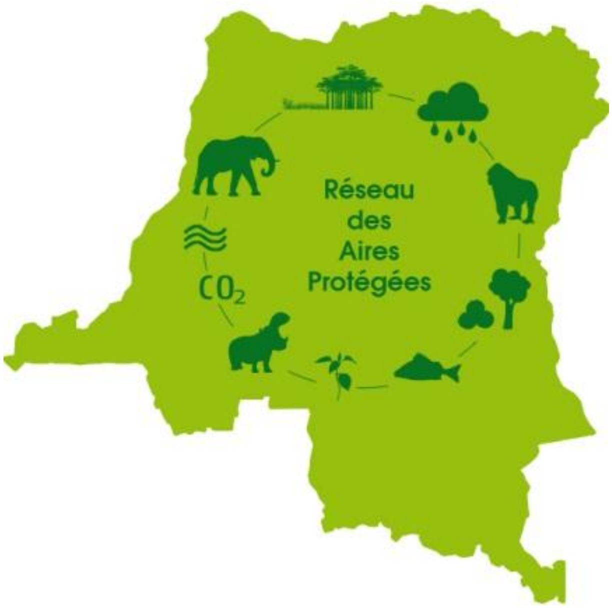
Program to Reinforce the Protected Area Network

Technical Report

Preliminary Results of a Freshwater Biodiversity Marxan Analysis for the Democratic Republic of Congo



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The Program to Reinforce the Protected Area Network (PARAP) is an initiative being jointly implemented by the *Institut Congolais pour la Conservation de la Nature* (ICCN) and the World Wide Fund for Nature (WWF) in the Democratic Republic of the Congo (DRC).

PARAP's objective is to assess the national protected area (PA) network in the DRC to provide practical recommendations for its consolidation and inform planning to realize the Government of DRC's commitment to establish a functional PA network that covers 17% of its national territory.

PARAP is being implemented through an integrated, step-wise approach that aims to balance the application of concepts of systematic conservation planning with more immediate practical priorities. The network-scale evaluation being realized through PARAP will be used to develop a national PA network strategy to improve the efficiency and effectiveness of the PA network in contributing to the long-term conservation and development goals of the DRC.

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Acknowledgements

We would like to thank the joint World Wide Fund for Nature (WWF) - *Institut Congolais pour la Conservation de la Nature* (ICCN) Program to Reinforce the Protected Area Network (PARAP), who funded this study and sponsored the first workshop of the GTT ED on February 23, 2012 in Kinshasa, Democratic Republic of Congo (DRC) with support from the German Federal Ministry of Environment, Nature Conservation and Nuclear Safety (BMU) through its International Climate Initiative (IKI). We would also like to thank the members of the Freshwater Technical Working Group (GTT ED) of PARAP, who kindly shared their expertise and feedback on the data inputs and process. In particular, special thanks to Paya de Marcken and Cyril Pélissier for their leadership and guidance.

There are many institutions and individuals who assisted with data compilation and review; here we list many of those who were individually involved but we also are grateful for the many datasets that have previously been compiled and that are used in the analyses. We appreciate the time that Patrick Lola Amani and Andre Mazinga of the *Observatoire Satellital des Forêts de Afrique Centrale* (OSFAC) spent reviewing available datasets and quality for the region. Our thanks also to Aurelie Shapiro of WWF-Germany for assistance with data compilation prior to the workshop and translation during the workshop, Matthew Steil of World Resources Institute for data and knowledge sharing, Bernhard Lehner of McGill University for providing us with a preliminary Pfafstetter-coded version of HydroSHEDS, and David Allen, Will Darwall, and Rob Holland for their guidance in the use of the IUCN freshwater biodiversity data.

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1. Introduction

1.1 Background

This work was undertaken for the joint WWF (World Wide Fund for Nature) and ICCN (*Institut Congolais pour la Conservation de la Nature*) Program to Reinforce the Protected Area Network (PARAP). The goal of PARAP is to assess the existing protected area system in order to provide recommendations for its consolidation and the establishment of an effective, comprehensive and sustainable national protected area (PA) system that conserves the biodiversity of the DRC and contributes positively and tangibly to poverty alleviation and the sustainable development of the DRC.

As part of its assessment, PARAP includes a component aimed at improving the integration of freshwater conservation and management into the PA system of DRC. The first step in the freshwater component of the PA system evaluation was to examine possible known areas of importance for freshwater species across the DRC. Given the relatively recently compiled IUCN freshwater species data for Africa (Darwall et al. 2008) and recent advances in systematic conservation planning for freshwaters, it was decided to use optimization techniques to assist in the identification of priority areas. The proposed methodology was presented at the first meeting of the Freshwater Technical Working Group (GTT ED) of PARAP (see Appendix 1 for a list of members and attendees) in Kinshasa on February 23rd, 2012. Below we present the full process, including compilation of existing data layers and decisions made regarding data use and methodology; the results of the analysis with different input parameters, and recommendations for next steps.

1.2 Systematic conservation planning

Conservation of biodiversity usually competes with other human interests and activities (Margules *et al.*, 2002), hence protection of all areas that contribute to the conservation of biodiversity is not feasible from a socio-economic perspective. Given these constraints, the prioritization of areas in terms of their importance or contribution to the conservation of biodiversity is a reasonable solution to find where to expend the limited resources intended for conservation purposes (Knight *et al.*, 2007). Conservation planning intends to find the areas that best represent the biodiversity under consideration and the processes that will allow its long term persistence (Margules & Pressey, 2000).

Systematic conservation planning (Margules & Pressey, 2000) aims to identify an optimum set of areas that cost-efficiently represent the desired conservation features (e.g., species, ecosystem types), using complementarity-based approaches and incorporating cost in the selection process. Complementarity is defined as the gain in representativeness of biodiversity when a site is added to an existing set of areas (Possingham et al., 2000). Methods that incorporate complementarity have been shown to lead to more effective representation of biodiversity features and more cost-efficient solutions than ad-hoc (Pressey & Tully, 1994), scoring or ranking strategies (Margules *et al.*, 2002; Pressey & Nicholls, 1989). Systematic conservation planning methods have been extensively applied to conservation problems in marine and terrestrial environments (e.g., Carwardine *et al.*, 2008; Klein *et al.*, 2008) and more recently to freshwater environments (Moilanen et al., 2008; Hermoso et al., 2011; Linke et al., 2011).

Freshwater systematic conservation planning is an emerging discipline that has started to receive special attention from the scientific community in the past 5 years as a response to the lack of effective conservation of freshwater biodiversity (Abell et al., 2007; Linke et al., 2008, 2011; Turak & Linke, 2011).

This is despite freshwater ecosystems being among the most diverse and threatened systems in the world (Strayer & Dudgeon, 2010) and being exposed to higher pressures than adjacent terrestrial or marine ecosystems (Malmqvist & Rundle, 2002; Nel et al., 2007). To date, there has been little emphasis on declaring protected areas for the primary purpose of conserving freshwater ecosystems and biodiversity (Saunders et al., 2002; Abell et al., 2007). Instead, uninformed opportunism has reigned, whereby conservation of freshwater ecosystems is peripheral to conservation goals developed for terrestrial ecosystems (Olden et al., 2010).

2. Data and methods

2.1 Spatial framework (Hydrosheds)

HydroSHEDS is a global hydrological framework that delineates catchments globally at multiple scales (Lehner et al. 2008). HydroSHEDS provides selected core and auxiliary data sets at 3 arc-second and 15 arc-second resolutions, including drainage directions and elevation surfaces. A vectorized stream network is available at 15 arc-second resolution only. HydroSHEDS is delivered as nested catchments, the highest resolution of which splits the Congo Basin into 30,344 subcatchments (Level 15; Figure 1)

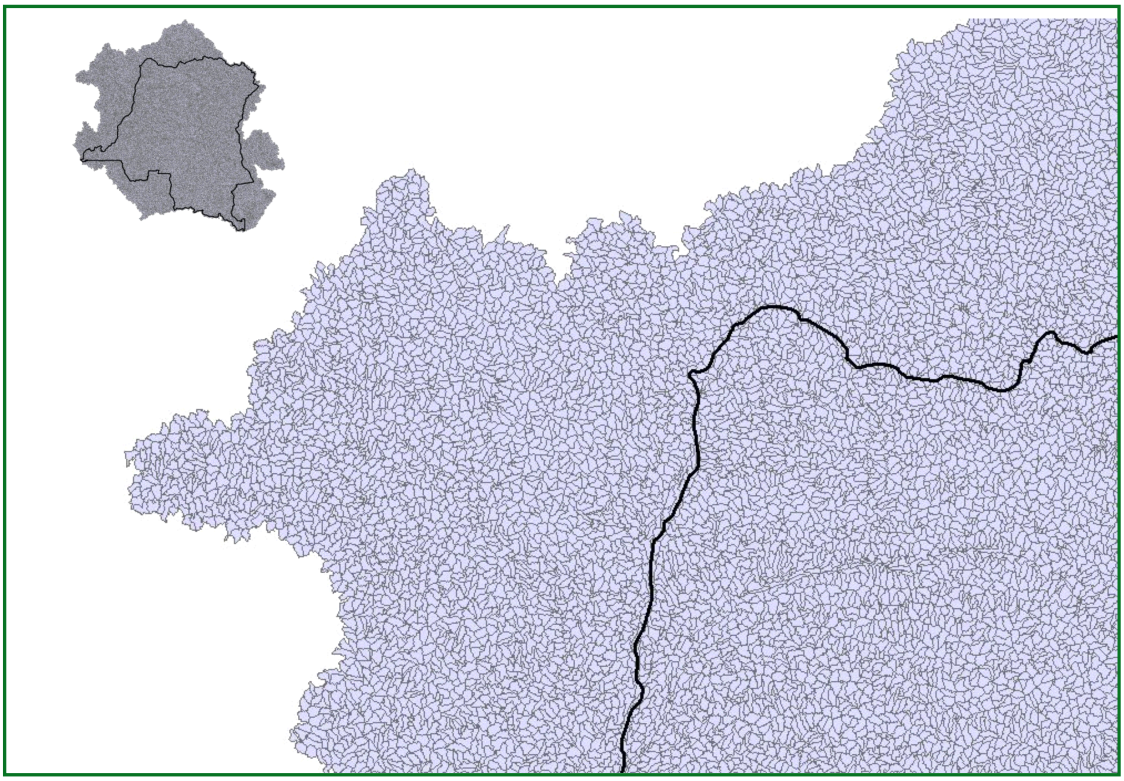
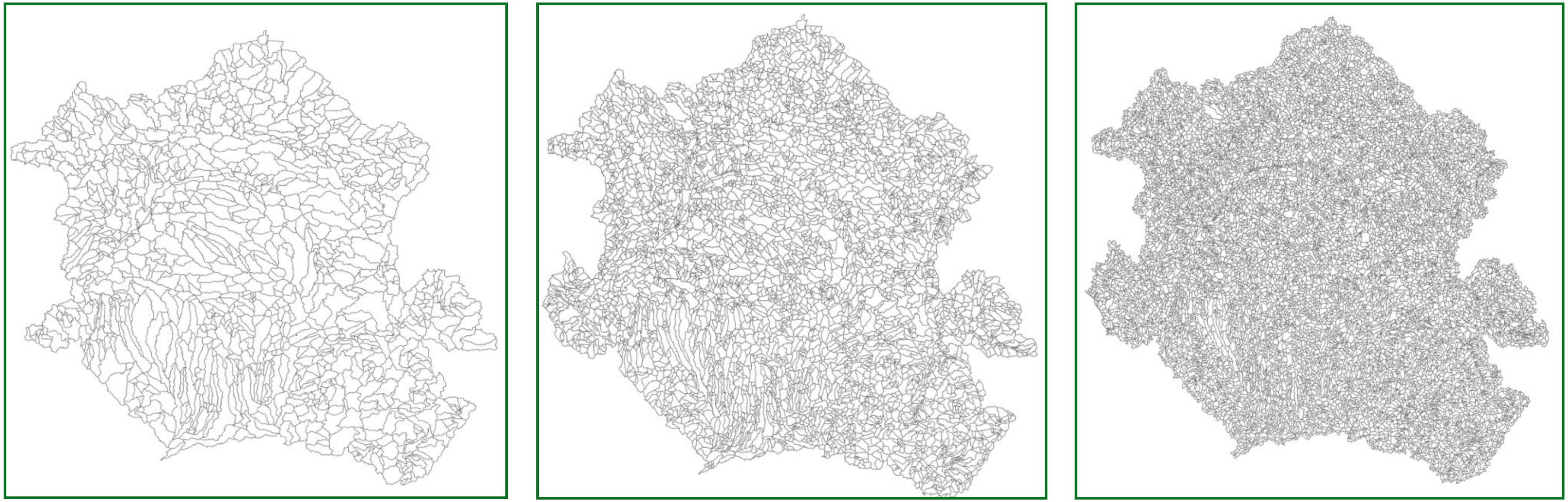


Figure 1. Highest resolution (Level 15) subcatchments for the Congo Basin

Level 15 subcatchments are delineated at a level of detail much beyond the level of data available and the optimisation in a conservation planning software would take days to process. We therefore examined levels 7,8 and 9 subcatchments, comparing the average size and number of subcatchments (Figure 2). We presented all three scenarios at the workshop in Kinshasa and the group decided to use HydroSHEDS Level 8, which splits the Congo Basin into 5255 subcatchments with an average size of 731 km^2. The average stream length per segment was 31.54 km, making up a total of 164843.1 km of stream length within the subcatchments.



Level 7 -1255 subcatchments

Level 8 – 5255 subcatchments

Level 9 – 15115 subcatchments

Figure 2. HydroSHEDS planning units at catchment levels 7, 8 and 9.

Out of the 5255 subcatchments (hereafter called planning units), 3135 had more than 50% of their area inside the Democratic Republic of Congo (DRC). In total, over 50% of the Congo Basin is encompassed within DRC (see Figure 3).

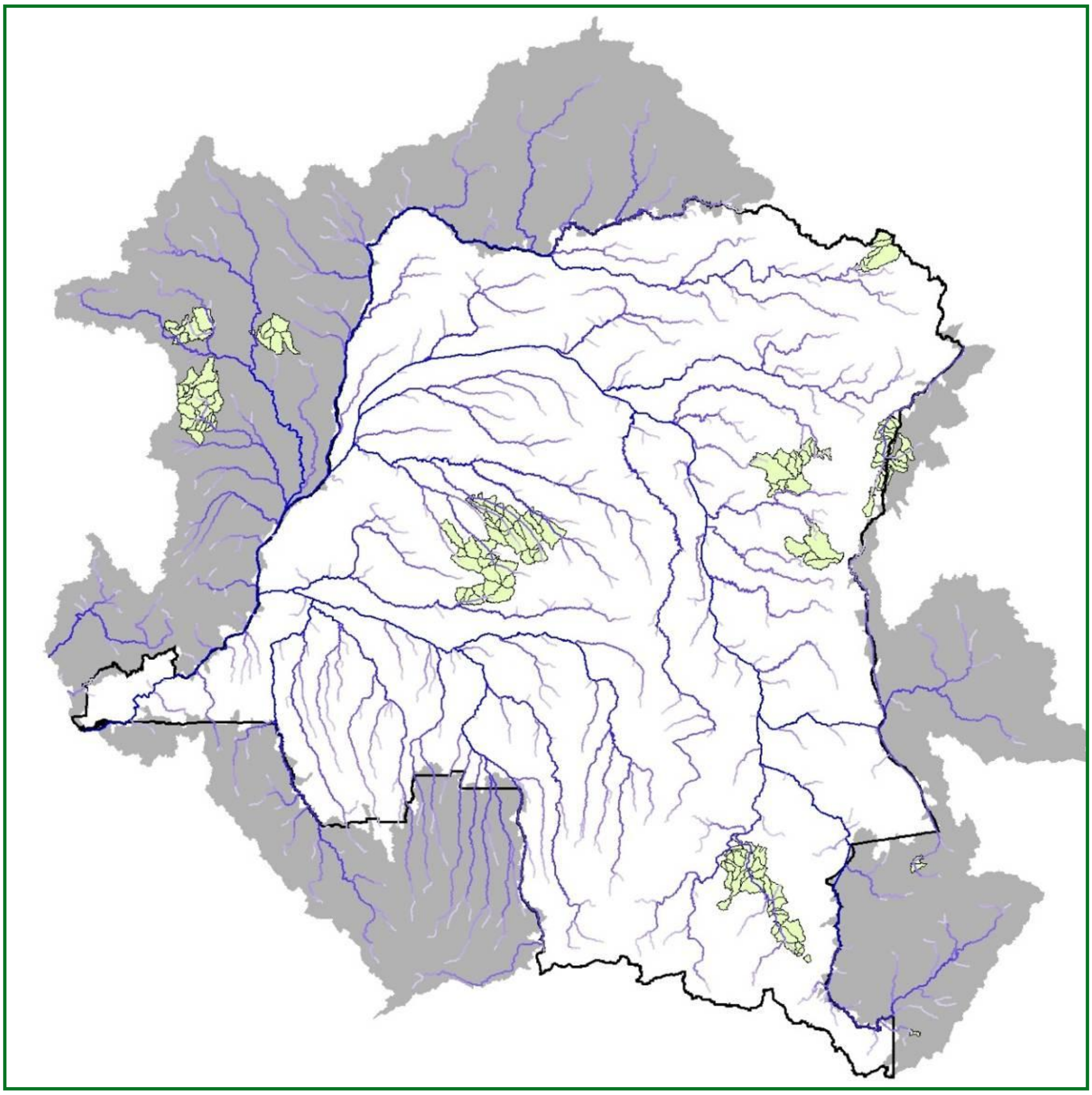


Figure 3. Subcatchments by country: areas outside of DRC (greyed out) and areas that are designated as already protected (in green).

