Protected Areas Resilient to Climate Change, PARCC West Africa

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Assessment of Protected Area Connectivity in West Africa

ENGLISH

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Executive Summary

The PARCC project focuses on identifying risks and adaptive measures for protected areas in West Africa in response to climate change and variability. To inform the choice of pilot sites, this assessment looks at protected areas and links between them, with a particular focus on the borders of Mali, Chad, Gambia, Togo, Sierra Leone, Burkina Faso, Cote d'Ivoire and Ghana. We aimed to identify: (i) important protected areas and (ii) links between them, which, if improved, should contribute most effectively to connectivity of the protected area network.

We used a set of generic focal species as surrogates to represent variation amongst terrestrial species. These surrogates were not based on actual species, but were a combination of habitat preferences (forest, grassland and generalist) and maximum dispersal distances (short, 1km; medium, 10km; long, 100km). We used these characteristics with the graph theory software Conefor. This approach models protected areas containing habitat as patches and the Euclidean (straight line) distance between them as links. Functional links were those within these maximum dispersal distances. For each generic focal species, we produced results based on the varIIC connector index, which measures contribution as a stepping stone connector. Protected area values were calculated from the overall change in connectivity of the protected area network when a protected area was removed. Potential link importance values were calculated by measuring the connectivity change of the network, from iteratively inserting links up to 10km longer than the maximum dispersal distance of each generic focal species. These link importance values thus measure their contribution to connectivity if an intervention (e.g., protected area expansion, corridor management) could help bridge such gaps allowing a functional link between protected areas.

For each combination of generic focal species characteristics, we produced results for the varIIC connector contribution for individual protected areas and links, focusing on those near or crossing country borders. The dispersal distance with the largest number of protected areas that contribute via this stepping stone index was long, followed by medium and small. This result highlights the importance of using a variety of approaches to improve connectivity for species with different dispersal distances.

For short dispersal species, in most instances, habitat management and improvement should be preferentially targeted within protected areas, especially since habitat connectivity within protected areas is not adequately addressed in this study, most notably for forest or grassland specialists. Medium dispersal species, however, could be appropriate targets for link improvement work, especially for forest specialists where the varIIC connector contributes most to overall habitat availability. For long dispersal species, targeting link improvement may be less cost effective considering that a potentially high number of barriers may be present; therefore protected area habitat management or expansion, particularly in those with high varIIC connector scores, may be the best use of resources.

The approach used highlights key protected areas and links for improving overall connectivity of the protected area network, and it informs the prioritisation of further fieldwork within the context of the PARCC West Africa countries as a whole. Methodological changes to address the various assumptions made in this work could provide more ecologically realistic results, but would require more detailed analyses.

1. Introduction

Project background

The goal of the Protected Areas Resilient to Climate Change (PARCC) West Africa project is to enhance the conservation and sustainable management of representative protected area (PA) ecosystems in West Africa through strengthened assessment and adaptation to the effects of climate change. The PARCC project focuses on five main countries (Mali, Chad, Gambia, Togo and Sierra Leone) with a further three which could be involved in transboundary aspects (Burkina Faso, Cote d'Ivoire, Ghana).

The main elements of this work will be to identify risks to PAs as a consequence of climate variability and change, and to plan for adaptive measures that should be undertaken to minimise those risks. As transboundary initiatives are likely to offer some of the most effective solutions, some pilot sites will be selected to assess how PAs could improve their resilience on the ground. One of the criteria for informing the choice of pilot sites is an assessment of the connectivity of the current PA system for West Africa, with a particular focus on transboundary PAs.

Connectivity assessment for protected areas

To prevent the negative effects of habitat fragmentation and isolation, such as the loss of genetic diversity and essential ecological processes, connectivity conservation typically aims to (i) maintain existing links and patches or to (ii) restore/create links between habitat patches (Ewers and Kapos, 2011). Restoration efforts are typically focused at the site scale, but considering the potential impacts of climate change, it is important to consider the larger context of such efforts to focus on where they could most benefit overall connectivity (Baldwin *et al.,* 2012; Noss *et al*., 2001).

A variety of spatially explicit computer modeling approaches have been used to prioritise conservation efforts. These are generally based upon patch-matrix-corridor approaches, where patches of suitable habitat are surrounded by a matrix of less suitable and less permeable habitat in between, with habitat corridors providing functional connectivity between patches. Graph theory is increasingly being used to provide connectivity indices for such modeled landscapes and has been able to move beyond providing simple descriptive indices and towards providing a practical tool for conservation practitioners (Saura and Torné, 2009).

As species vary in their dispersal ability (and habitat preferences), there is no single connectivity metric to measure connectivity of a landscape for all species (Ewers and Kapos, 2011). Therefore, depending on the aims and scope, a study may decide to focus on connectivity for a single species (Carroll *et al*., 2011), a suite of representative/focal species (WHCWG, 2010), or use generic characteristics to attempt to cover a broad range of species preferences (Minor and Lookingbill, 2011). The latter approach, which is used in this study, is not based directly on actual species but on broad representative characteristics, and, from here on, is referred to as the *generic focal species approach* (Eycott *et al.*, 2007).

Aim of the assessment

The aim of the assessment is to highlight the location of possible transboundary areas of particular interest. This is achieved through the identification of the following:

1. The existing PAs most important for connectivity, and
2. The links between PAs which would be the most important to enhance connectivity.

Particular attention has been paid to transboundary sites, primarily in order to inform the choice of pilot sites.

2. Methods

Software

We used the software QGIS and PostGIS for GIS analysis and map production, and R and the graph theory software Conefor to calculate connectivity indices. Our study area consisted of a 300km buffer around the eight PARCC countries of interest, to incorporate connectivity to adjacent countries. We clipped all datasets to this extent for this analysis.

Protected areas

We collected protected area (PA) data from the World Database on Protected Areas (WDPA) (IUCN and UNEP-WCMC, 2013). This is the most consistent and comprehensive global dataset for PAs. We obtained additional PA polygons for Chad prior to their inclusion in the WDPA, which were incorporated into our analysis, as they represent important changes to the PA network. We removed all UNESCO Man and Biosphere reserves, as some are established for reasons other than biodiversity conservation.

Some PAs lacked associated polygons and were present as point data in the WDPA dataset. Where these points had attributes for the size of the PA they represent, we created circular buffers equal to this area. As these points represent a high level of uncertainty for detailed spatial analysis, we removed any with a proposed status. We combined PAs that were adjacent to, or overlapping with, each other and removed polygons smaller than 100m^2 that were obvious artifacts of this process. In order to explore the variation associated with including PA point data in our analyses, we compared a subset of our final results with those from an additional protected area dataset that contained no point PAs (i.e., polygons only) (see Annex 5).

Generic focal species as biodiversity surrogates

For this study, we aimed to assess the connectivity between Pas, for a set of twelve generic focal species to attempt to represent the range of species that are present in the study area. These twelve generic focal species were not based upon specific species, but are combinations of three broad habitat preferences and three dispersal abilities. We used habitat preferences for (i) forest specialists; (ii) grassland specialists; and (iii) habitat generalists. These represent some of the notable ecosystems in the study area, as well as generalist species that are able to traverse multiple ecosystems. We combined these with maximum dispersal distances of 1km, 10km and 100 km, to represent species with short, medium and long range dispersal abilities. These values were used by Minor and Lookingbill's (2010) work on mammal connectivity in PAs, but should also represent differing dispersal abilities for species in other taxonomic groups.

Connectivity indices and software

We used graph theory software Conefor to model connectivity as it is able to produce a variety of indices for individual PAs and the links between them, as well as for the landscape as whole. Graph theory has been used in a variety of disciplines to represent complex interlinked systems, based upon nodes and the links between them.

When applied to species connectivity, nodes represent habitat patches, and links represent the distance between patches (through the matrix). This software requires as inputs dispersal information for the species in question, an appropriate indicator of habitat quality and the distances between habitat patches. We derived such inputs for each of our generic focal species to use in this software.

