph, D. O'Grady, H. P. Possingham, C. Rodinini, R. J. Smith, M. Venter, and J. E. M. Watson. 2014. Targeting global protected area expansion for imperiled biodiversity. *PloS Biology* **12**:e1001891.

Willis, S. G., W. Foden, D. J. Baker, E. Belle, N. D. Burgess, D. J. Carr, N. Doswald, R. A. Garcia, A. Hartley, C. Hof, T. Newbold, C. Rahbek, R. J. Smith, P. Visconti, B. Young, and S. H. M. Butchart. 2015. Integrating climate change vulnerability assessments into systematic conservation planning. *Biological Conservation* **190**: 167–178.