Protected areas for the region were derived from the World Resources Institute data for the DRC, Central African Republic (CAR), Cameroon, and Republic of Congo (ROC) and from the World Protected Area Database for all other countries within the Congo Basin (IUCN and UNEP 2009). Based on consultation with members of the GTT ED, we decided to consider any protected area designated as Level I or a national park as protected, given that these are the highest level of protection and highest likelihood to remain under protection into the foreseeable future. A total of 176 subcatchments (3%) across the basin were classed as protected (>50% of the subcatchment in Level I or as national park), covering an area of 114,471.9 km^2. In the DRC, 3.6% of the subcatchments (125 out of 3125) were classed as protected.

2.2 Conservation features

The conservation features we had available came from three sources:

- An aquatic ecosystem system type classification derived by WWF (Shapiro et al. 2007)
- The IUCN freshwater species database for Africa (Darwall et al. 2011)
- IUCN data for aquatic mammals (IUCN et al. 2008) and amphibians (IUCN et al. 2008).
- Freshwater classification

We intersected the shapefile of the aquatic ecosystem types with the planning units. While the ecosystem classification was roughly at the same scale as the planning units, some of the classes overlapped with multiple subcatchments. We therefore calculated the area of each subclass (classes for cascades, discharge, slope, vegetation and wetlands) in each planning unit and used these as input features in Marxan (see Table 1).

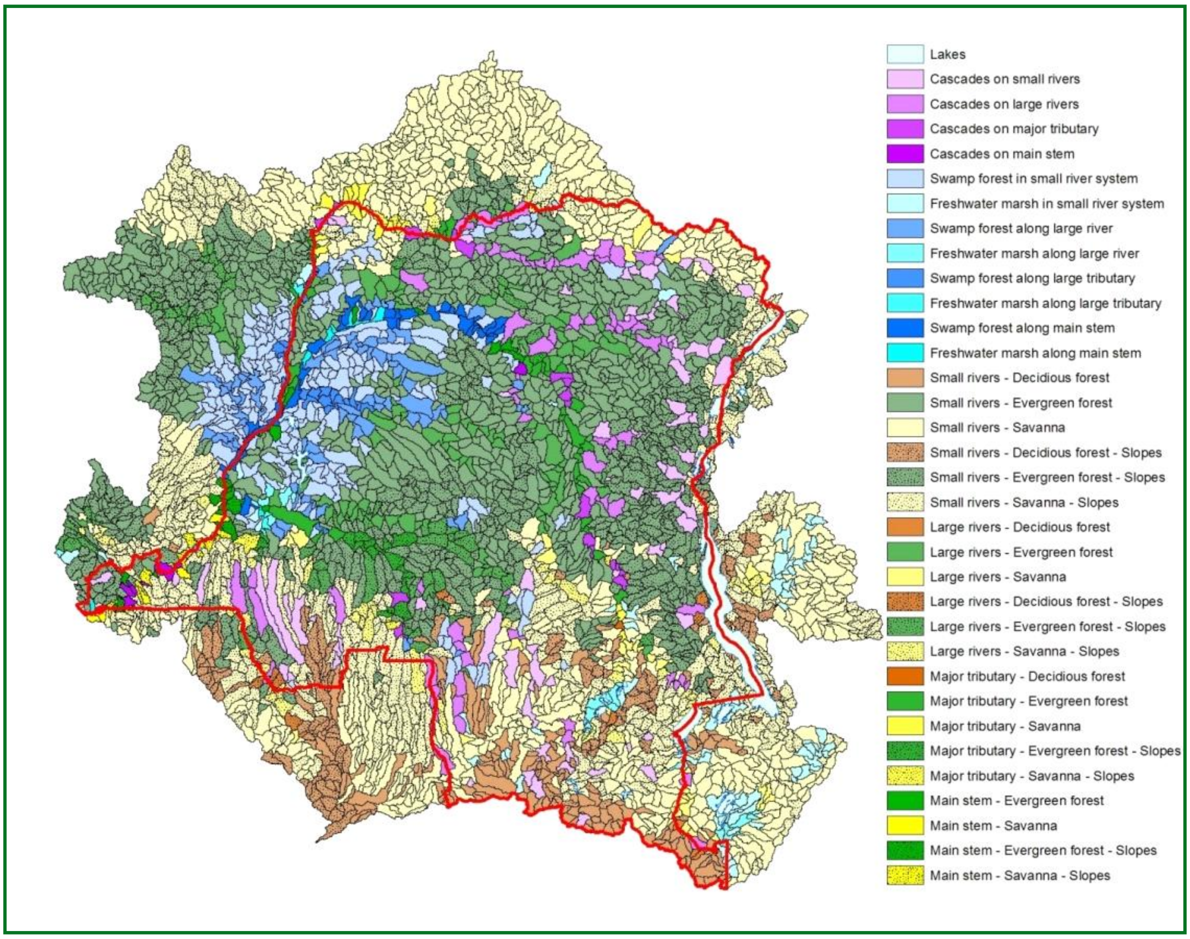


Figure 4. Aquatic ecosystem types in the Congo Basin.

Table 1. Example table for input of freshwater ecosystem type classes

Planning Unit	Feature	Sqkm of subcatchment in class
230	Cascade absent	500
	Cascade present	200
	Vegetation class 1	0
	Vegetation class 2	5
	Vegetation class 3	95

2.3 IUCN freshwater species

The second dataset – and also the main dataset in Marxan – used was the database derived by the IUCN for their African freshwater biodiversity assessment (Darwall et al. 2011). This dataset contained data for:

- crabs
- molluscs
- odonata
- fish
- plants

Initial analysis however showed that the species polygons that had been mapped to Hydro1K-derived catchments (USGS 1996) would not properly overlap with the HydroSHEDS framework.

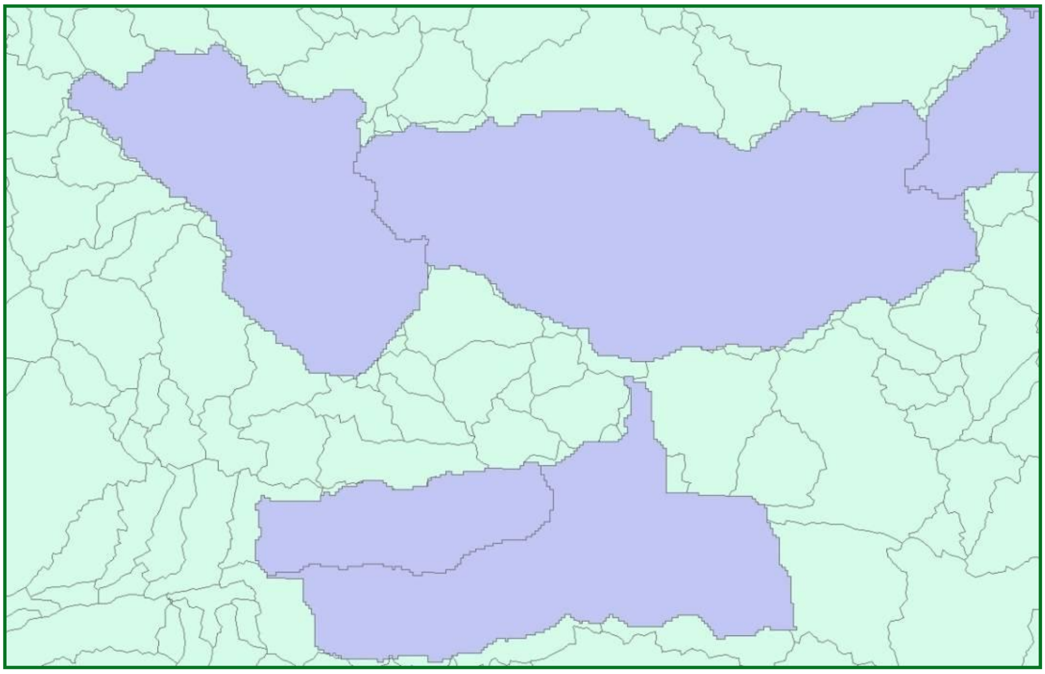


Figure 5. Non-overlapping species distributions from the Hydro1k-derived catchments (in blue) overlayed over Level 8 HydroSHEDS catchments.

This causes problems when species are not native to the Congo Basin, but occur in the neighboring basins (see Figure 6).

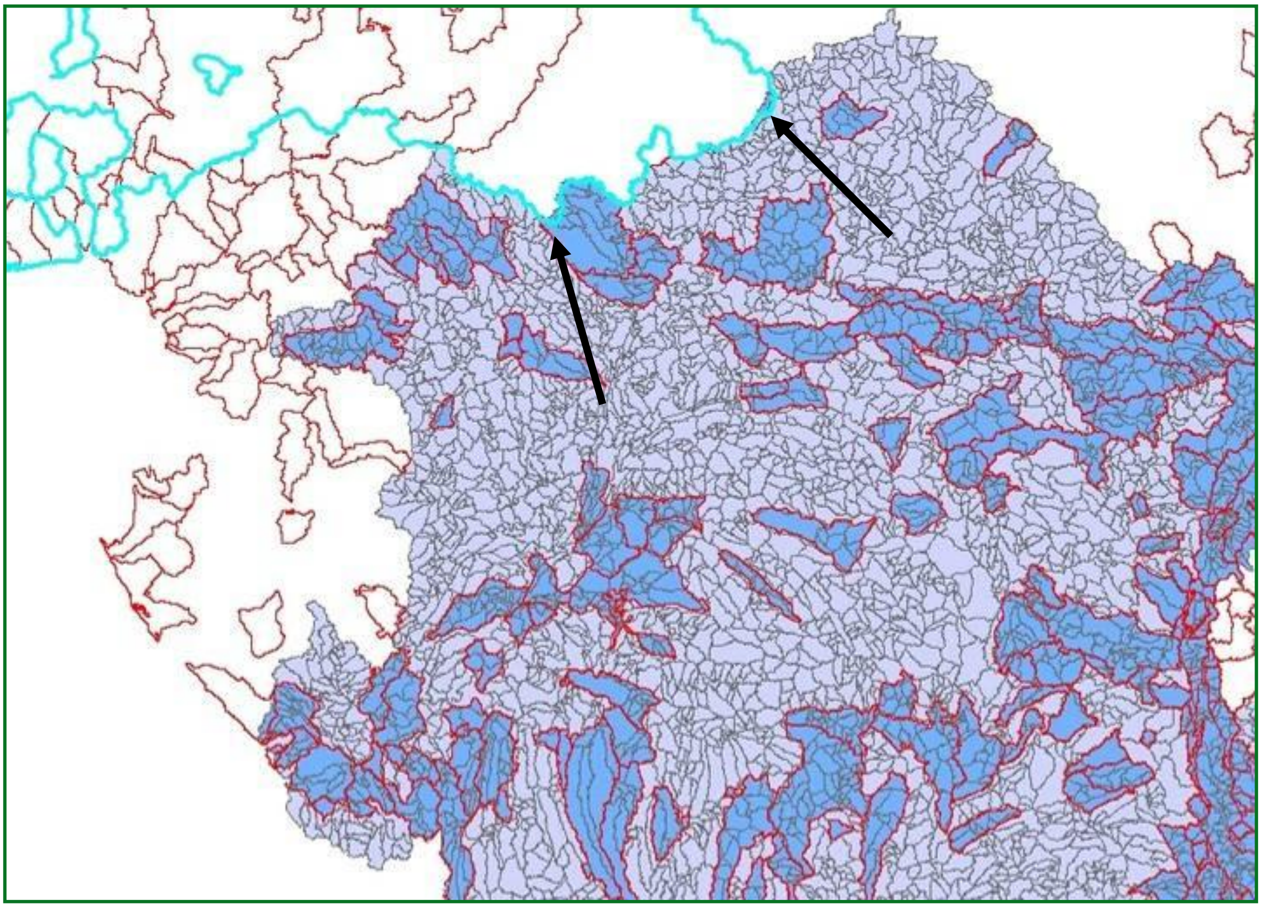


Figure 6. Example of species that occur in neighbouring basins but are attributed to the Congo. The light blue outline shows the boundary of a species that appears to overlap with the Congo Basin, but in reality, does not occur within it.

This type of error would cause problems in all kinds of biodiversity assessments. In a Key Biodiversity Area-style approach (Holland et al. 2012) for example, these species would be labelled as endemics and therefore flag the border catchments as highly valuable. This problem is similar in Marxan. An endemic (or in this case pseudo-endemic) taxon will automatically flag a planning unit as irreplaceable and the planning unit will automatically end up in a conservation plan. Unfortunately we could not check all of the over 2500 species in the database manually, so we developed an algorithm to detect species that only occur on the edge of the Congo basin.

All of the species with their entire distribution area within a 25 km buffer along the Congo River catchment's border were flagged as false positives. This was done by comparing the total area of each species within the Congo River catchment and the area within the 25 km buffer. Whenever AreaBuffer ≤ AreaCongo the species was not considered for further analyses. While we cannot guarantee detection of all of these species, we conducted spot checks and did not find additional species that legitimately occurred only outside of the Congo Basin.

Table 2. Number of false positive species identified for each taxa. A false positive species was one that had its entire range only within a 25 km buffer along the edge of the Congo Basin and thus was identified as a species whose distribution had erroneously been attributed to the Congo Basin due to a mis-match in the Hydro1K and HydroSHEDS-derived subcatchments.