We linked the broad habitat preferences to corresponding land cover classes (see Annex 2) from GLC 2000 land cover (Bartholome and Belwarde, 2005). We measured habitat quality for each PA as the sum of the area of these land cover classes. We only included PAs for which the relevant land cover classes covered more than 1% of their area, thus removing those that were either: (i) of little or no use to the generic focal species; (ii) may represent errors in the land cover class (e.g., small isolated forest patches in a desert ecoregion); or (iii) not likely to have sufficient habitat to facilitate movement within the PA. For this analysis, we did not consider habitat for species outside PAs and we calculated Euclidean (i.e., straight-line) distances to model dispersal between those Pas with 'habitat'. We ran models in Conefor for each of the generic focal species using the corresponding values for patch quality, distance between patches and their maximum dispersal distance.

We focused on a component of the Integral Index of Connectivity (IIC) (Saura and Torné, 2009) from the Conefor software, which measures connectivity in terms of habitat availability. For this index, a patch is either connected or not, depending on whether it lies within the maximum dispersal distance of the species in question (other indices, such as the PC index, convey advantages from the use of probabilistic connections and dispersal kernels, however, processing times were not practical). Conefor calculates the importance of each patch (i.e., a PA containing habitat) to the network as a whole by removing each patch in turn and comparing the difference (varIIC) to the overall integral index of connectivity (IIC) of the entire network. This change index (varIIC) can be split into three components, which for this analysis we focused on the varIIC connector component:

varIIC = varIIC intra + varIIC flux + **varIIC connector**

The varIIC intra component represents contribution via internal patch connectivity, and varIIC flux the contribution of connected patches that do not act as stepping stones but are connected to other patches (i.e., terminal nodes). The varIIC connector component measures the importance of a patch (i.e., PA) as a connector between two, or more, patches that are not otherwise functionally connected. A brief exploration of the contribution of each of the three components is given in the discussion.

We chose to focus on the connector component, primarily as it is most relevant for highlighting PAs that connect across borders and it avoids the tendency to assign higher connectivity values to patches with large areas, as is found with some other indices. This component takes account of the habitat area of all of the patches that it connects, but not its own, making it well suited as a metric for assessing connectivity across borders.

In addition to the patch importance, we assessed potential contribution of improving links between patches by iteratively modeling links between PAs that would not normally be connected (i.e., currently outside species maximum dispersal distance) as being connected, calculating (varIIC) link importance values for each. These values represent the added contribution to connectivity if the quality of the connection could be improved, such as through improved habitat or PA extension. To limit processing time, we modeled improvement for all links up to 10km above the maximum dispersal distance of each of the generic focal species: short dispersal links between 1km and 11km; medium links from 10km to 20km; long from 100km to 110km.

3. Results

The maps within this section show a subset of the results from the full analysis, focusing on: (i) protected areas (PAs) near borders (within 10km) and (ii) links near borders (within 1km). For each of these, results are arranged according to habitat preferences and maximum dispersal distances of the various generic focal species:

- Forest specialists:
  - Short dispersal ability (≤1km)
  - Medium dispersal ability (≤10km)
  - Long dispersal ability (≤100km)
- Grassland specialists:
  - Short dispersal ability (≤1km)
  - Medium dispersal ability (≤10km)
  - Long dispersal ability (≤100km)
- Generalist specialists:
  - Short dispersal ability (≤1km)
  - Medium dispersal ability (≤10km)
  - Long dispersal ability (≤100km)

The above generic focal species characteristics attempt to represent some of the range of species preferences in the study area.

The legend for each of the PA maps shows the contribution of each of the PAs as a stepping stone connector (i.e., the varIIC connector component of the habitat availability metric, varIIC). In the legends of the link importance maps, the varIIC values represent the connector component only, as by their nature links can only contribute to habitat availability through this component. Colour categories were chosen to represent relative importance for the specific generic focal species characteristics assessed and therefore should not be compared directly between maps.

Additional results are presented in the following Annexes:

1. The changing number of links between PAs for the three dispersal distances used in this study: 1km, 10km, 100km, for all West African PAs.
2. Land cover classes used to represent habitat within PAs, for the focal species in this study.
3. Importance of PAs as connectors to the entire PA network in PARCC countries, for generic focal species.
4. Potential importance of improving links between PAs to the entire PA network in PARCC countries, for generic focal species.
5. Change in the varIIC Connector index from removal of buffered point PAs from analysis.

Protected areas: importance as stepping stone connectors

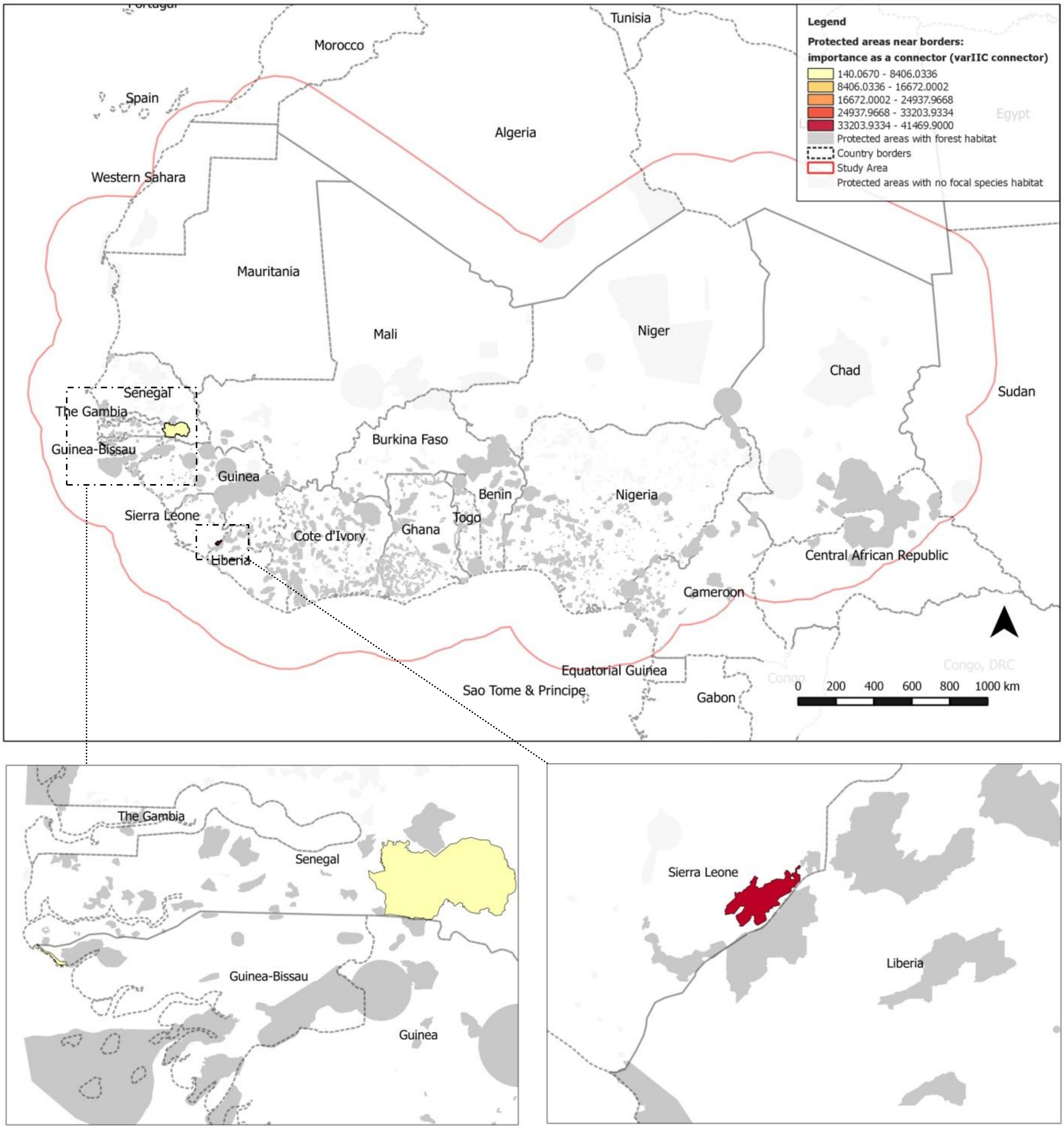

Figure 1. Importance of PAs as connectors (stepping stones) for generic focal species: **forest specialists with short range (1km) maximum dispersal abilities.**

Only three PAs near borders contribute to the connector index for short range dispersal forest species:

- Gola Rainforest National Park in Sierra Leone (with the largest contribution of the three);
- Niokolo-Koba National Park in Senegal; and
- Varela National Park, a very small coastal PA in Guinea-Bissau.