Taxa	Number false positive species
Fish	256
Odonata	39
Molluscs	36
Plants	21
Amphibians	10
Crabs	8
Mammals	2
Total	372

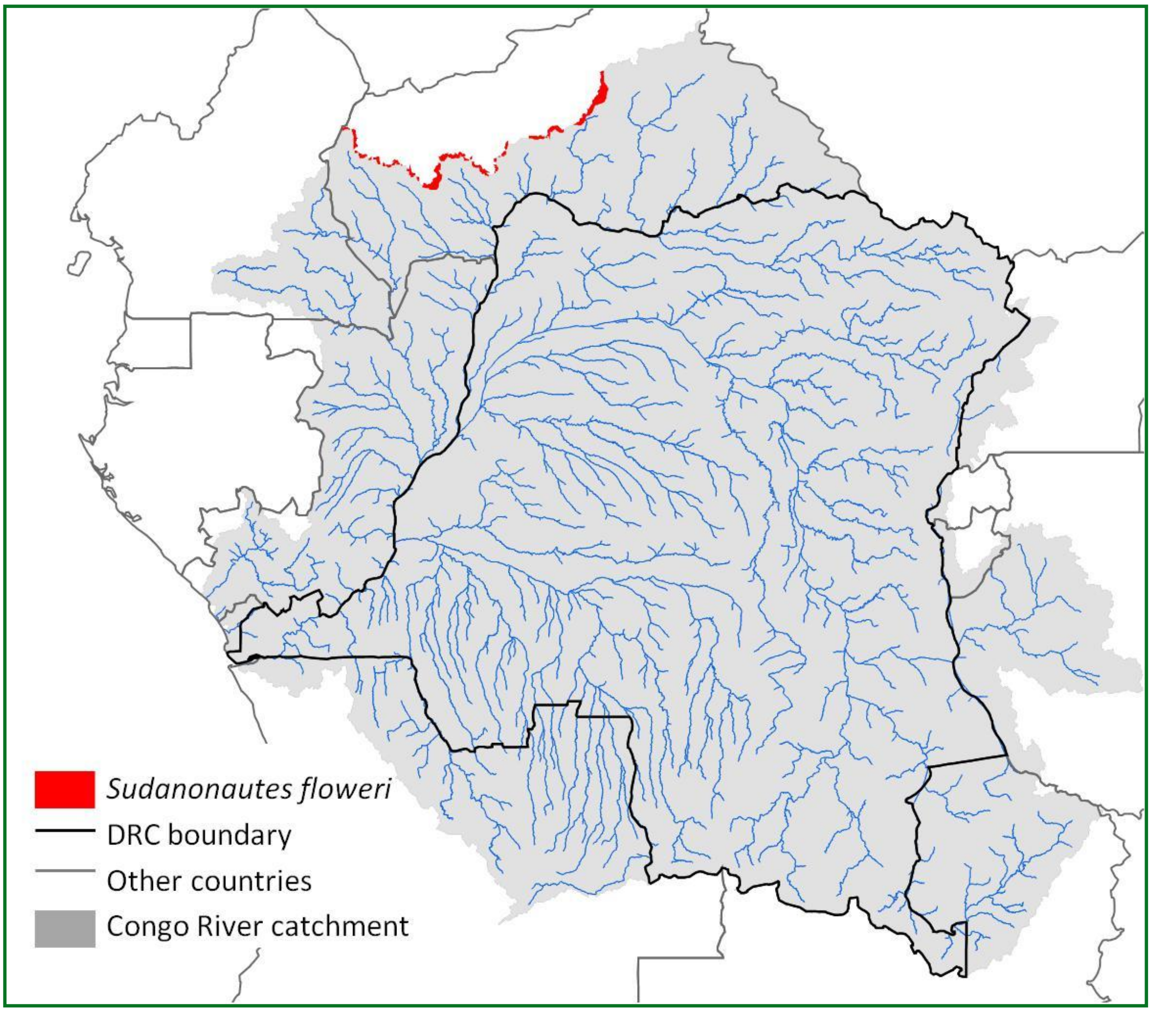


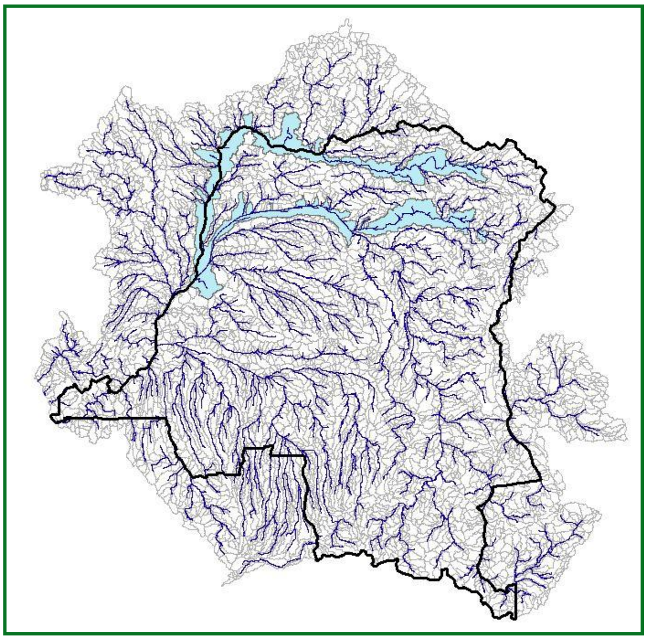
Figure 7. Spatial distribution of fish species Sudanonautes floweri in the Congo River catchment. This species was identified as a false positive coming from Lake Chad catchment.

After eliminating these species, we had a total of 2297 taxa remaining in the dataset.

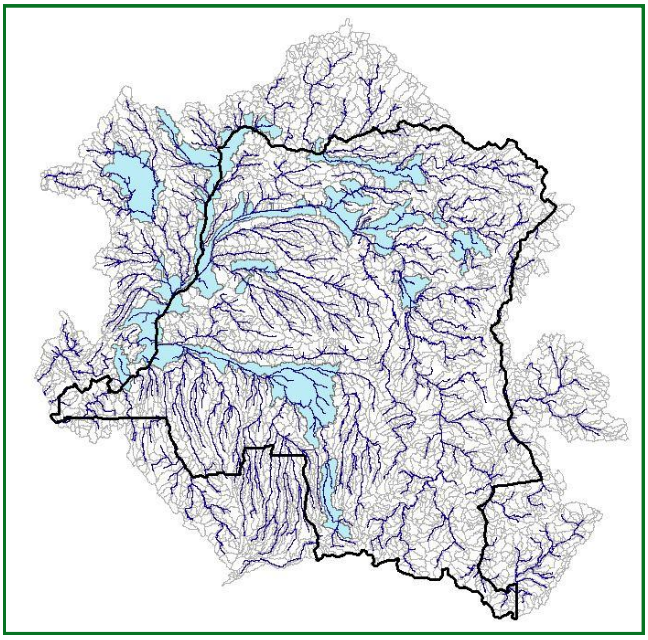
Table 3. Number of species included in the analysis, after removing false positives.

Taxa	Confidence	Number of taxa	Total occurrences
Fish	Very High	1274	346306
Crabs	Very High	50	5335
Molluscs	High	244	133109
Odonates	Medium	450	740525
Plants	Low	279	61874
Total		**2297**	

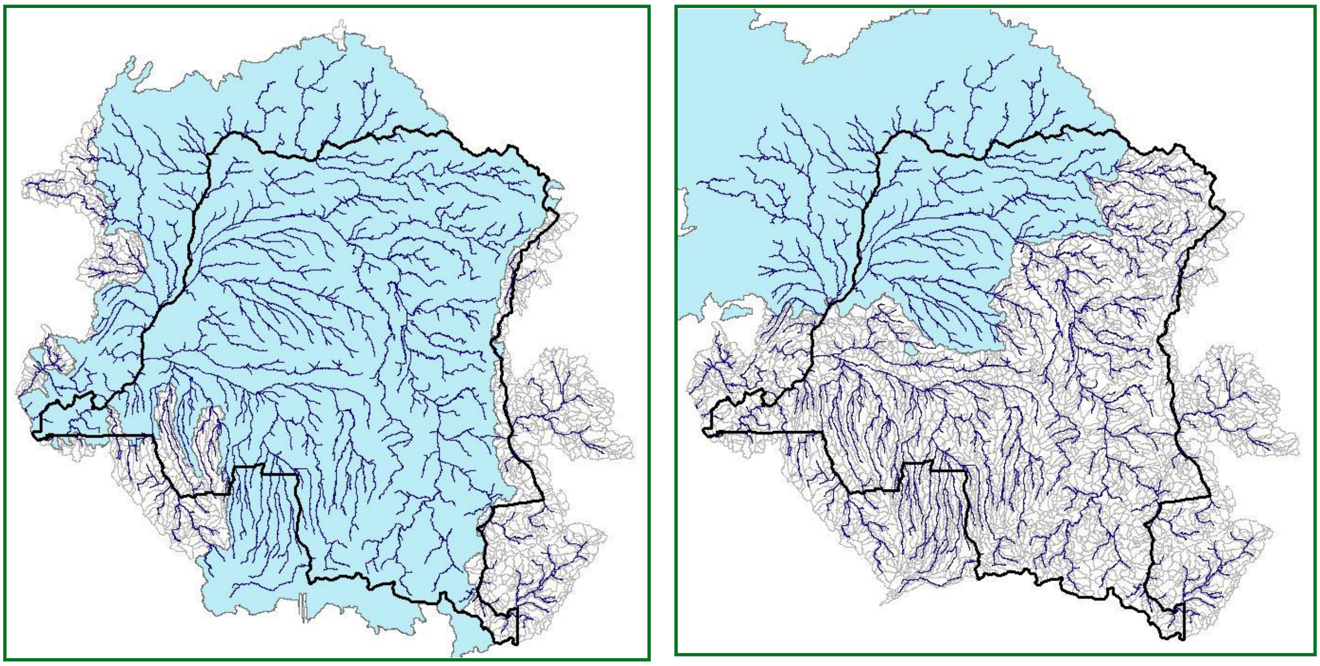
Visual inspection of the different data layers shows different levels of precision in the assessments of the IUCN groups of experts that concatenated the distributions. Fish data, for example, were very detailed. Spatial precision for fish was at the subcatchment level, while many plant assessments were just rough estimates of the planning regions (see Figure 8). We therefore assigned different levels of confidence to these classes, from very high for fish and molluscs, to very low for plants. For this analysis however, we kept all of the taxonomic groups in the analysis. Following the recommendation of colleagues at IUCN involved in the development of the data, we used all taxa records that were flagged as “extant” and “probably extant”, Presence codes 1 and 2 in the IUCN datasets.



Barbus mawambiensis



Mesoborus crocodilus

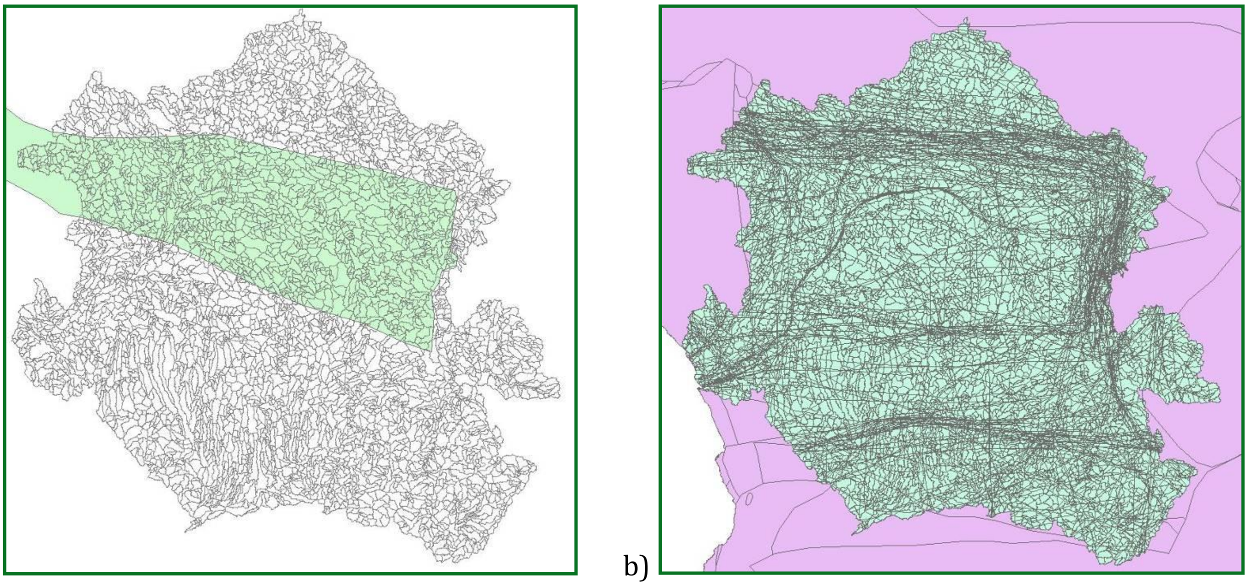


Uapaca guineensis *Letestuella tisserantii*

Figure 8. Maps of four species distributions demonstrating the higher level of detail for fish (panels above) and lower level of detail provided for plants (panels below).

2.4 IUCN mammal and amphibian data

In addition to the IUCN freshwater data, we also processed mammal and amphibian data from the IUCN. We also had data for aquatic reptiles, but there were only 2 very widespread species, which we decided not to include. In comparison to the detailed and spatially coherent freshwater datasets, the mammal and amphibian data often seemed hand-drawn and not as rigorously mapped.



a) b)

Figure 9. Distribution for a) a single frog species (Afrixalus laevis) and b) all amphibian species.

The amphibian data had an additional complicating factor: often records were single site records. Many of these were from 1943, and sometimes their taxaonomy was not well resolved. An example is *Hyperolis pustulifer*, a frog species which only occurs in one planning unit. The website Amphibiaweb describes it as: "*Hyperolius pustulifer* is probably a synonym of *Hyperolius kivuensis*." (Amphibiaweb 2012). However, this species marks the planning unit as 100% irreplaceable, therefore adding bias to the analysis. When running Marxan with all the amphibians included, the results changed dramatically, mainly because of these single records.

We therefore decided to remove amphibians from the analysis. We kept mammals, however, as distributions were more widespread and seemed slightly more reliable, albeit also very coarse. We ran the edge analysis described above and intersected the species files with the planning units to calculate the area in which the species is expected to occur.

2.5 Threat data layers used in the analysis

Many different datasets were compiled to characterise threats to the conservation of freshwater biodiversity and ecosystems in the Congo River Basin. These threats included impacts derived from human activities such as roads or deforestation. All the datasets were checked for quality and consistency across the study area with the *Observatoire Satellital des Forêts de Afrique Centrale* (OSFAC). As a consequence of this screening some of the datasets were excluded from further analyses and three main layers were used in the final analysis of threats to freshwater systems across the basin: roads within DRC, deforestation within DRC and Human Footprint within the entire Congo River Basin. In this section, we describe those datasets that were included in the final analysis; in section 2.4 we highlight some of the other datasets that were considered but not used. A list of all datasets initially considered for use in the threat analysis is provided in Table 4.

Table 4. Data layers considered for inclusion in the threat analysis.

Name	Type of Data	Extent	Source	Included in Analysis?	Justification for Inclusion/Exclusion
Globcover 2009	Landcover	Global	http://ionia1.esrin.esa.int/	No	Some categories combine degraded and natural vegetation types
GLC2000, Africa, v5	Landcover	Global	http://bioval.jrc.ec.europa.eu/products/glc2000/products.php	No	More recent datasets available
Fragment-ation Analysis	Index derived from landcover	Congo Basin	WWF-Germany. Used simplified classification of Globcover 2009 for analysis of Riitters Fragmentation Index to identify core, patch, and transition forest/natural vegetation.	No	Originally developed for terrestrial applications such that rivers are considered to fragment the forest, thus may underestimate the quality of riparian forests for aquatic systems
WWF-US Congo Basin Dams Dataset	Point locations of dams	Congo Basin	WWF-US compiled from FAO 2005, MONUC 2003 and WWF-DRC data sources.	No	Dams not linked to rivers with some locations on land and difficult to determine correct river location.
Digital Chart of the World Roads	Roads as line features	Global	http://www.maproom.psu.edu/dcw/	No	Significant difference in extent of roads presented versus country-level data
WRI Roads	Roads as line features	Republic of Congo, DRC, Central African Republic, Cameroon	http://www.wri.org/publication/atlas-forestier-interactif-du-congo-interactive-forest-atlas-congo http://www.wri.org/publication/interactive-forest-atlas-democratic-republic-of-congo http://www.wri.org/publication/interactive-forest-atlas-central-african-republic http://www.wri.org/publication/interactive-forestry-atlas-cameroon-version-2-0	No	Includes extractive roads but datasets do not cover all Congo Basin countries
Afripop	Population	Africa	www.afripop.org Examined DRC data for this analysis. Uses data from the 1998 DRC population estimate at the ville level and redistributes it using settlement locations from Landsat.	No	Interpolation creates artifacts at edges of administrative units that would cause misinterpretations for the objectives of this analysis
Geonames Cities	Population data by city	Global	http://ws.geonames.org/	No	Population data outdated for certain locations but not others
Forest and Mining Concessions	Locations of concessions	Regional	www.wri.org and www.rdcmoabi.org	No	Decided that these datasets should be included in post-hoc analyses
WCS/CIESIN Human	Index of disturbance	Global	http://sedac.ciesin.columbia.edu/data/set/wildareas-v2-human-footprint-geographic Index of disturbance derived from nine global data layers	Yes	Included as proxy for regional disturbance. Considered best available

Footprint			covering human population pressure, human land use and infrastructure, and human access.		and most consistent data at the regional scale.
DRC Roads	Roads as line features	DRC	http://www.rgc.cd/	Yes	Considered most up-to-date source of DRC road data.
FACET DRC Deforestation Data	Forest cover loss 2000-2005 and 2005-2010	DRC	http://www.osfac.net/index.php?option=com_content&view=article&id=28&Itemid=135&lang=en	Yes	Most detailed and recent data on deforestation in DRC.