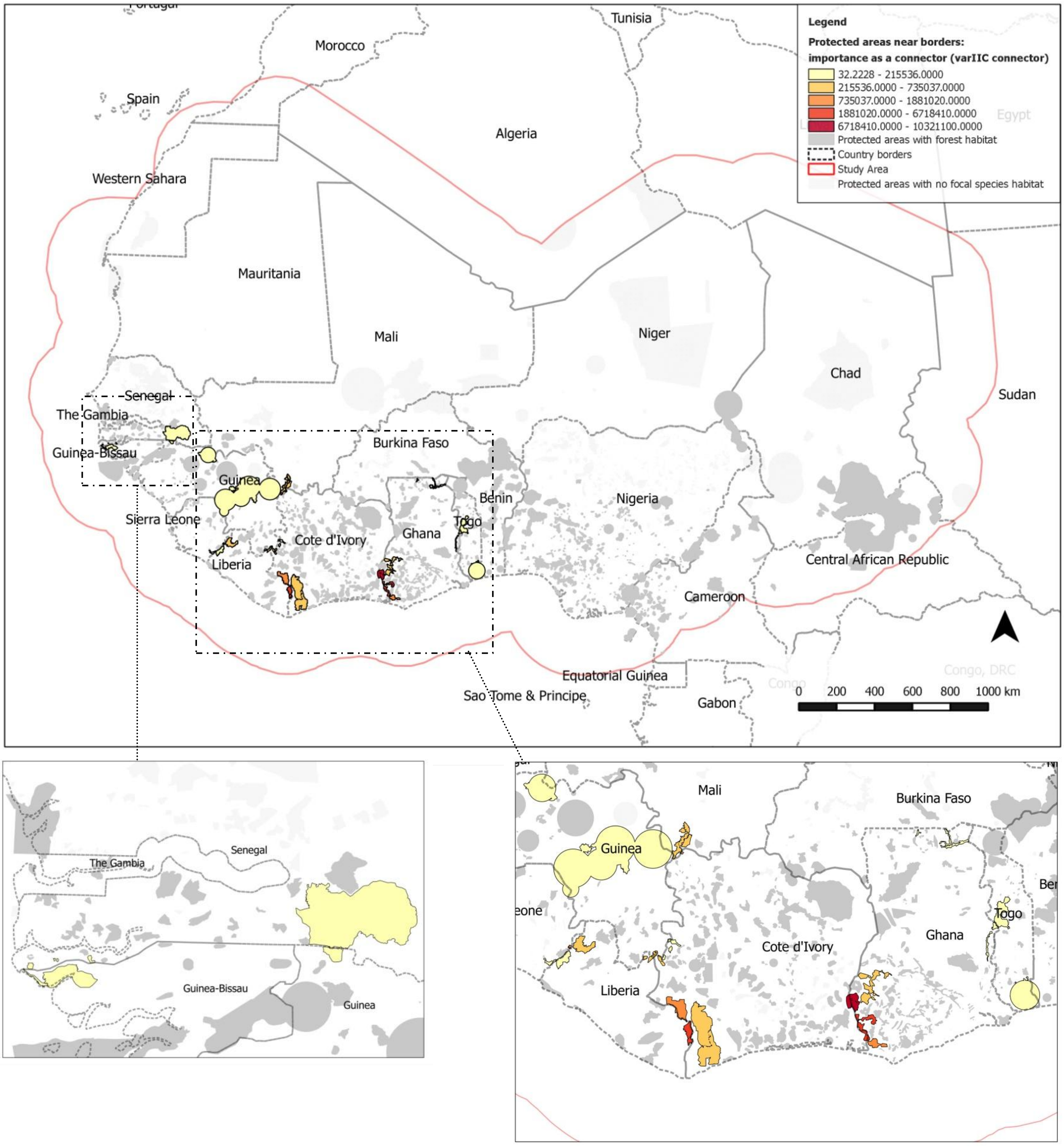

Figure 2. Importance of PAs as connectors (stepping stones) for generic focal species: **forest specialists with medium range (10km) maximum dispersal abilities.**

The most important connector PAs for medium range dispersal forest species are found in two main areas:

- The PAs along the Ghana-Cote d'Ivoire border: Diambarakrou and Tanoe Classified Forests, in Cote d'Ivoire; Bia National Park and the Forest Reserves of Sukuzuki, Bia Tawya, Diadieso, Boin River, Disue River, Yoyo River, and Tano Ehuro, and Tano Anwia, in Ghana; and
- Grebo National Park in Liberia (and to a lesser extent the classified forests of Gouin, N°58 and N°77 found to the north of this PA in Ghana).

There are three other areas of slightly less importance, which include the following PAs:

- Foya National Park in Liberia, and Gola Forest National Park in Sierra Leone;
- Wildlife Reserves of Djangoumerila, Nienendougou, Djinetoumanina and Dialakoro in Mali, and Mt Manda Classified Forest in Cote d'Ivoire; and
- National Parks of East Nimba and Nimba West in Liberia, and Mount Nimba Strict Nature Reserve World Heritage Site in Guinea.

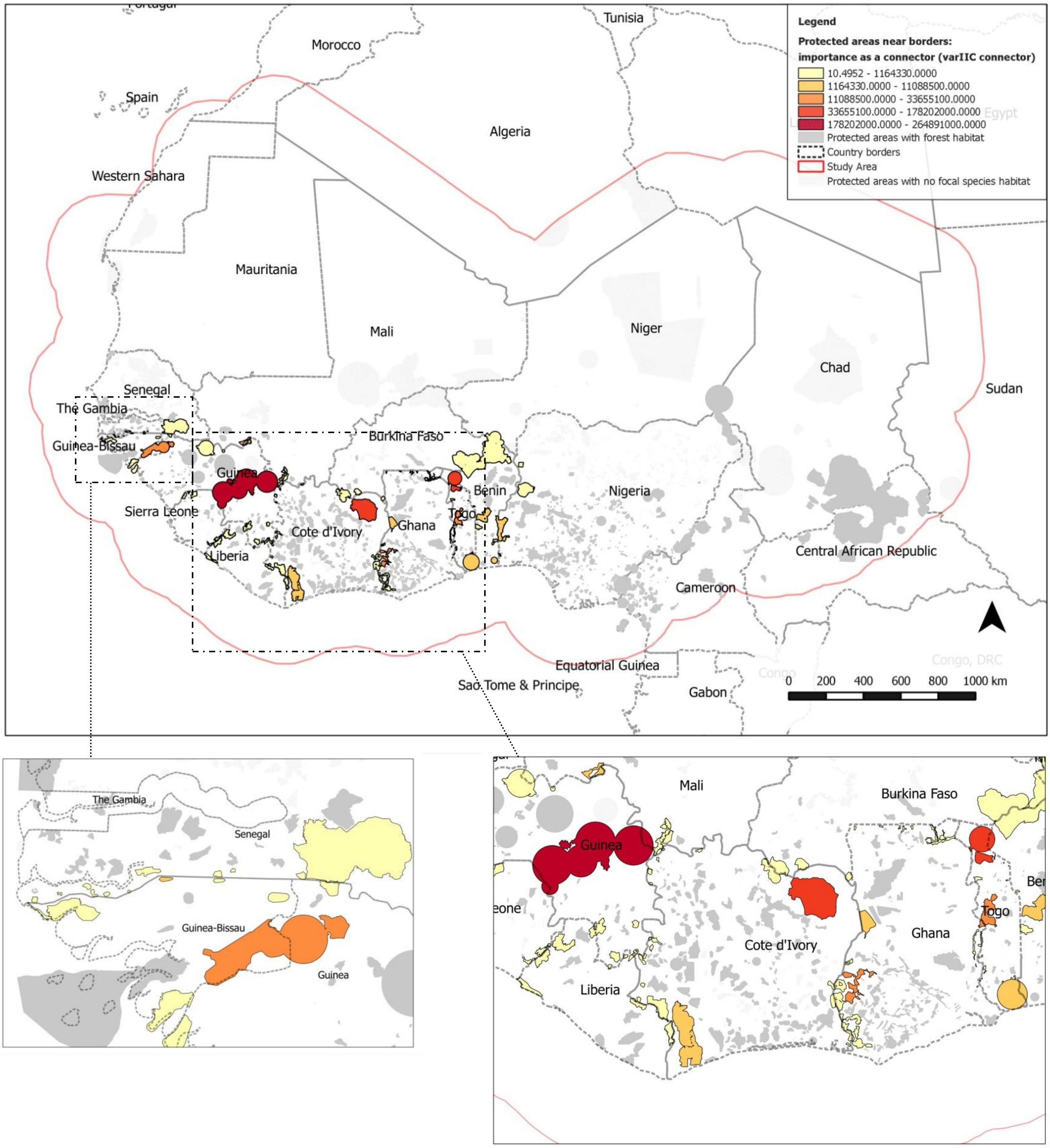

Figure 3. Importance of PAs as connectors (stepping stones) for generic focal species: **forest specialists with long range (100km) maximum dispersal abilities.**