2.6 DRC Roads

Road data for DRC were sourced from the *Le Referentiale Geographique Commun de government de RDC* (RGC; http://www.rgc.cd/; Figure 10). Although we examined several road datasets that covered parts of the study region, we were unable to find one that mapped roads across the entire region, and, thus, were concerned about potential bias that would be introduced by using datasets that mapped roads with different levels of detail (Table 4). In consultation with OSFAC, DRC roads were weighted by type of road to correlate with level of use, and thus, impact on surrounding areas (Table 5). In order to come up with a threat score for roads for each planning unit, we calculated the length of each type of road by planning unit, multiplied each road type by its relative weighting, then added the weighted values together and divided by planning unit area.

Table 5. Weightings by type of road for DRC road data.

Type of Road	Weighting of Impact
National	5
Regionale Principale	4
Regionale Secondaire	3
Locale	1

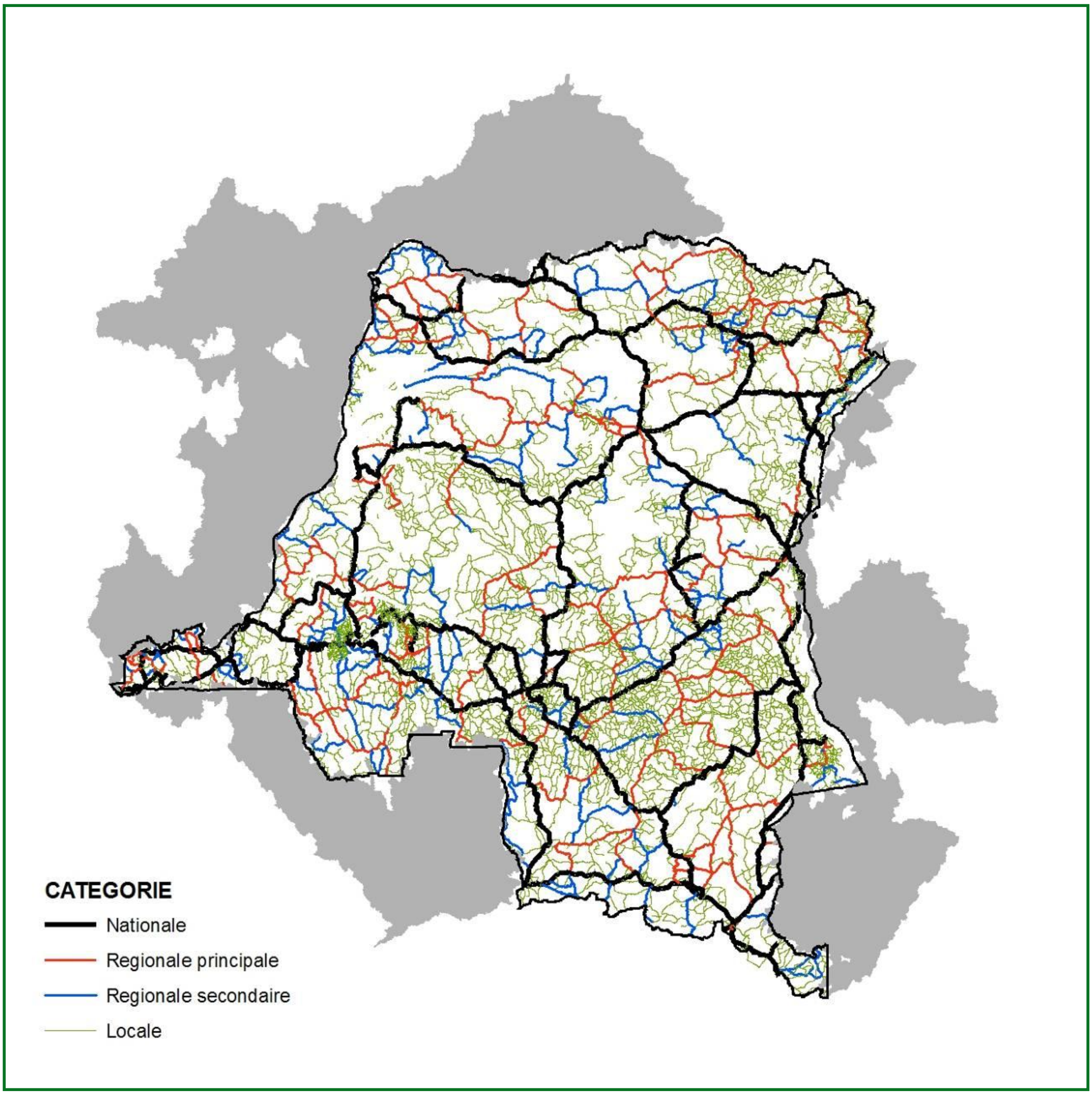


Figure 10. Distribution of roads in the DRC (data downloaded from http://www.rgc.cd/ May 2012).

2.7 DRC Deforestation

Because landcover datasets available for DRC do not distinguish between disturbed and natural vegetation classes, we decided to use deforested areas as a signal of landuse change. Data were compiled from FACET (2010), which provides deforestation data from 2000-2005 and 2005-2010. In order to determine the relative level of deforestation in each planning unit, we first assigned each cell a value: 0 for those that were not deforested between 2000-2010; No Data for those that were outside of DRC or not forest; and 1 for those that experienced forest loss between 2000-2010. We then averaged the number of forested cells in a planning unit that had experienced deforestation to come up with a score for level of deforestation that the planning unit had experienced.

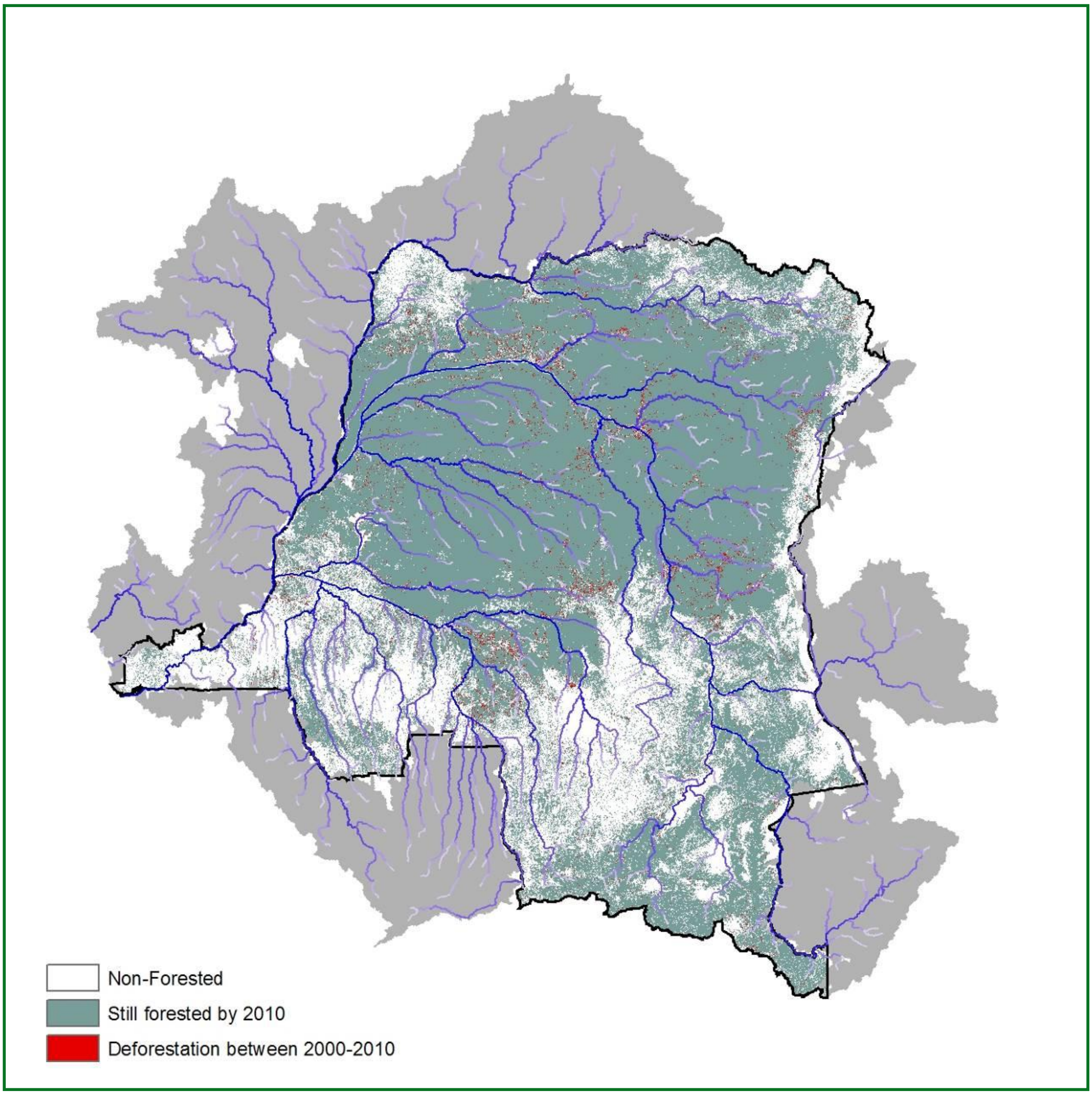


Figure 11. Deforestation data for the DRC between 200-2010 (FACET 2010).

2.7.1 Human footprint

Human footprint was sourced from the global footprint map developed by Sanderson et al. (2002), freely available at http://sedac.ciesin.columbia.edu/wildareas/. This index summarizes four different sources of human perturbation (population density, land transformation, access and electrical power infrastructure) mapped at a spatial resolution of $1km^2$, and ranges between 0-100 (0 indicating no human influence, and 100 highly perturbed by human intervention) (see Sanderson et al. 2002 for more details on this index). The human footprint for each planning unit was calculated as the average index value of all $1km^2$ grid cells within a planning unit.

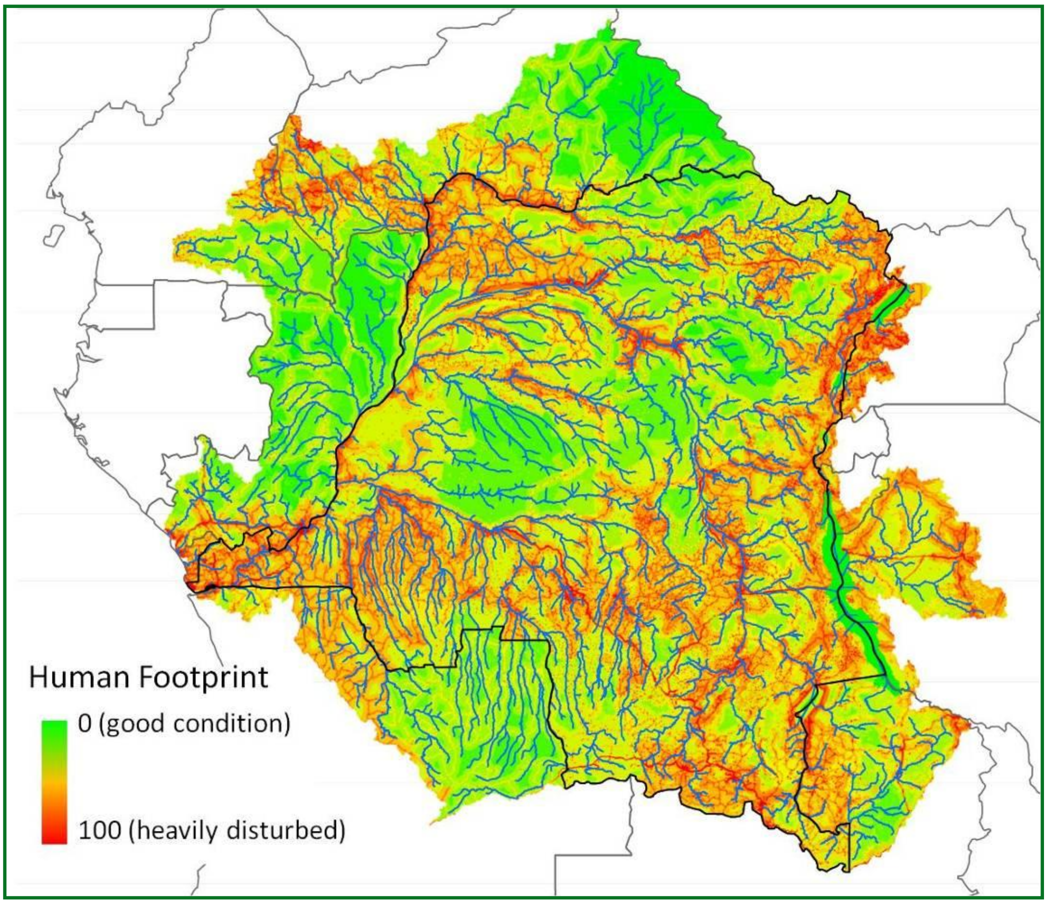


Figure 12. Human Footprint in the Congo River Basin.

2.8 Layers not used in the analysis

2.8.1 Fragmentation

A forest fragmentation map for the Congo River Basin was available from A. Shapiro (WWF-DE). This map was produced using Riitters' fragmentation index (Riitters et al. 2000) on a simplified version of the Globcover 2009 map (land cover classes were reclassified into "forest" and "non-forest"). This index was originally developed for terrestrial ecosystems as an estimate of the patchiness of remnant forest. Because it was developed for terrestrial applications, it used water bodies as one of the elements that creates forest patches. In a freshwater planning context, this translates into overestimation errors of the degree of fragmentation of riparian forests or those close to river channels or lakes. This could lead to an underestimation of the quality of riparian forest depending whether the river channel was wide enough as to be detected in Globcover (even intact riparian forests close to a wide stretch would be erroneously classified as fragmented). For this reason this map was considered not appropriate for the freshwater analysis and was not included.