Many more connector PAs were identified as being important for long range dispersal forest species, in particular the large PA complex in Guinea made up of the Ramsar Sites of Niger-Mafou, Niger Source, Niger-Niandan-Milo, and Sankarani-Fié, as well as Haut Niger National Park (Kouya core area) and Kourani-Oulete-Dienne Classified Forest. It is, however, important to note that there is inherent uncertainty for PAs composed entirely or in part of buffered points.

The following connector PAs were also found to be of significant importance:

- Oti-Keran/Oti-Mandouri UNESCO-MAB Biosphere Reserve, Bassin versant Oti-Mandouri Ramsar Site and Kéran National Park in Togo, which are found close to the WAP ('W', Arly, Penjari) transboundary PA between Benin, Burkina Faso and Niger; and
- Comoé National Park UNESCO-MAB Biosphere Reserve in Cote d'Ivoire, near the Burkina Faso and Ghana borders.

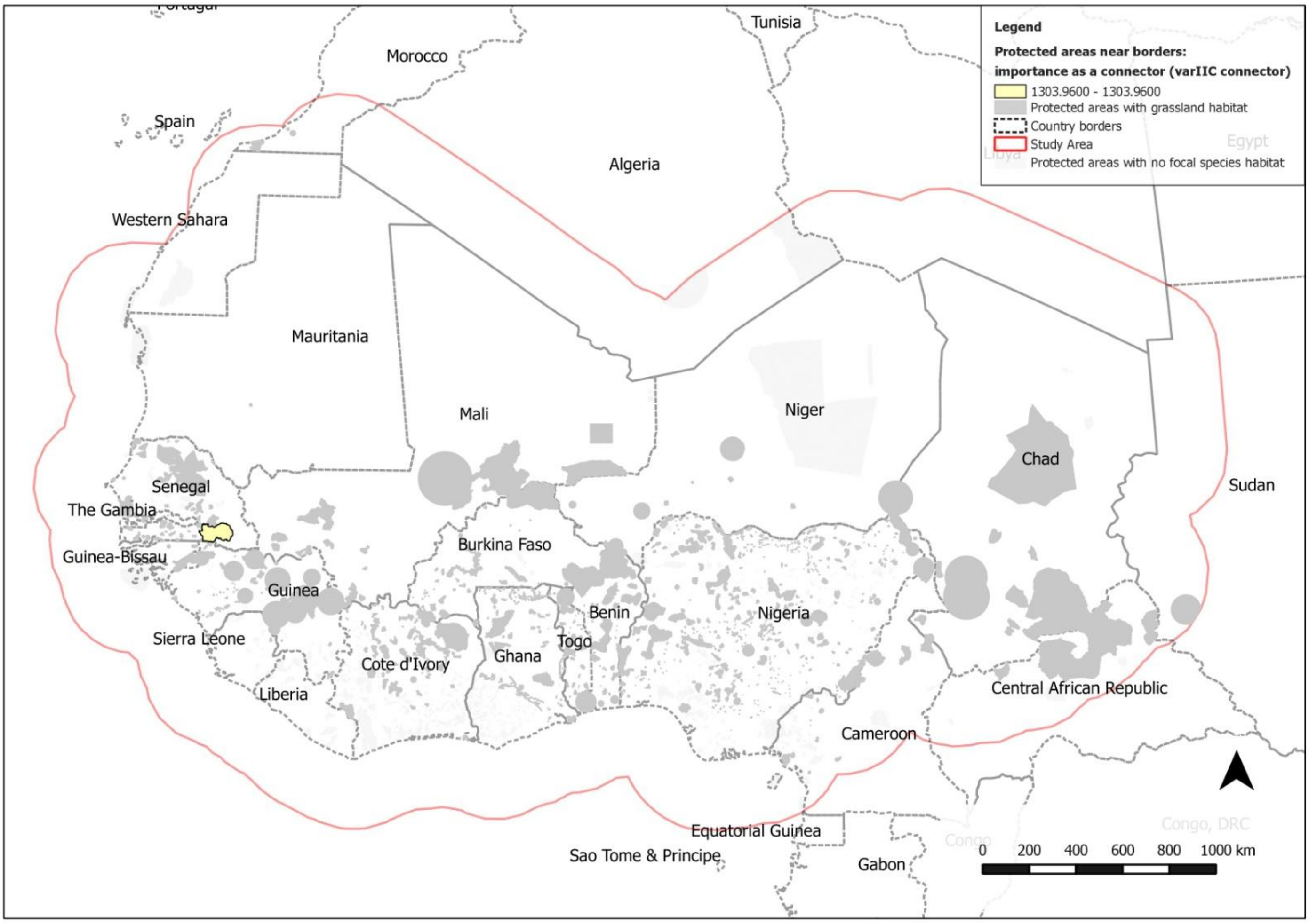

Figure 4. Importance of PAs as connectors (stepping stones) for generic focal species: **grassland specialists with short range (1km) maximum dispersal abilities.**

For short range dispersal grassland species, only one PA near country borders contributes to connectivity as a stepping stone connector: Niokolo-Koba National Park in Senegal, next to the border with Guinea.