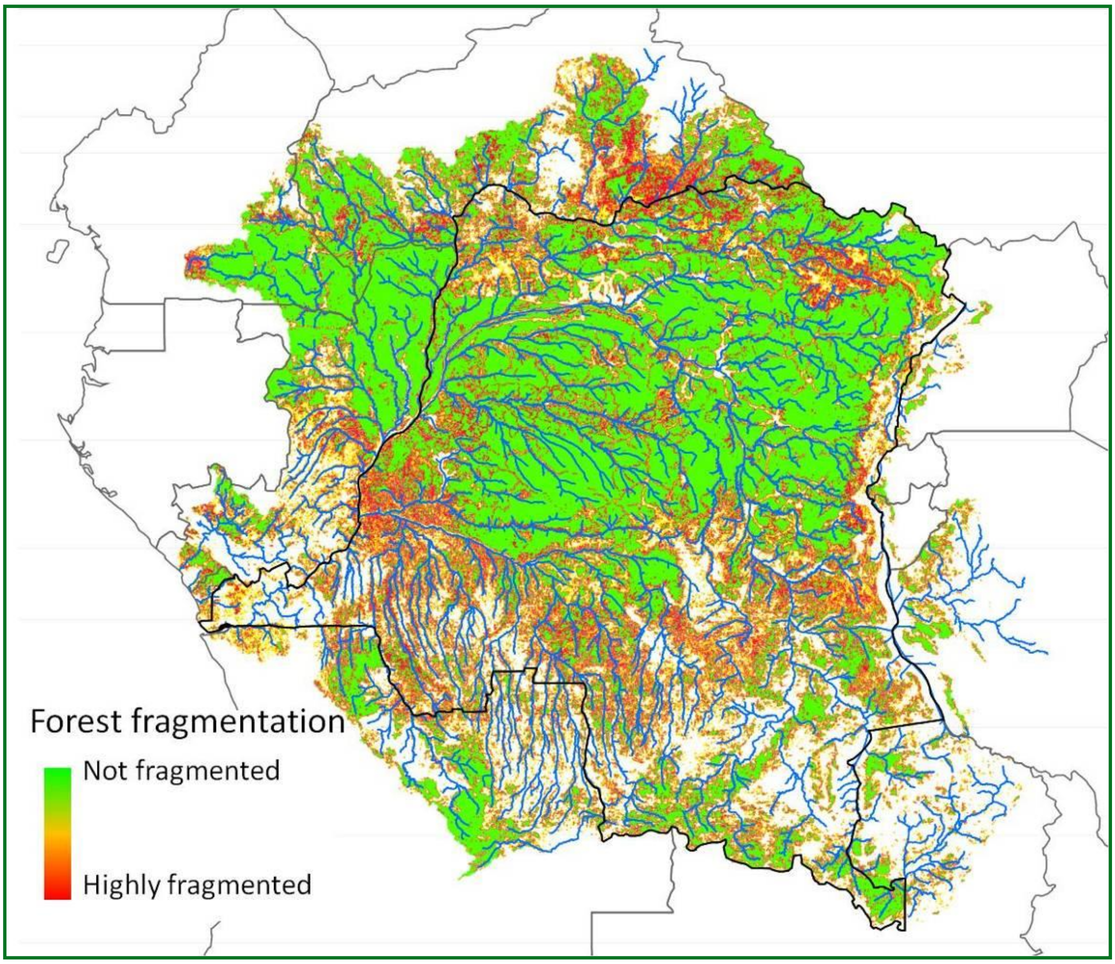


Figure 13. Forest fragmentation index.

2.8.2 Dams

A database on the spatial distribution of dams was compiled by WWF-US from FAO (2005), MONUC (2003) and WWF-DRC data for the whole of Africa. This dataset contained the location of 156 dams within the Congo River catchment. However, information regarding the dam's potential impact (e.g., dam's height, reservoir's capacity) was not available for all dams.

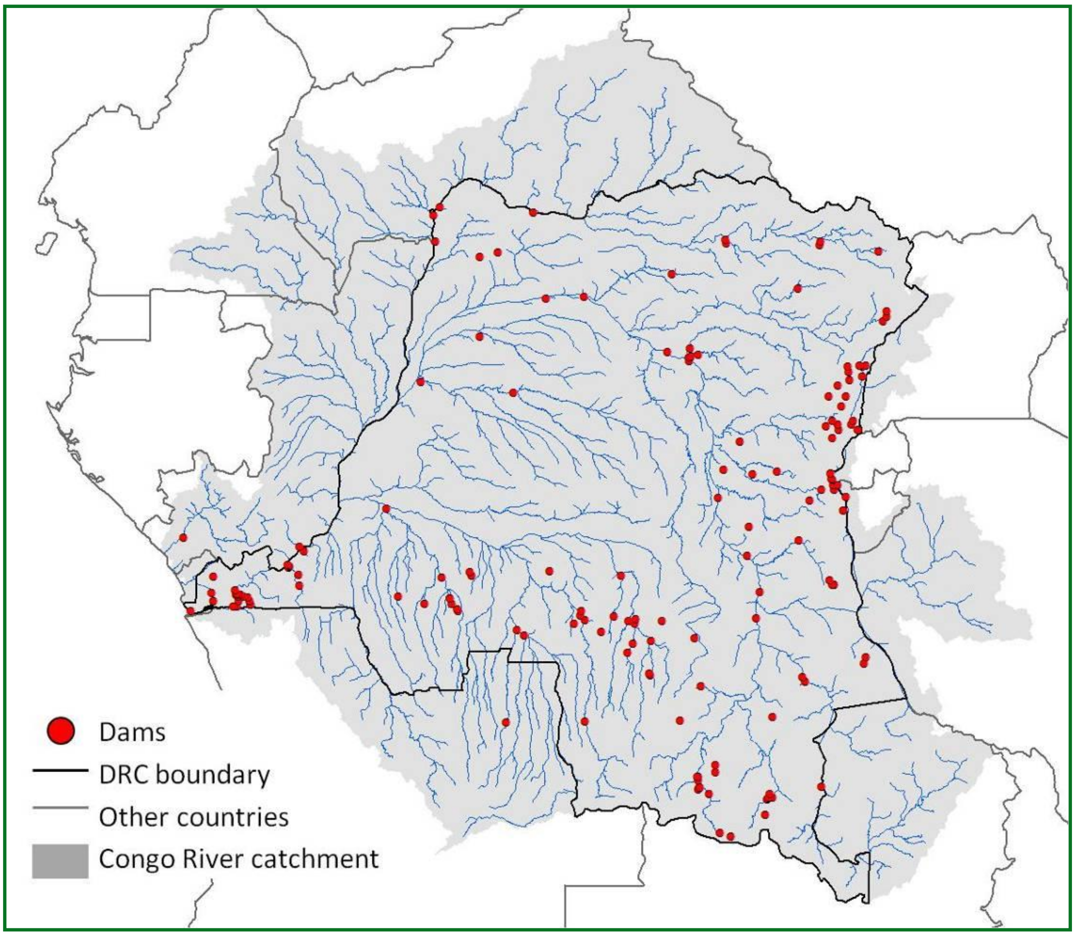


Figure 14. Spatial distribution of dams in the Congo River catchment.

Furthermore, as is often the case with point locations of dams, the locations of dams in the database were often not precise or incorrectly located (Figure 15 and Figure 16). Due to these errors, we decided not to use this dataset in the analysis.

Figure 15. A dam that is attributed to the wrong side arm of a river – and therefore located in the wrong subcatchment.

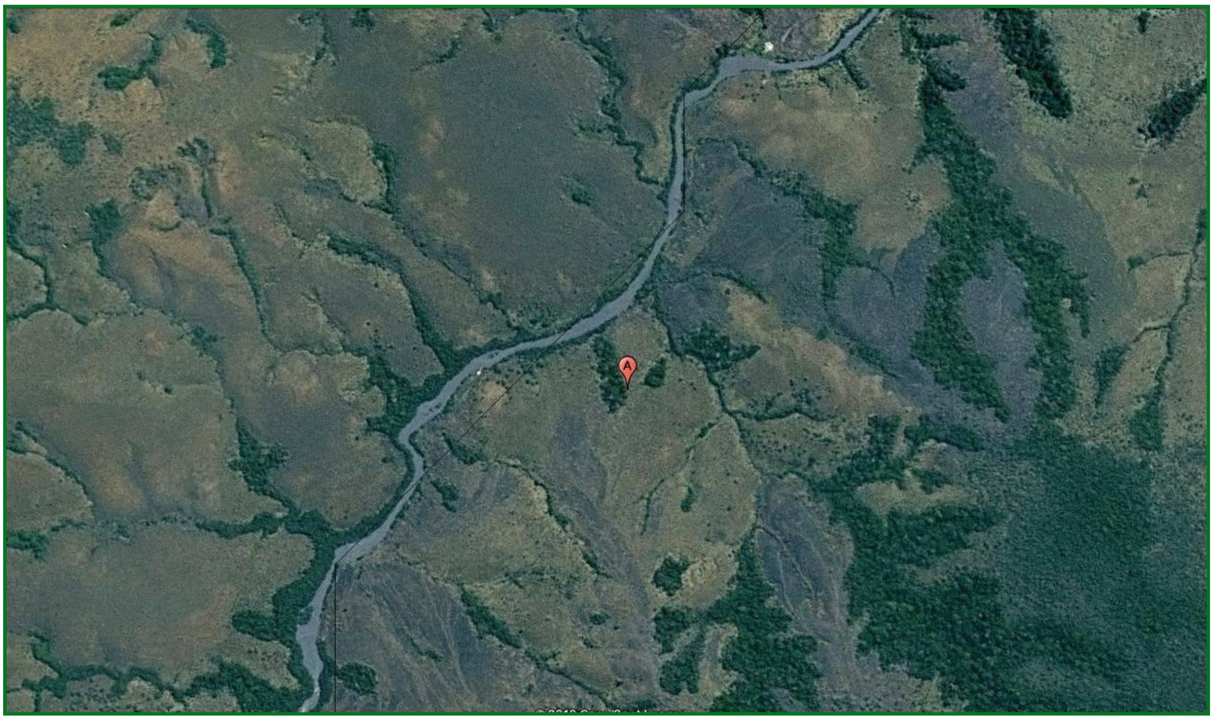


Figure 16. Incorrect entry in the dam database, as no dam was found nearby.

2.8.3 Population density

Two different sources of population density were considered but not included after evaluation of their spatial accuracy. Despite the spatial resolution of the Gridded Population of the World (developed by the Socioeconomic Data and Applications Centre, SEDAC; http://sedac.ciesin.columbia.edu) and Afripop (www.afripop.org) being adequate for this analysis (both are available at 100m resolution) the data used to construct the maps were often as coarse as the province scale for large areas in the Congo River catchment. For this reason, these datasets were not considered for the analyses.

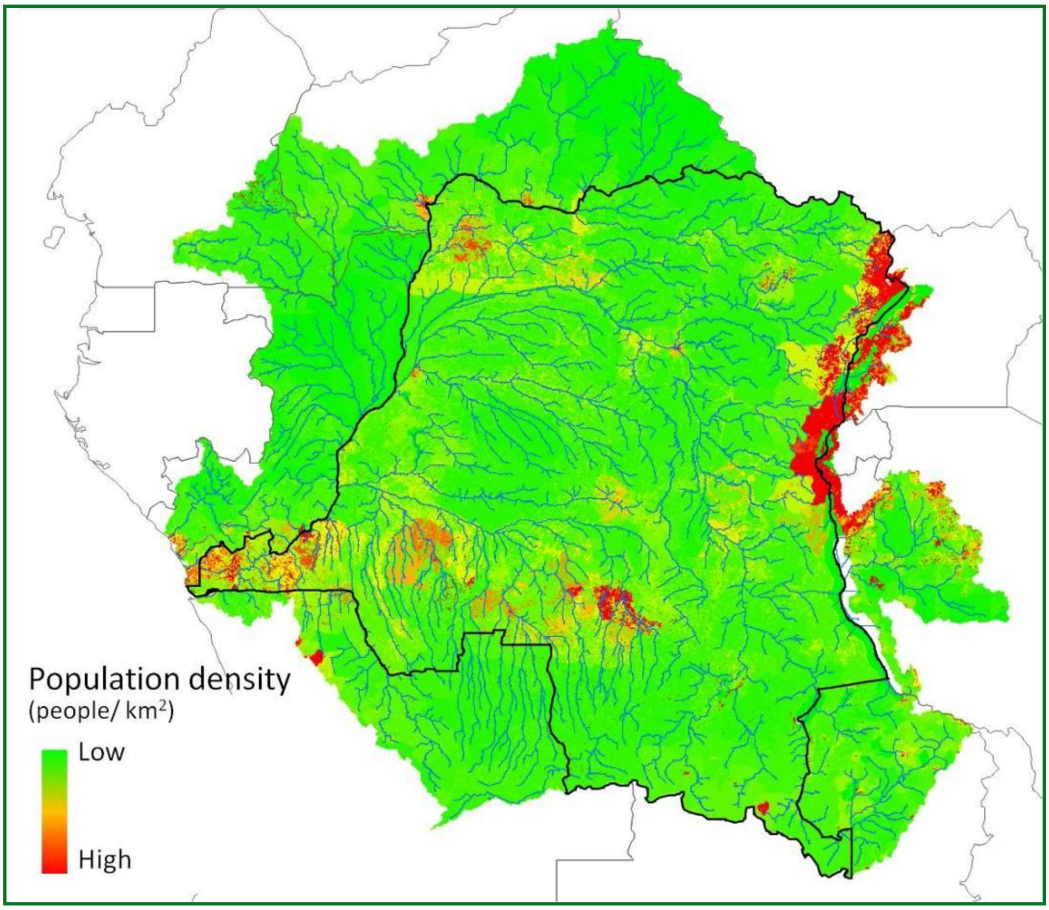


Figure 17. Population density data by planning unit sourced from Afripop.

2.9 Threat aggregation and propagation

2.9.1 Threat aggregation

As documented above, the DRC road and deforestation data and the globally available Human Footprint data were deemed the most suitable datasets available for this analysis. Because we are propagating threat data downstream in the analysis, it was important to include data for the entire Congo Basin. However, as presented in sections 2.3 and 2.4, it was challenging to compile threat data layers that had been consistently compiled across all nine countries within the basin. Thus, we decided to combine DRC deforestation data (FACET 2010) and the DRC roads layer (Downloaded from RGC 2012) with the Human Footprint data using principal components analysis (PCA). PCA identifies common gradients in datasets and removes redundant information. This leaves the signal for the recent deforestation from the FACET data and the roads layer intact, but adds information on other disturbances such as population pressures that are included in the human footprint data. Kinshasa, for example, was considered as 'not recently deforested' in the FACET deforestation data since that dataset reflects deforestation from 2000-2010; hence lower levels of impact were detected when using the deforestation and roads layers alone. The human footprint layer added this signal without removing the more detailed impacts available from DRC-specific datasets.

We first ran the PCA on the log-transformed DRC data only, in which principal component 1 amounted to 55.4% of the variation explained. All three variables on the stressor gradient had similar high loadings (roads=0.59, deforestation=0.50, human footprint = 0.62). We ran a regression with the stressor gradient as the independent variable and the log-transformed human footprint as the dependent (r^2=0.69) to be able to backcalculate an estimated stressor gradient for subcatchments outside the DRC.

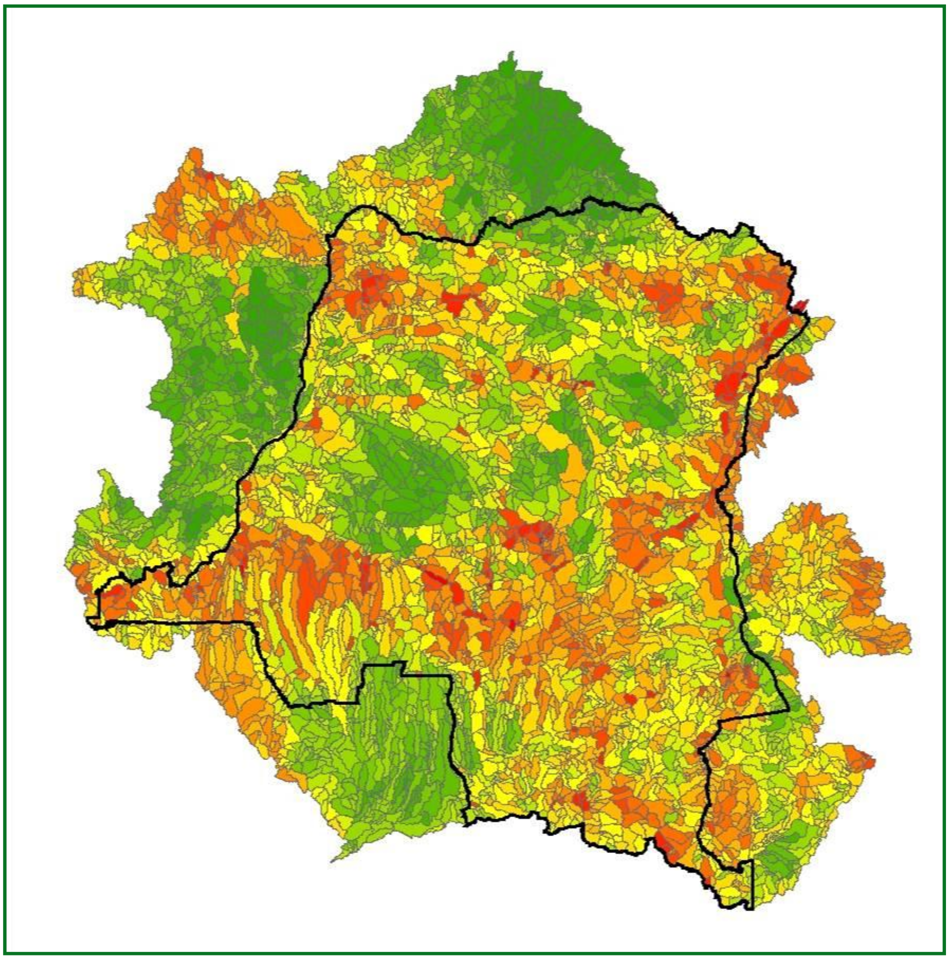


Figure 18. Threat gradient for the entire basin based on an extrapolated PCA. (Red=area of high disturbance, yellow=medium disturbance, green=low disturbance).