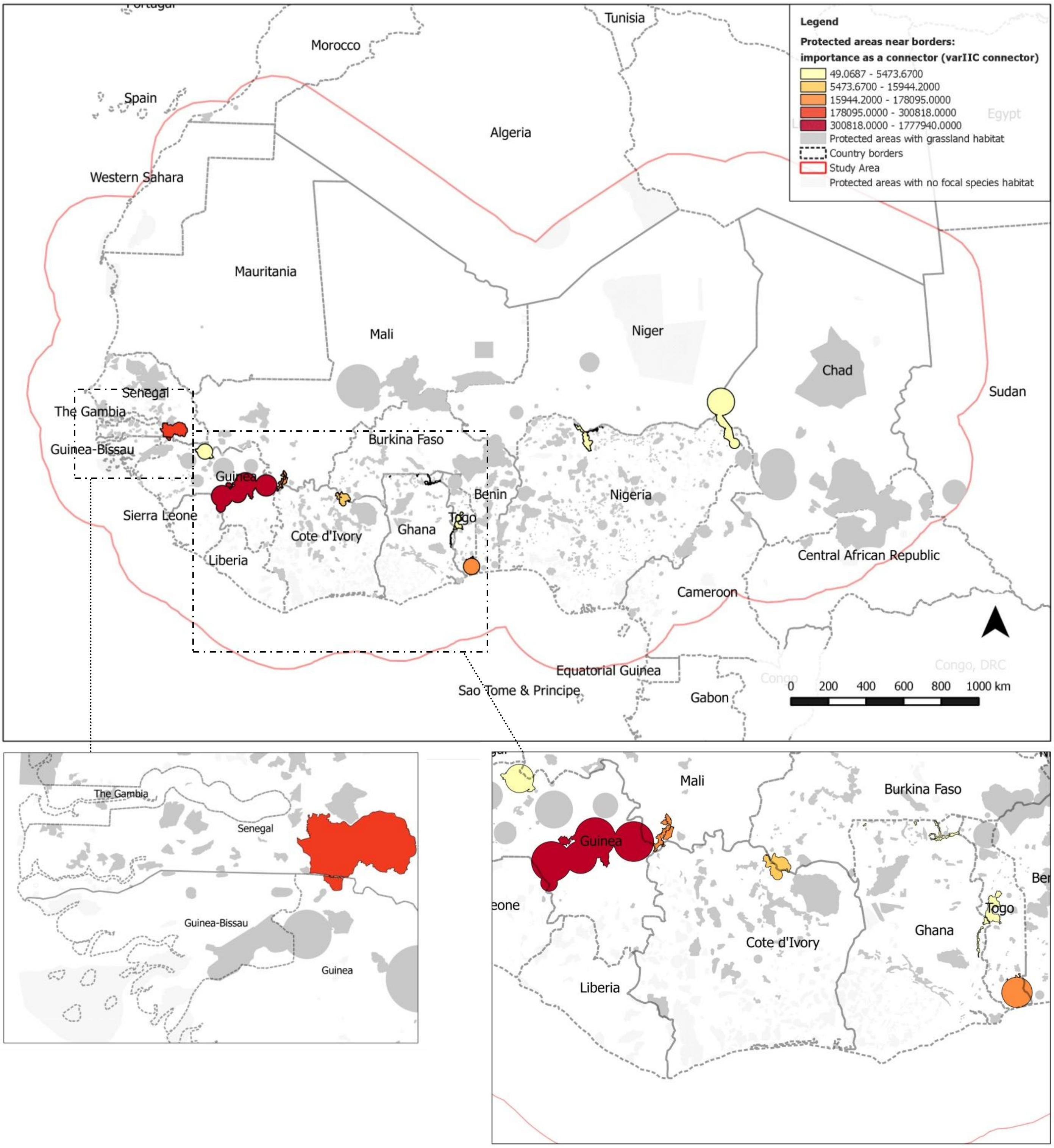

Figure 5. Importance of PAs as connectors (stepping stones) for generic focal species: **grassland specialists with medium range (10km) maximum dispersal abilities.**

The most important connector PAs for medium range dispersal grassland species are the PA complex found in Guinea (however, as noted above, these PAs are actually buffered points and should hence be treated with caution). In addition, the following PAs also make a significant contribution:

- Niokolo-Koba National Park, in Senegal, and Badiar national Park in Guinea; and

- Wildlife Reserves of Djangoumerila, Nienendougou, Djinetoumanina and Dialakoro in Mali, and Mt Manda Classified Forest in Cote d'Ivoire; and
- *Zones Humides du Littoral du Togo* Ramsar Site in Togo, near the Benin border.

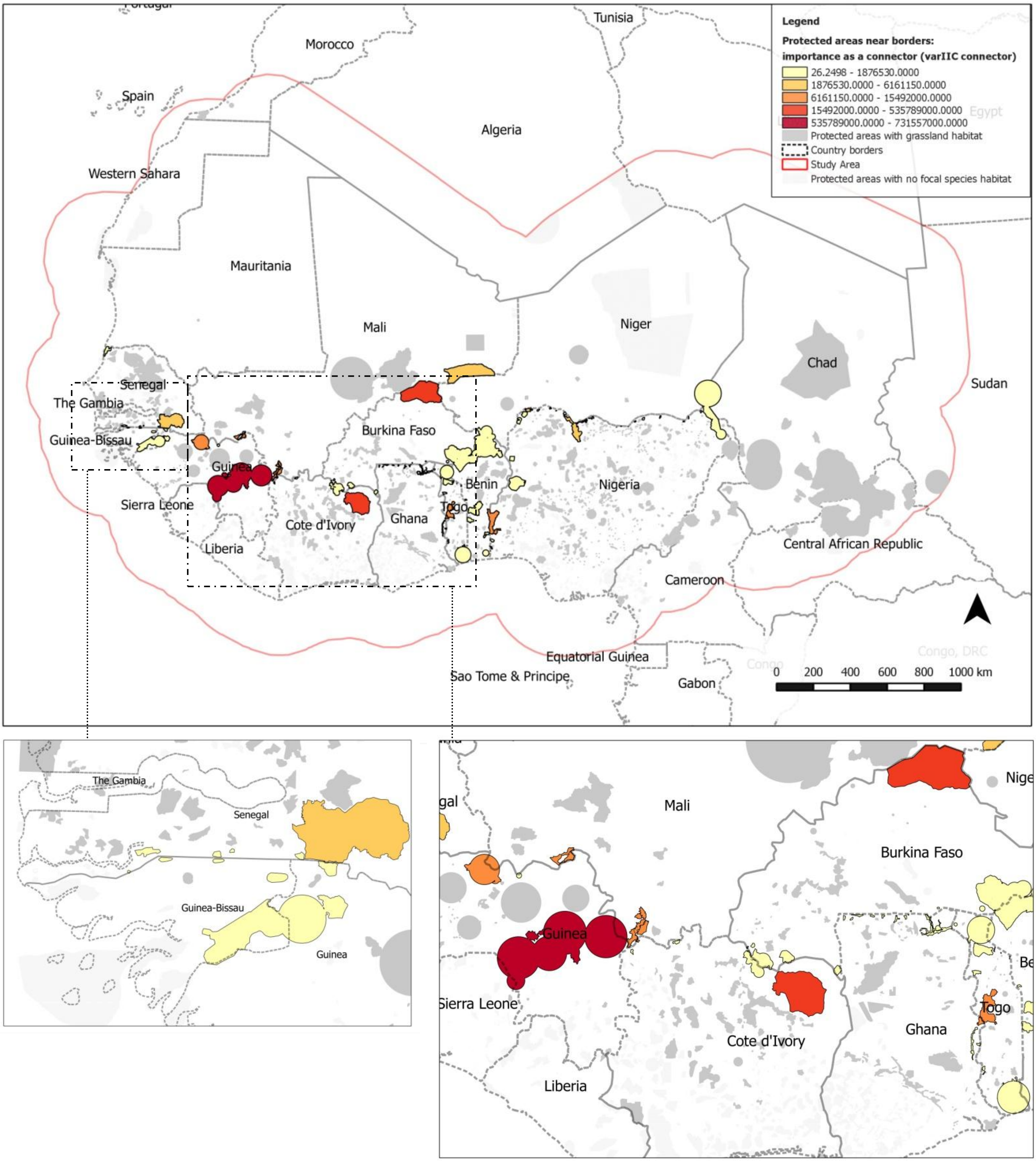

Figure 6. Importance of Pas as connectors (stepping stones) for generic focal species: **grassland specialists with long range maximum dispersal (100km) abilities.**

Similar connector PAs (and several more) are found for long range dispersal as for medium range dispersal grassland species. In addition to the PA complex in Guinea (see description and caveat above), the following connector PAs have been identified:

- Comoé National Park World Heritage site in Cote d'Ivoire, near the Burkina Faso and Ghana borders; and
- Sahel Partial Faunal Reserve in Burkina Faso, along the border with Mali and Niger, and adjacent to Mali's Gourma Partial Elephant Reserve.