2.9.2 Threat propagation

The local condition of the catchment surrounding a river reach contributes more to the river condition than a far away upstream threat. However, it is necessary to propagate threats downstream, as upstream threats will influence local condition. This way, we can also account for transborder degradation, as including threat in the overall cost of a planning unit will steer protected areas away from degraded upstream catchments. The overall measure of threat at each subcatchment outflow is a weighted average of the all subcatchments above the pour point. We used the method described by Stein, Stein & Nix (2002) and (Linke et al. 2012)

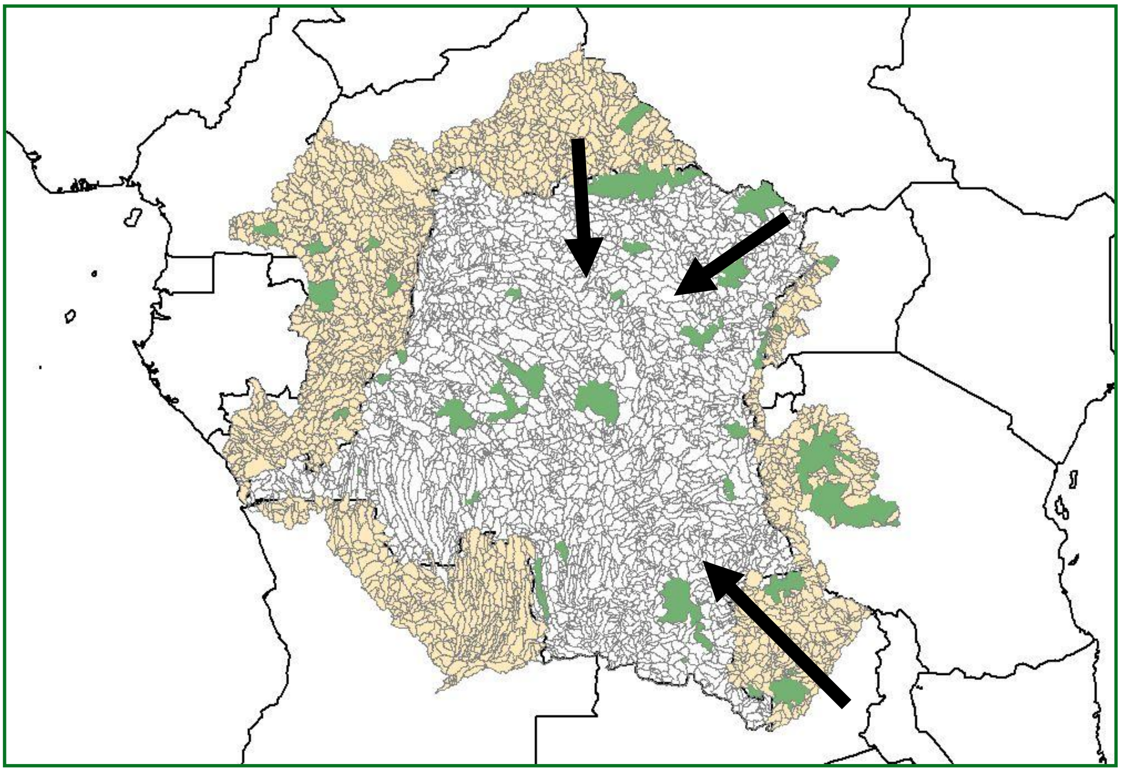


Figure 19. Threats from upstream areas in neighbouring countries and all upstream catchments need to be considered in evaluating the level of threat that a particular subcatchment might face.

2.10 Marxan set up and analysis

Identification of priority areas was carried out using the conservation planning software Marxan (Ball et al. 2009). Marxan uses an optimization algorithm to try to find a near-optimal combination of planning units where all the species are represented in a minimum required area (conservation target), while accounting for some additional constraints such as cost associated with each planning unit or spatial connectivity. This is done by trying to minimize the objective function in Equation 1, which includes cost of planning units in the solution and other penalties for not achieving the conservation target for all the species (Feature Penalty, weighted by Species' Penalty Factor, SPF). An additional penalty can be specified in the objective function to force the spatial aggregation of planning units included in the solution and to maximize connectivity within priority areas.

$$Objective\ function = \sum_{planning units} Cost + SPF \sum_{features} Feature\ Penalty + CSM \sum Connectivity\ Penalty$$

(Equation 1)

In the following sections we outline the steps taken to set up Marxan inputs before running the analysis.

2.10.1 Features

As described in 2.2, we clipped the species and freshwater ecosystem classes to the planning units. We then calculated the area of each feature (species and classes) in each planning unit, which was occupied by the feature. However, if a feature occupied less than 10% of a planning unit it was counted as not present. This was done to avoid the problem with the spatial errors detailed in 2.3.

2.10.2 Planning units and cost

Accurate estimates of monetary cost were not available for this study. Alternative non-monetary surrogates for cost, such as estimates of condition or threat, have been highlighted as they are easier to obtain and more intuitive for biologists to understand (Naidoo et al., 2006). When these alternative surrogates are used, the problem formulation changes slightly and instead of trying to find the cheapest way of achieving all conservation targets, the aim is to find the areas in best condition (subject to lower levels of threats) where all conservation targets can be achieved. Adequacy of reserves (likelihood of long term persistence of biodiversity within reserves) is enhanced, given that near pristine areas will be selected to protect species whenever possible (some species might only occur in degraded areas). As a cost surrogate, we scaled the aggregated and propagated threat described in section 2.9 in each subcatchment between 0.33 (lowest threat) to 1 (highest threat). This was then multiplied by the area in the subcatchment. While the actual area is still important in the plan (as it should be, considering it is highly correlated to the cost), it gets discounted if the threat level is low.

*Final PU Cost=threat scaling factor * area in subcatchment*

2.10.3 Species penalty

A high SPF (10) was used to force the achievement of conservation targets for all species and ecosystem types. This was done so species targets are always achieved.

2.10.4 Connectivity

To account for the potential longitudinal propagation of disturbances and movement requirements of freshwater biodiversity along river networks, we included the longitudinal connectivity rule for Marxan described in Hermoso et al. (2011). Under this rule, a penalty applies when the upstream or downstream connections of selected planning units are not included in the solution. To avoid forcing the selection of whole catchments, the connectivity penalty is weighted by the distance between the planning units

penalty = 1/distance

Reflecting the functioning of freshwater ecosystems, closer upstream or downstream planning units receive a higher penalty than distant ones, so their inclusion is more important. This component of connectivity ensures that planning units selected are spatially aggregated along the river network.

The relative importance of the connectivity penalty can be scaled by the parameter CSM (connectivity strength modifier, see Eqn. 1). If CSM is set to 0, the term drops out of equation 1 and a standard conservation planning exercise – without any explicit spatial clumping component – is carried out. In contrast, if CSM is set to a high value, most of the catchment upstream of the selected features needs to be included to minimize the objective function. This effectively creates a 'whole-of-catchment' protection scheme, similar to the heuristic scheme used by Linke et al. (2007). For this reason different CSM values were tested to explore the trade-off between connectivity and area required.

The asymmetric connectivity function in Marxan as described by Beger et al. (2010) was used here. By including this rule, the operators of the conservation planning software can specify whether they want only upstream connectivity, only downstream connectivity or bi-directional connections. In the latter case, different weights can be specified for upstream and downstream connections. In our study, for simplicity and to demonstrate the functionality of the connectivity penalty, we only used upstream connections.

The Pfafstetter coding system describes the network topology of any river network (Figure 20). In any terminal catchment, a river system is split into the four major contributing catchments, as well as connecting sub-catchments. The main stem segments are then coded with uneven numbers between 1 and 9. The four major tributaries are coded with even numbers between 2 and 8. The resulting nine sub-catchments are then again sub-divided in the same way and the digits added to parent sub-catchments (for sub-catchment 2, the resulting sub-divisions would be named 21, 22…29). As demonstrated in Figure 20, this can be then used to construct a connectivity penalty file for Marxan.

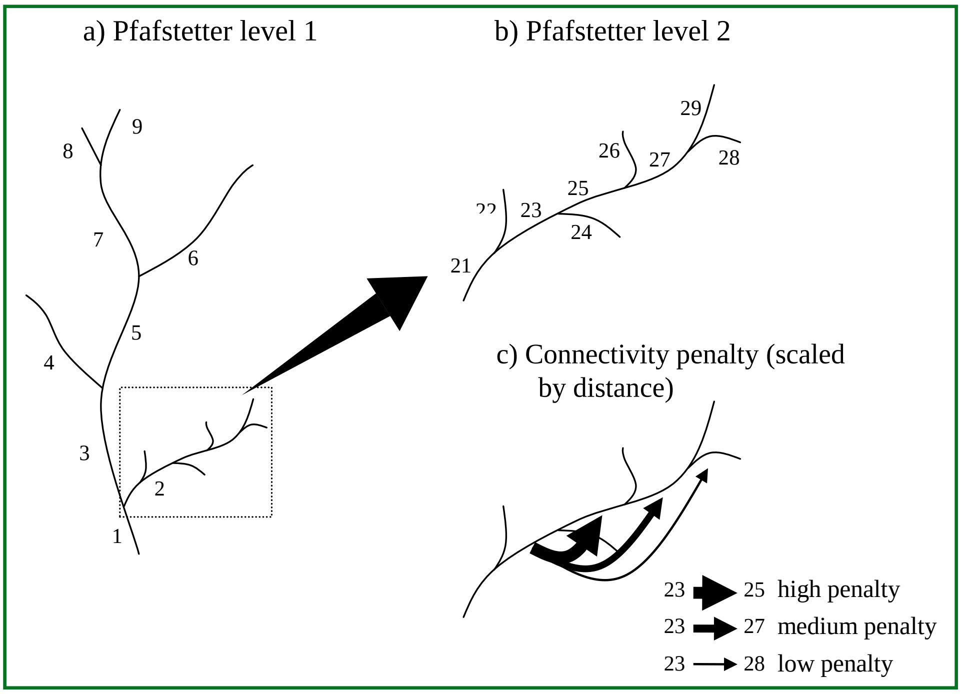


Figure 20. Example of Pfafstetter coding used in this study and the estimate of connectivity penalties for Marxan.

3. Conservation planning analysis and results

We ran multiple scenarios in Marxan using different species targets and connectivity penalties as outlined below. We shared the results with and solicited feedback from the GTT ED both at the workshop in Kinshasa and post-workshop via electronic means. We initially 'locked in' protected areas (Level I and national parks) in both the DRC and neighbouring countries in running the Marxan scenarios. "Locking in" of a planning unit means that it is automatically selected to be in the solution set. We then compared the results to a 'clean slate', by re-running the analysis without protected areas "locked-in", meaning that planning units that contained national parks had the potential to be part of the solution set but were not automatically considered to be part of it. We also examined how often each planning unit occurred in the solution set (called the selection frequency of the planning unit) with and without national parks "locked in" to the solution set.

3.1 Species targets

Below is a graph that shows the amount of total area that would be within priority areas selected by Marxan as we vary the target level for individual species. The target level for individual species is the amount of area of a particular species' distribution that we want to be captured within the Marxan results (i.e., the freshwater priority areas that are identified by Marxan).

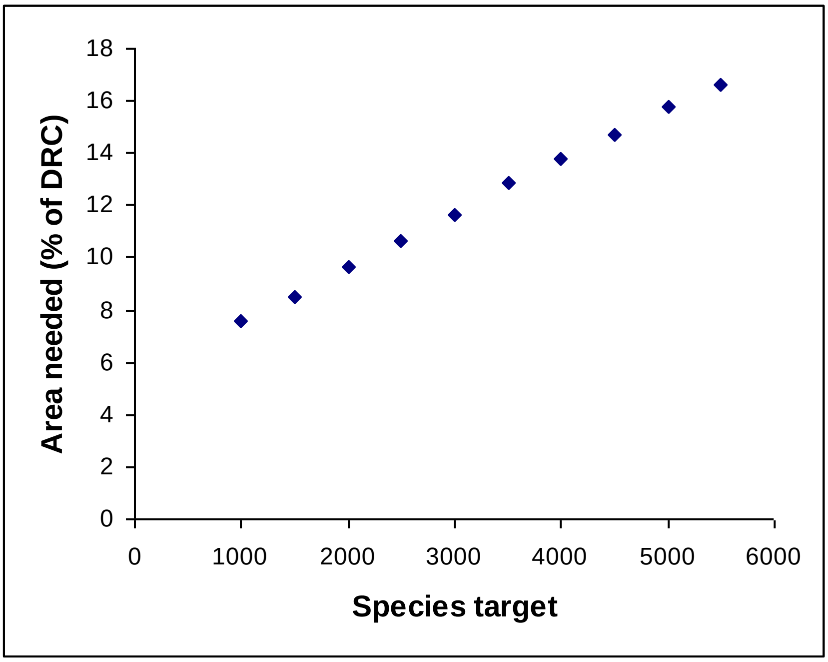


Figure 21. The area required (as percentage of DRC's total area) to meet varying levels of species targets (sq km).

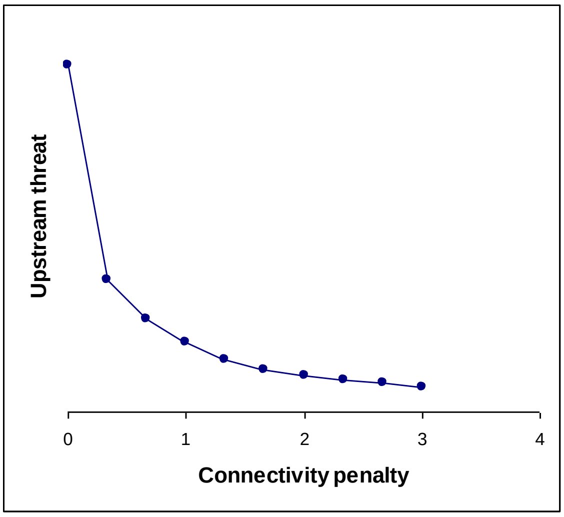
Species and ecosystem class targets would ideally be set based on the ecological requirements and life history of individual species. However, that information is not available for the majority of aquatic species in the DRC. *We therefore recommend using a set amount of area for each species*. Doing so allows for rare species to have a larger proportion of their range encompassed in the results. For example, about 7% of fish species (84 out of 1274) from the Congo Basin have a distributional range of less than 5,000 sq km, such that if a blanket target of 5,000 sq km was set, then each of those species would have 100% of their range captured in the priority areas selected by Marxan; and a proportionally smaller part of each species' range would be selected for species with ranges > 5,000 sq km. See Table 6 for information on the number and percent of species that would have 100% of their range captured in priority areas at varying target levels. No freshwater ecosystem type classes are 100% represented at the current target levels. A higher target also means that a greater amount of widespread species' ranges is required in the solution set, such that a much larger proportion of DRC would be needed in any possible solution.

Table 6. Number and percent of species with 100% of their range captured in priority areas at varying target levels.