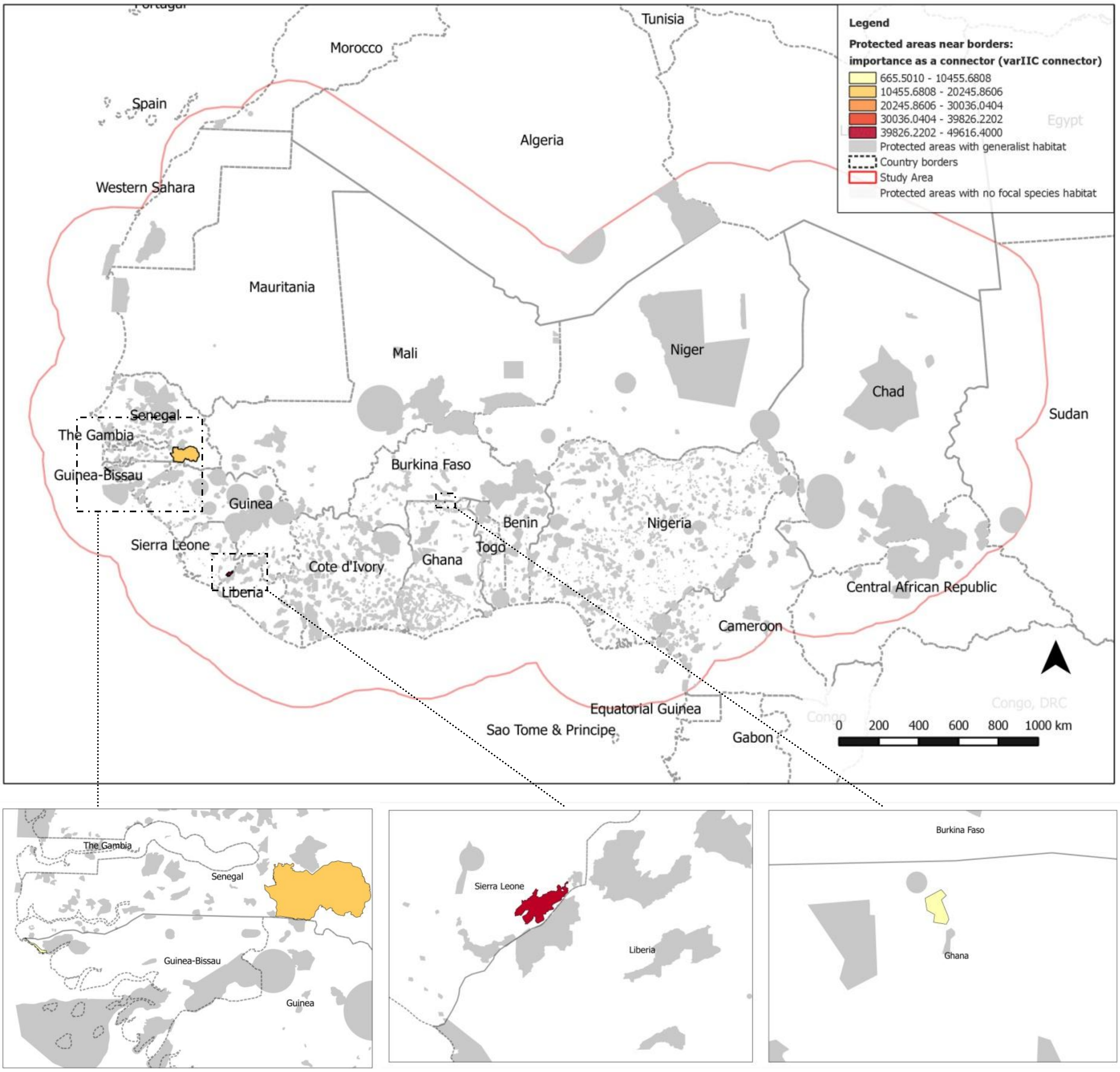

Figure 7. Importance of PAs as connectors (stepping stones) for generic focal species: **generalists with short range (1km) maximum dispersal abilities.**

The connector PAs which appears to be the most important for short range dispersal generalists are:

- Gola Rainforest National Park, in Sierra Leone (the most important one);

- Niokolo-Koba National Park, in Senegal; and
- Navrongo North Forest Reserve, in Ghana near the border with Burkina Faso (to a lesser extent).

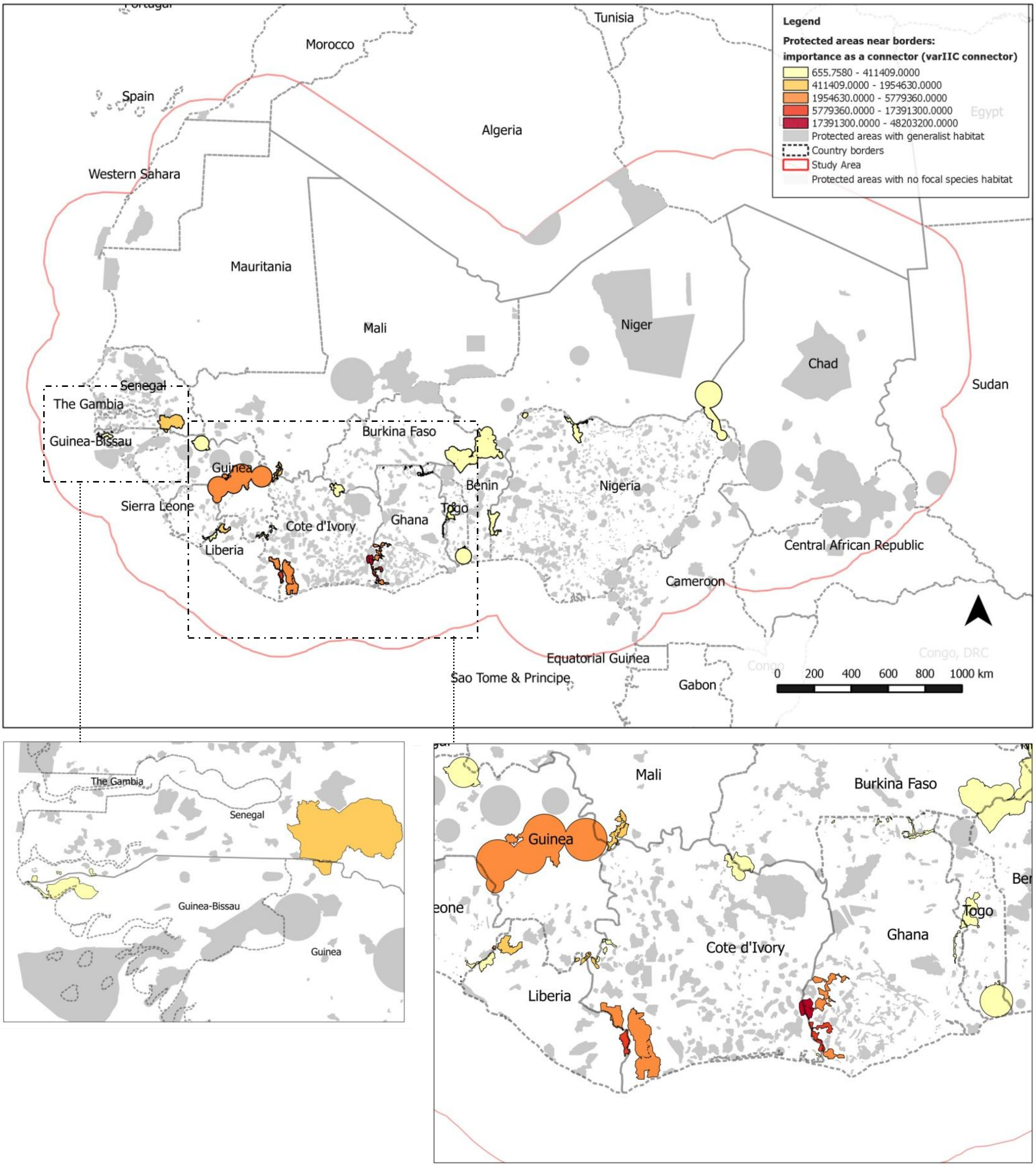

Figure 8. Importance of PAs as connectors (stepping stones) for generic focal species: **generalists with medium range (10km) maximum dispersal abilities.**

The PAs with the highest values as connectors for medium range dispersal generalists are:

- The PAs along the Ghana-Cote d'Ivoire border: Diambarakrou and Tanoe Classified Forests, in Cote d'Ivoire; Bia National Park and the Forest Reserves of Sukuzuki, Bia Tawya, Diadieso, Boin River, Disue River, Yoyo River, and Tano Ehuro, and Tano Anwia, in Ghana; and
- Grebo National Park in Liberia, near the Cote d'Ivoire border.

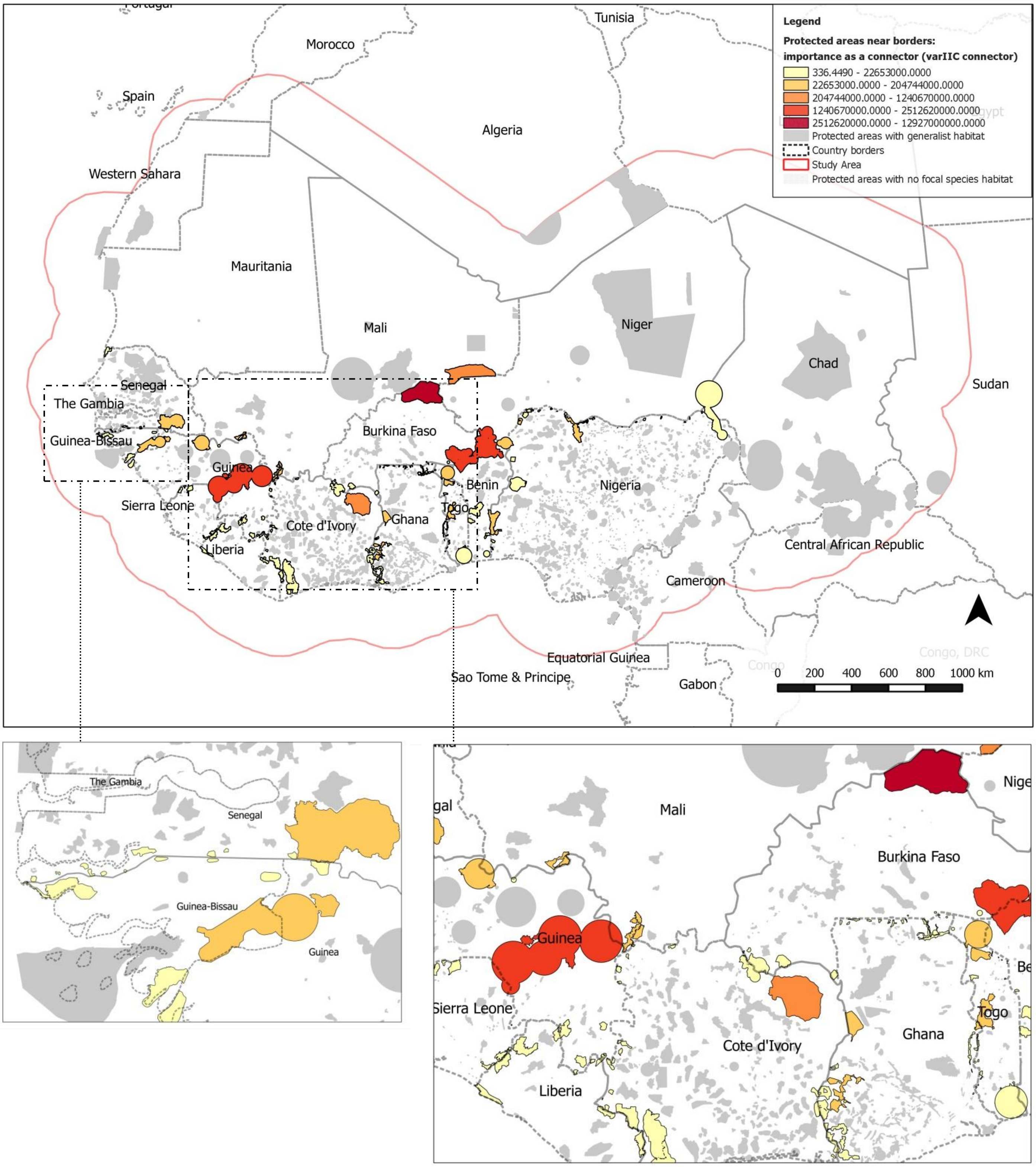

Figure 9. Importance of PAs as connectors (stepping stones) for generic focal species: **generalists with long range maximum dispersal abilities.**

In addition to the PAs running through Guinea (mentioned above), the most important priority connector PAs for long range generalists are found in the following areas:

- Sahel Partial Faunal Reserve in Burkina Faso, along the border with Mali and Niger, and adjacent to Mali's Gourma Partial Elephant Reserve; and
- WAP transboundary complex made of three protected areas: Arly Partial Faunal Reserve in Burkina Faso, Penjari Hunting Zone in Benin and 'W' Transboundary Park in Benin, Burkina Faso and Niger.

Two other areas also appear to be important for long range generalists:

- Comoé National Park World Heritage site in Cote d'Ivoire, near the Burkina Faso and Ghana borders; and
- Ansongo Menaka Integral Wildlife Reserve in Mali.

Links: potential importance as connectors, if improved

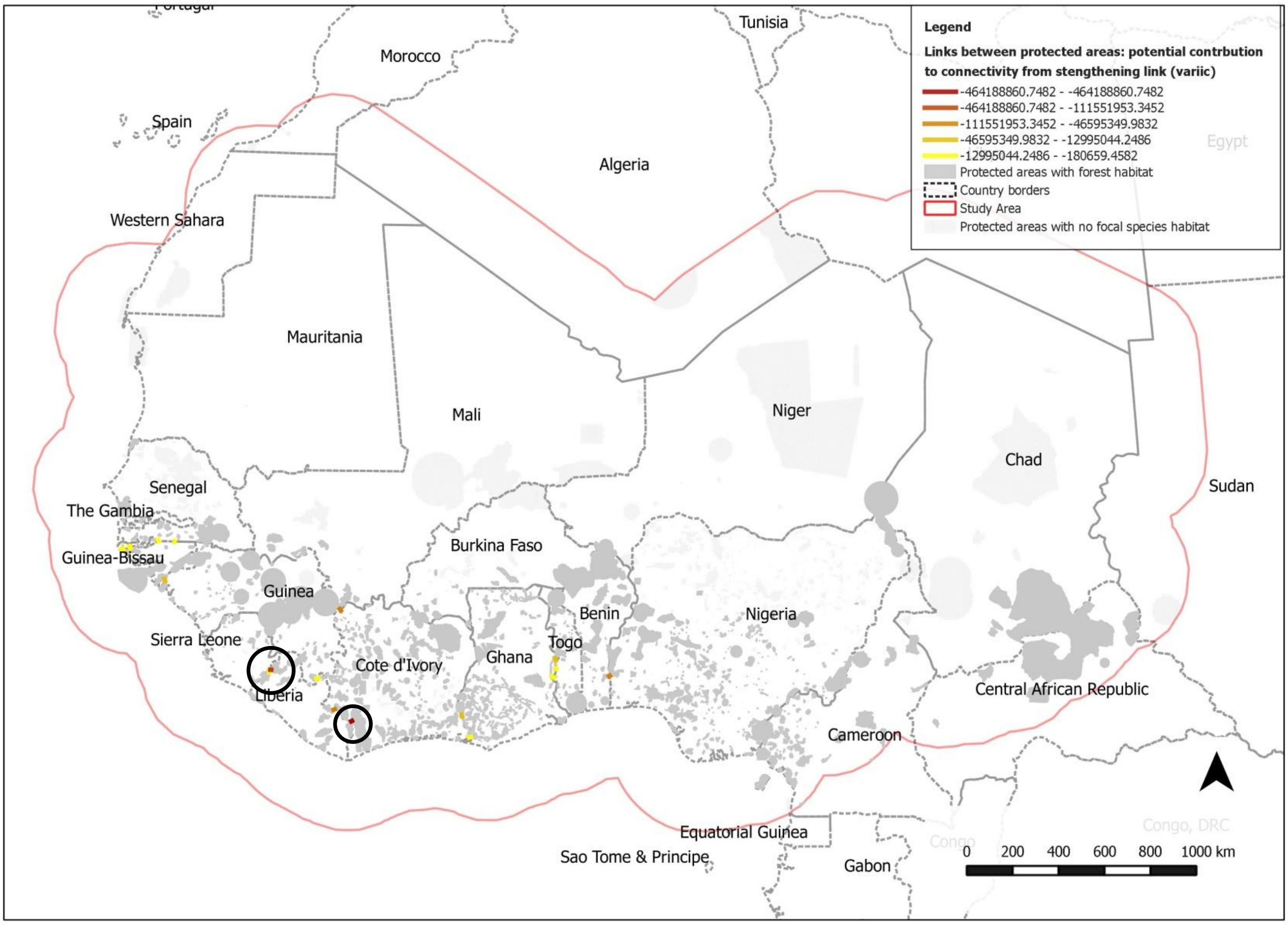

Figure 10. Potential importance of improving links between PAs for generic focal species: **forest specialists with short range (1km) maximum dispersal abilities.**

For short dispersal forest specialists, the transboundary links with highest potential contribution if strengthened are the ones:

- Between Grebo National Park in Liberia and Taï national Park World Heritage Site in Cote d'Ivoire; and
- Between Foya national Park in Liberia and Gola Rainforest National Park in Sierra Leone.