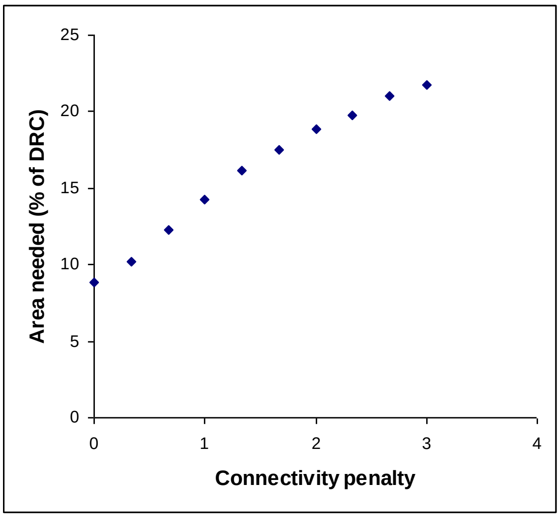
	Range (sq km)		
Taxonomic Group	**<2000**	**<2500**	**<5000**
Crabs	1 (2%)	1 (2%)	3 (6%)
Fish	17 (1.3%)	25 (2%)	84 (6.6%)
Molluscs	9 (3.7%)	11 (4.5%)	26 (10.7%)
Plants	1 (.3%)	1 (.3%)	1 (.3%)
Odonata	3 (0.7%)	3 (0.7%)	6 (1.3%)
All Features	31 (1.3%)	41 (1.8%)	120 (5.2%)

3.2 Including the connectivity penalty

While a species target of 5000 km² requires about 16% of the area when not considering connectivity, targets need to be set lower when including upstream protection. We therefore ran a series of calibrations with a species target of 2000 km².



a)



b)

Figure 22. a) Declining upstream threat with increasing connectivity penalty at a target of 2000 km² b) Area needed to reach a target of 2000 km² as the connectivity penalty increases.

The optimal connectivity penalty (CP) minimizes upstream threat while also minimizing the value of the CP – it is located at the vertex of the curve between upstream threat and the connectivity penalty (Figure 22a). When using 2000km² as the target, the optimal CP is 1.3 (Figure c) and the amount of area included in the solution set is 547,000 km² (16.1% of the total area). Based on these analyses, we would recommend, for a species and ecosystem area target of 2000km², that the connectivity penalty be set at 1.3, as it allows for some level of riverine connectivity without overly increasing the total area in priority areas. Note that if targets change, a new connectivity calibration might be needed, as this would change the spatial configuration of the protected areas. All four Marxan-generated solution sets shown in Figure 23 meet the targets set for species and freshwater ecosystem types (apart from 31 species that have ranges less than 2000 km2).

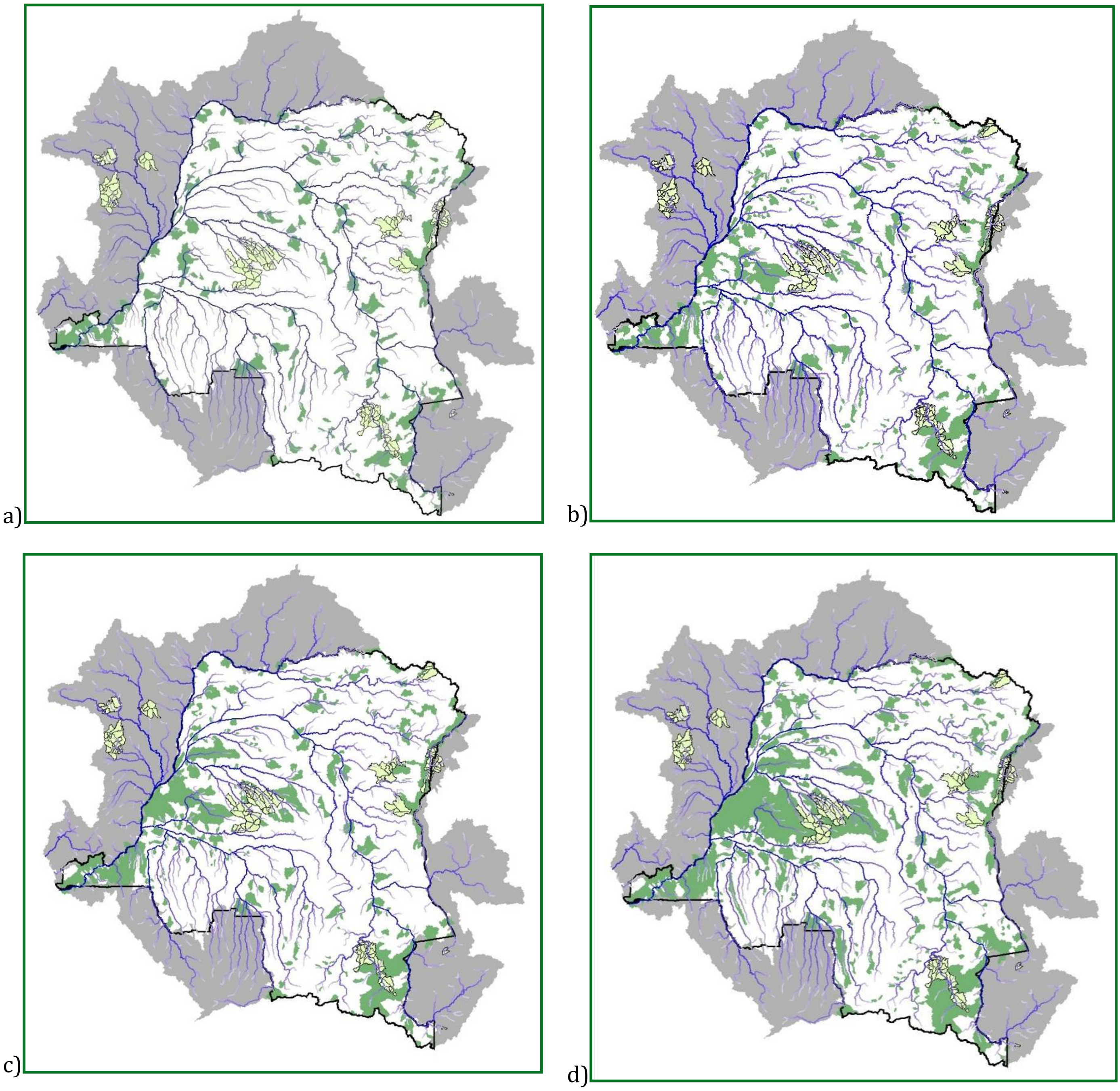


Figure 23. Sets of Marxan-generated solutions for freshwater priority areas at a) CP 0 b) CP 1 c) CP 1.3 and d) CP 3, species target at 2000km^2, and national parks locked in.

3.3 Selection frequency

The map in Figure 24 displays the frequency with which a particular planning unit was selected during the Marxan runs within the scenario with a target of 2000km², a CP of 1.3, and with national parks “locked-in”. Planning units with a high selection frequency are those that most often allow Marxan to meet the targets that we set.

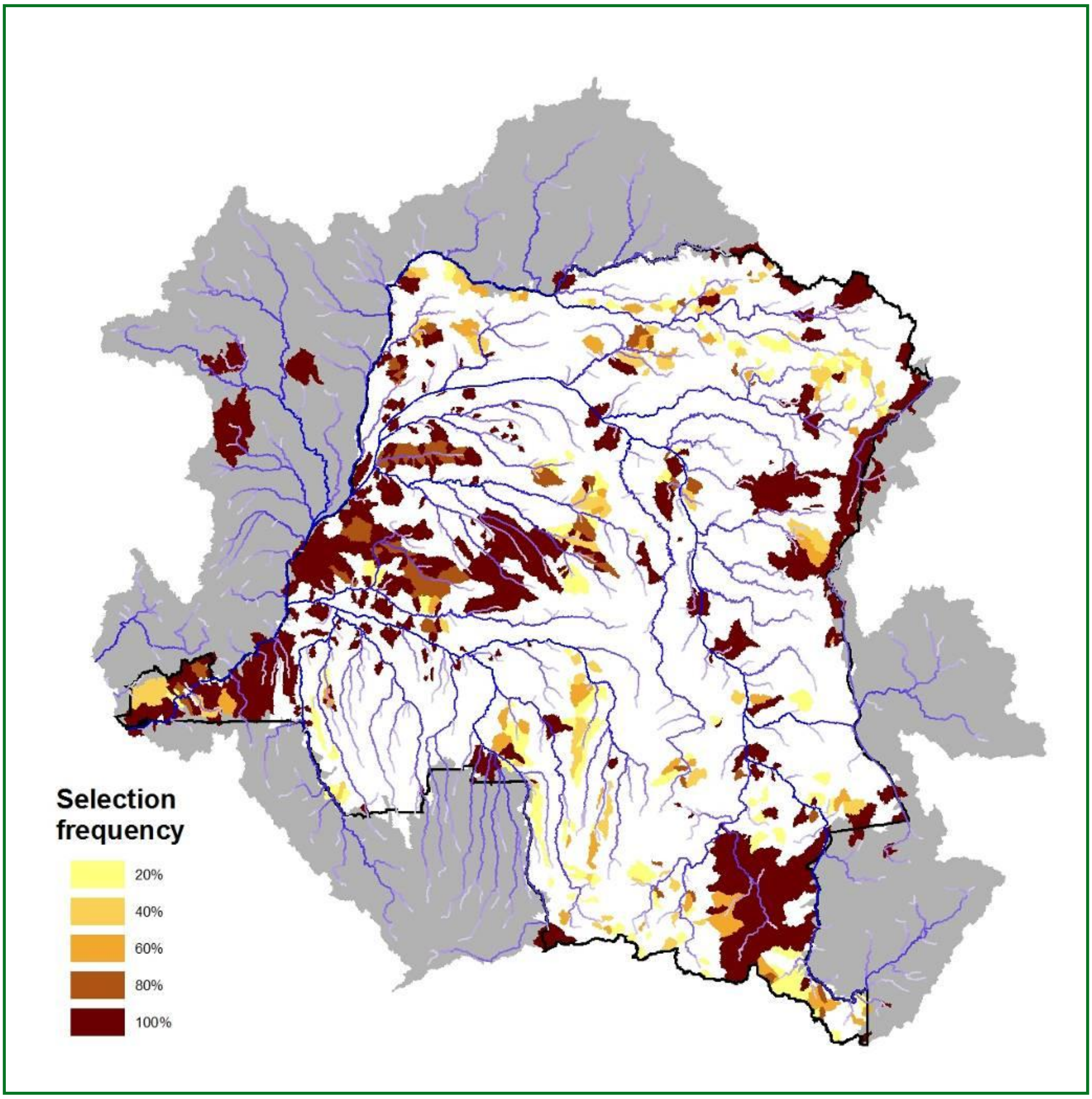


Figure 24. Selection frequency of planning units in the Marxan scenario with a 2,000km² target, CP of 1.3, and national parks “locked-in”. The higher the selection frequency of a planning unit, the more frequently it occurred in Marxan-generated solutions, such that it is considered of higher value for meeting the targets set in Marxan.

3.4 Comparison of results without ‘locking in’ national parks

We evaluated how much “locking in” the current set of national parks and other Level I protected areas in DRC affected the results of the Marxan analysis, by re-running the 2,000 km² and CP1.3 scenario without the national parks “locked in”. The results are quite similar to those in Figure 22c, except that some planning units have been selected preferentially that are not continuous with existing national parks (Figure 25). We also examined how the selection frequency changed with the national parks "locked in" or not. The results show that planning units adjacent to national parks are preferentially selected in the analysis when national parks are forced into the solution set (Figure 24), but that those units are not necessarily those with the highest selection frequency if national parks are not "locked in" to the solution (Figure 26). Figure 26 highlights those areas that repeatedly are selected to meet the freshwater species and ecosystem targets that were set in the analysis and the overlap of those areas with the full set of protected areas in the DRC. Thus, providing some initial guidance on the location of potential priority areas for freshwater species and ecosystems, where targeted sampling could occur in order to verify the status and occurrence of freshwater species and ecosystems within current protected areas.

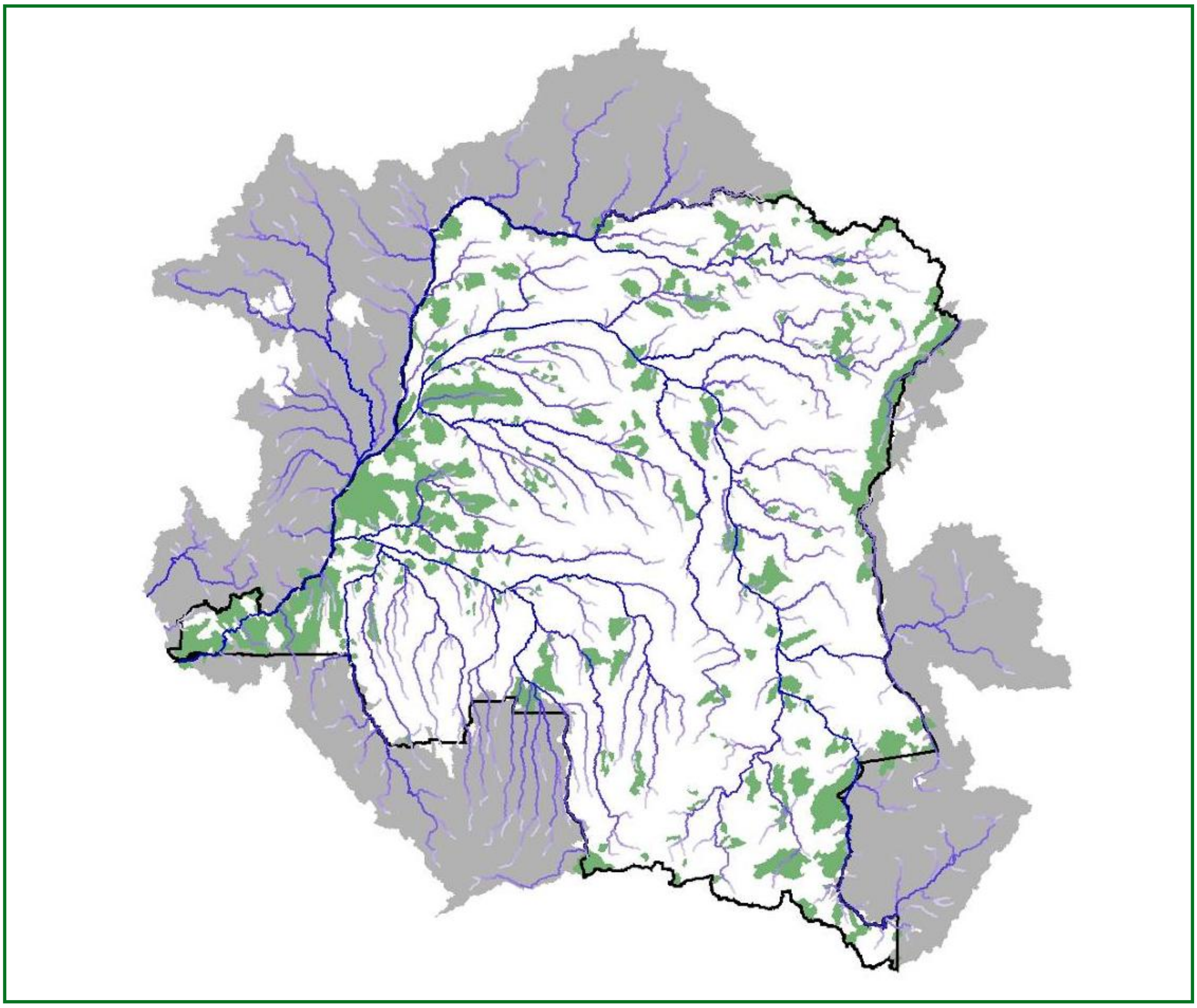


Figure 25. The Marxan-generated best solution for freshwater priority areas at CP 1.3, species target at 2000km^2, and without national parks locked in.

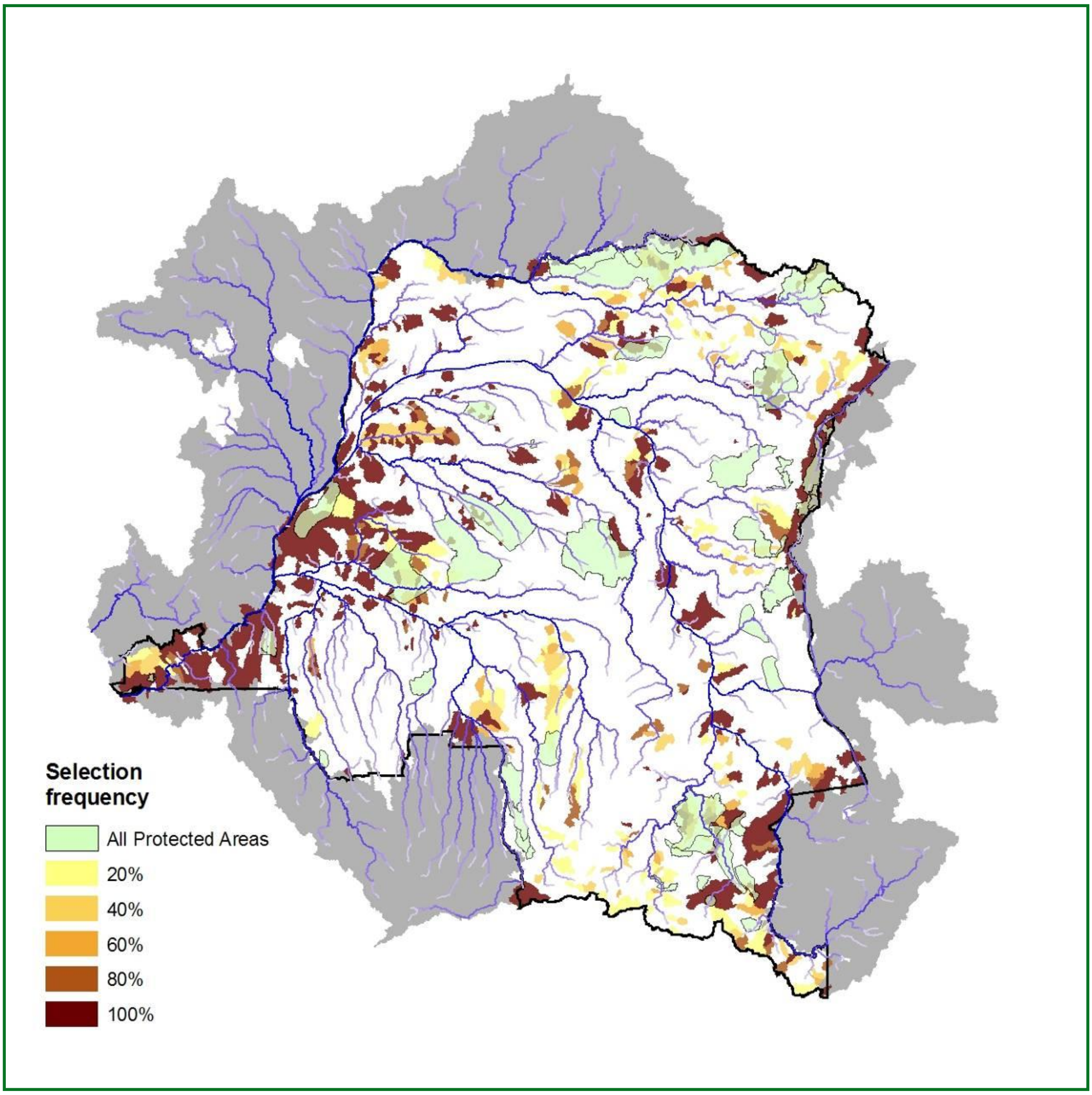


Figure 26. Selection frequency of planning units in the Marxan scenario with a 2,000km2 target, CP of 1.3, and national parks not "locked-in". Protected areas of all levels in DRC are displayed in green (source: FORAF).

4. Conclusions & Recommendations

This is the first systematic conservation planning exercise in the Congo basin that includes multiple species as well as dealing with upstream disturbance. However, some of these preliminary results will have to be treated with a degree of caution – as every analysis based on large-scale and GIS-based data has to be.

4.1 Data uncertainties

4.1.1 Species data

As detailed in Table 3, we had varying degrees of confidence in the species data. As with all large scale assessments, one needs to balance information lost by not including existing species records with overestimating current records. In our case, the different sets of taxonomic experts for the Africa-wide freshwater assessment seemed to label species as 'extant' and 'probably extant' in different ways. Most assessments use the extant flag for actual observation. However, while fish and crab experts have estimated extremely precise areas for the 'probably extant' areas, plant and odonate experts have drawn large undifferentiated areas, perhaps due to different levels of data quality. This might hinder more detailed interpretation of the conservation plan – one should not really expect a plant species in every single subcatchment that it is flagged in. However we do not believe this has a large influence on the analysis. In a case like Figure 8c where a plant is estimated in every single tributary, this plant will actually drop out of the analysis – as its target will be automatically fulfilled by selecting other species. To test this, we removed the 25% most widespread species from the analysis and could show that the results are not at all affected by their removal.

The mammal and amphibian data are distinct in that they are:

- Not clipped to geographic entities
- Often seem hand-drawn
- Represent a mix of very large scale estimates and point data

To improve accuracy and to be able to include the data in a future planning exercise, we recommend cleaning the data and potentially using catchment-based units for species ranges of the aquatic mammals and amphibians.

While we are reasonably certain that our detection algorithm for false positives worked (see 2.3), we would encourage further manual checking of the removed species to ensure that we did not remove a taxon that should have remained in the analysis.

4.1.2 Environmental/disturbance data

Groundtruthing of the overall accuracy of the environmental data with experts from OSFAC confirmed that the combined layer of roads, deforestation and human footprint seems to show an accurate picture for the DRC. However, the current disturbance layer has a number of limitations:

- We could not include dams in the analysis due to the inaccuracies detailed in 2.8.2
- As described in 2.8.3, direct population data were too coarse to include. Instead the human footprint was included as a proxy. However, if improved population data were able to be acquired for both the DRC and/or the surrounding countries then that would be beneficial.
- Additional disturbance layers for the neighboring countries would also be helpful. At the moment this is circumvented by re-scaling the human footprint. However, experts from OSFAC have voiced a concern that the human footprint might be slightly overestimating impacts in the Republic of Congo, for example.

See Section 3.4.3 for specific recommendations on improving the data inputs.

4.2 Conservation adequacy – targets and connectivity

4.2.1 Conservation targets

In this analysis we used a blanket target of 2000 km^2 for all of the conservation features, both species and freshwater ecosystem classes. As stated in section 3, we set the target at this level because it enabled a relatively well protected upstream network (see 4.2.2) while keeping the total area within priority areas at around 15%. This should only be seen as a first step though as it ignores important biological realities. Targets should be set based on ecological needs instead of a mathematical calibration. For example, migratory fish obviously need a much larger area than a small headwater invertebrate. While this is still an emerging area of research, we suggest that these issues be discussed at future meetings of PARAP expert groups. The Congo Basin process with its well-mapped fauna and experts can deliver an important contribution to the entire field of conservation planning if it can find a way to recommend more flexible and meaningful targets.

4.2.2 Connectivity

The connectivity calibration demonstrated in Figure 22 will deliver optimal upstream protection while not requiring entire catchments to be selected as part of the priority area network. As disturbance is factored in, this also drives the selection process away from highly disturbed areas. However, the actual calibration should also be reviewed in a future workshop. Local expertise will determine whether an optimal inflection point has been chosen on Figure 22 or whether – based on local knowledge on the severity of disturbance and the propagation of threats – more or less upstream disturbance will be recommended.

4.3 Alignment with the 2007 terrestrial and freshwater expert assessment

In 2007 the Ministry of the Environment and ICCN initiated a country-wide biodiversity assessment to identify priority areas for conservation, and to contribute strategic data to inform government legal reviews, conversion of logging titles and future national land use planning. The World Wildlife Fund was asked to assist in convening a workshop to identify these priority areas for conservation. Spatial data and outputs from a decision support system (DSS) were provided to guide expert opinion in a workshop setting to identify priority areas for terrestrial and freshwater biodiversity across the region. Below we have overlaid the output from the 2007 workshop with the Marxan solution for freshwater species and ecosystems using a target of 2,000 km^2 and CP of 1.3 (Figure 27). It is encouraging to see the high level of overlap between these solutions despite them being developed with different methodologies and the former including additional terrestrial species in its analysis.

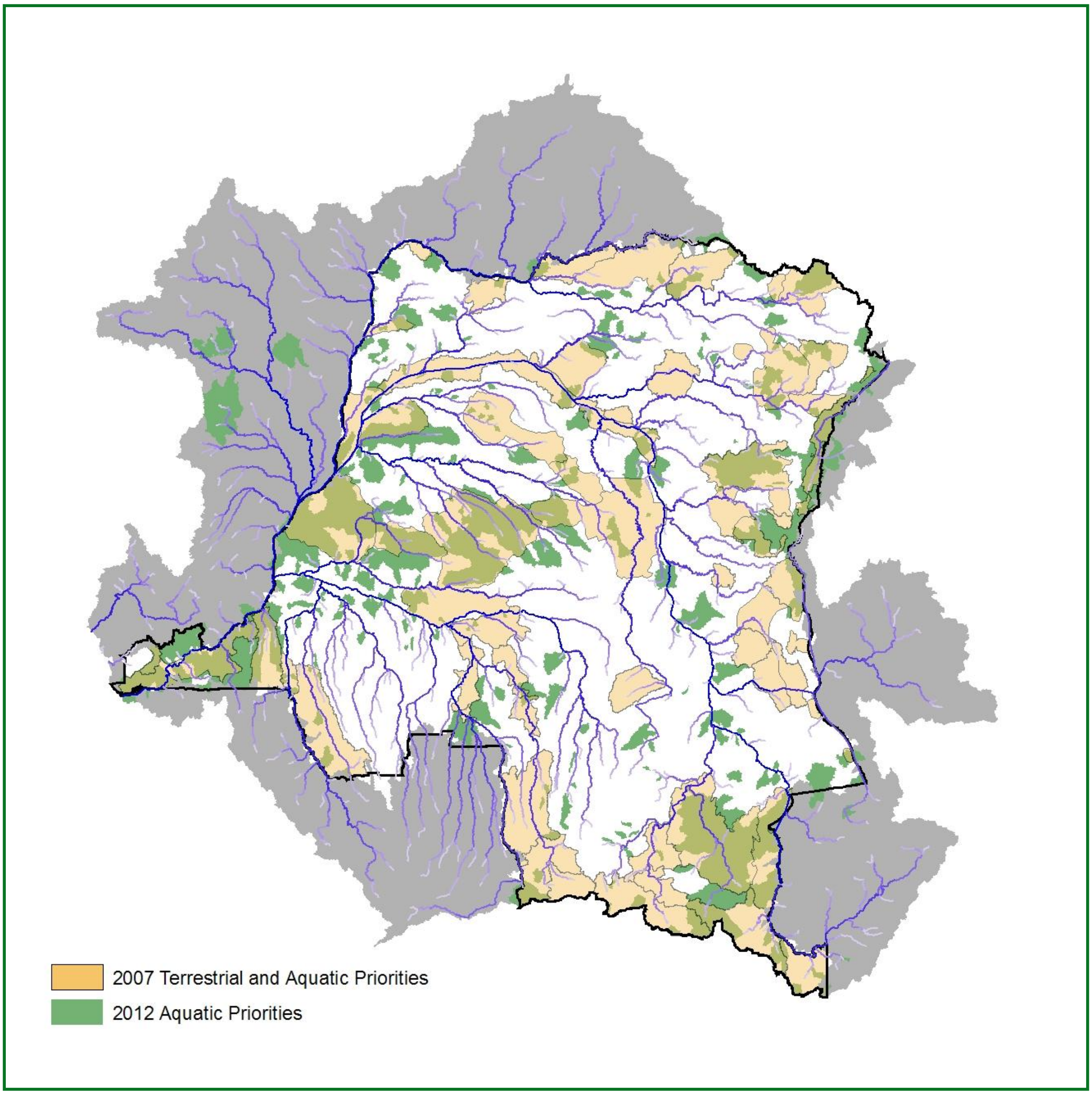


Figure 27. Combined terrestrial and aquatic priorities from the 2007 ICCN/WWF expert workshop (in beige) and Marxan-generated aquatic priorities using a target of 2,000 km2, CP of 1.3, and with national parks "locked in".

4.4 Proposed next steps

4.4.1 Further Analyses

We recommend that as the work of the GTT ED of PARAP moves forward other relevant datasets and considerations related to freshwater be incorporated into the discussion and decision making process. For example, the results of the analysis should be overlaid with mining and forestry concessions to highlight potential conflicts. Additionally, the benefits that humans derive from freshwater ecosystem services can provide critical underpinnings for any argument for protection of these systems. A spatially explicit evaluation of these services and their overlap with freshwater species and ecosystems either at the level of particular protected areas or across the basin would be an important input for the freshwater component of PARAP.

4.4.2 Groundwater

Groundwater-surface water interactions have been flagged as a high priority by workshop participants. So far groundwater has only twice been included in conservation planning exercises – once unconnected to terrestrial features (Michel et al. 2009) and once by Simon Linke in the Hunter region of NSW, Australia (publication in preparation). Despite the Hunter Valley being heavily mined and hence the groundwater topology being reasonably well resolved, it was hard to groundtruth real groundwater ecoregions. In the pilot study this was done based on known aquifers and estimated groundwater-surface water connections. This is currently being extended by PhD student Maria Gulbrandsen Asmyhr, who is conducting a genetic analysis of aquifer connectivity. While this seems a very far target for the Congo Basin, groundwater could be included in a next step if aquifers are mapped for the region.

4.4.3 Capacity building

Feedback from the workshop and afterwards indicates that there is need for further understanding of the inputs and outputs of Marxan, as well as technical training to build capacity in the region to undertake future analyses and update current ones. If Marxan is to be used in further analyses we recommend a 2-day workshop for managers and scientists to better understand the software and its capabilities before any technical workshop in which analyses are presented or in which experts provide input to analyses. Additionally, we recommend training at least one GIS specialist based in the region in the technical aspects of Marxan.

4.4.4 Recommendations for data improvement

Overall, the IUCN Africa freshwater assessment data – despite the coarse plant and odonate assessments – seem both scientifically sound and accurate. The only recommendation for the future would be to include an updated layer once the Hydro1K data is ported to HydroSHEDS.

Investments that will yield the biggest rewards are:

a) Updating the disturbance layers using both new data from the DRC, as well as from the entire basin. A relatively easy step will be to re-assemble the dam layers and clip accurate positions of dams to HydroSHEDS. Further steps could include collecting population data, especially from the DRC as well as neighbouring countries. Any other disturbance layers that can be obtained for all of – or just part of the basin – would be welcome, as long as protocols are developed on how they can be standardised basin-wide.

b) Cleaning up the mammal and amphibian databases. A costly but potentially necessary approach to include these important and charismatic groups is to convene a group of experts to refine these data for the Congo basin. This could yield highly refined data that could then be included in future analyses and planning.

4.4.5 Revisiting targets and connectivity

As stated above, this report should be regarded as a first step – a discussion point from which better parametarisation of the targets, as well as the connectivity requirements can be derived. Blanket area targets like the 2000 km^2 are an easy substitute, but cannot replace ecological knowledge. Obviously, a large mammal or a migratory fish species needs a larger range than a small crab or mollusc, which is likely to be mainly dependent on microhabitat and upstream water quality. Therefore, we recommend working with individual experts to set more ecologically meaningful targets.

Similarly, we recommend to ecologically test the connectivity calibration. While the calibration demonstrated in 22a is an ecologically meaningful calibration, the magnitude and scale of the disturbance axis can influence whether more or less upstream protection is needed. Scaling the influence of upstream disturbances can also be discussed at a workshop with local experts who can ground truth how far an upstream disturbance can propagate downstream.

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Annex 1: List of participants at the first meeting of the Freshwater Technical Working Group (GTT ED) of PARAP, February 23, 2012, Kinshasa, DRC.

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