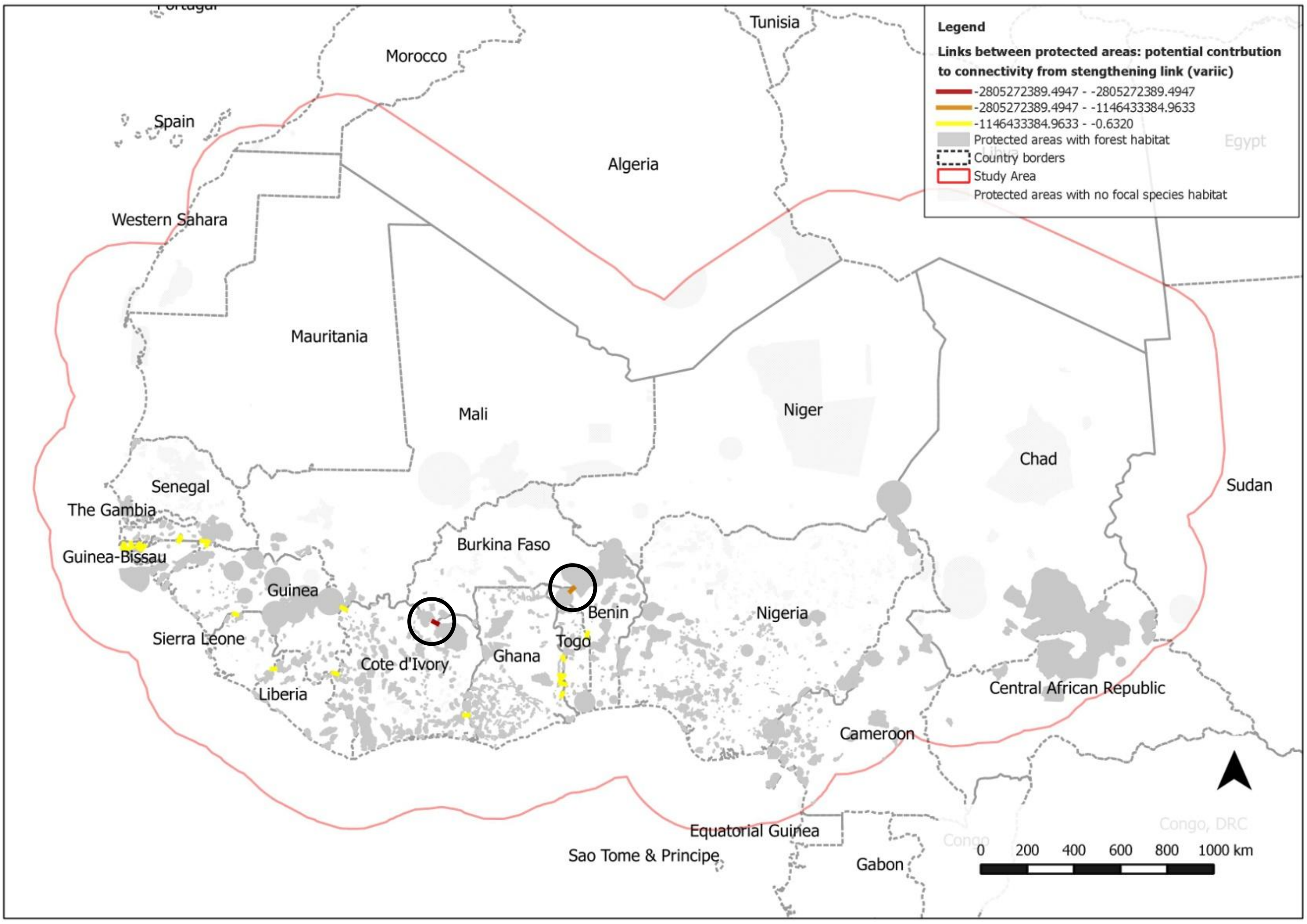

Figure 11. Potential importance of improving links between PAs for generic focal species: **forest specialists with medium range (10km) maximum dispersal abilities.**

Important potential links for this medium range forest species are found:

- Between Comoé National Park World Heritage site in Cote d'Ivoire and Logoniegue Classified Forest in Burkina Faso; and
- Between Kéran national Park in Togo and Pendjari Hunting Zone in Benin (which is part of the WAP complex mentioned above).

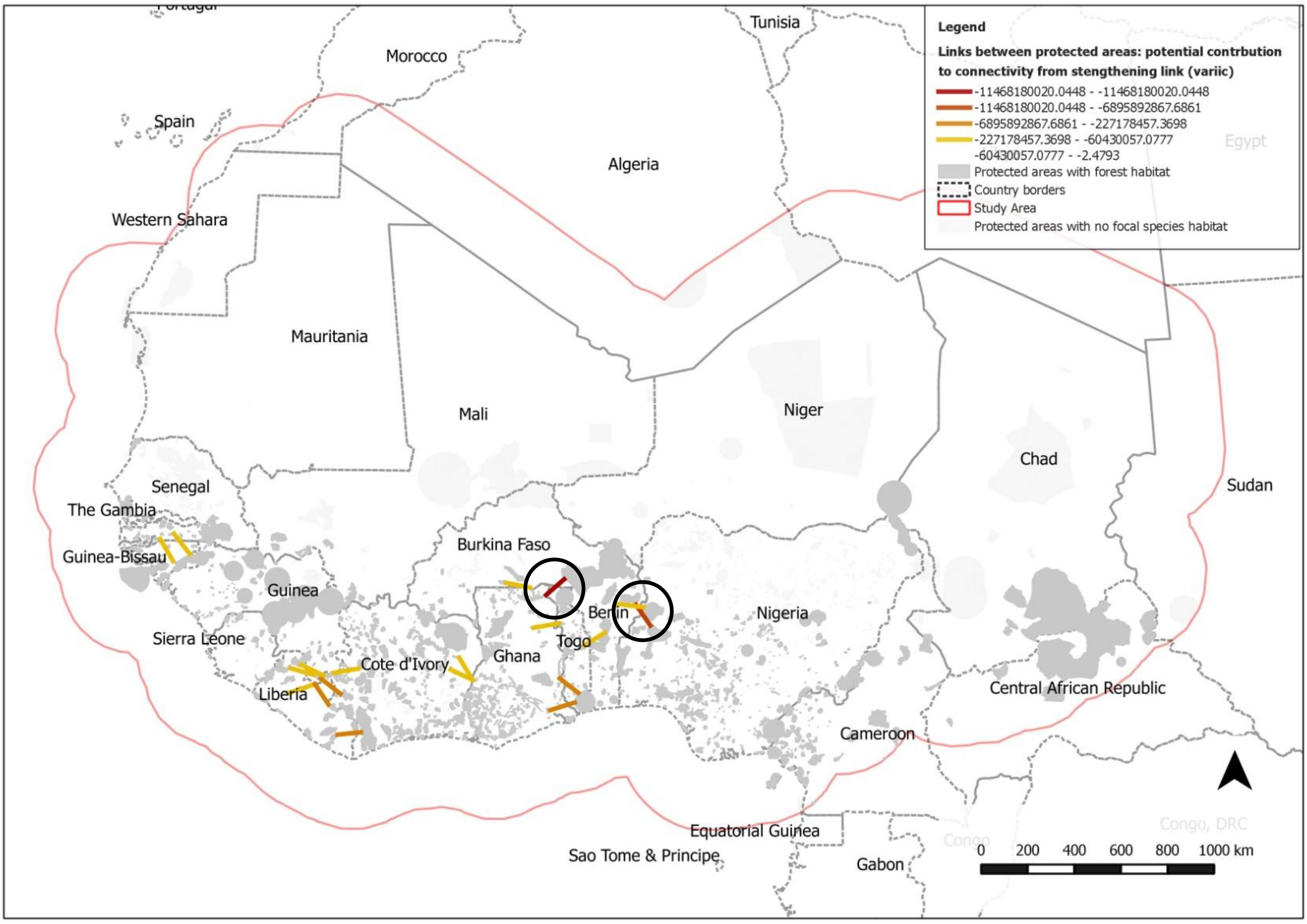

Figure 12. Potential importance of improving links between PAs for generic focal species: **forest specialists with long range (100km) maximum dispersal abilities.**

Among numerous long range transboundary links that should contribute highly if improved, the following ones appear as the most important:

- Between Pama Partial Faunal reserve in Burkina Faso (which is part of the WAP complex mentioned above) and Marago River and Gambaga East Forest Reserves in Ghana, through Togo; and
- Between *Trois Rivières* Forest Reserve in Benin and Vobera Forest Reserve in Nigeria.

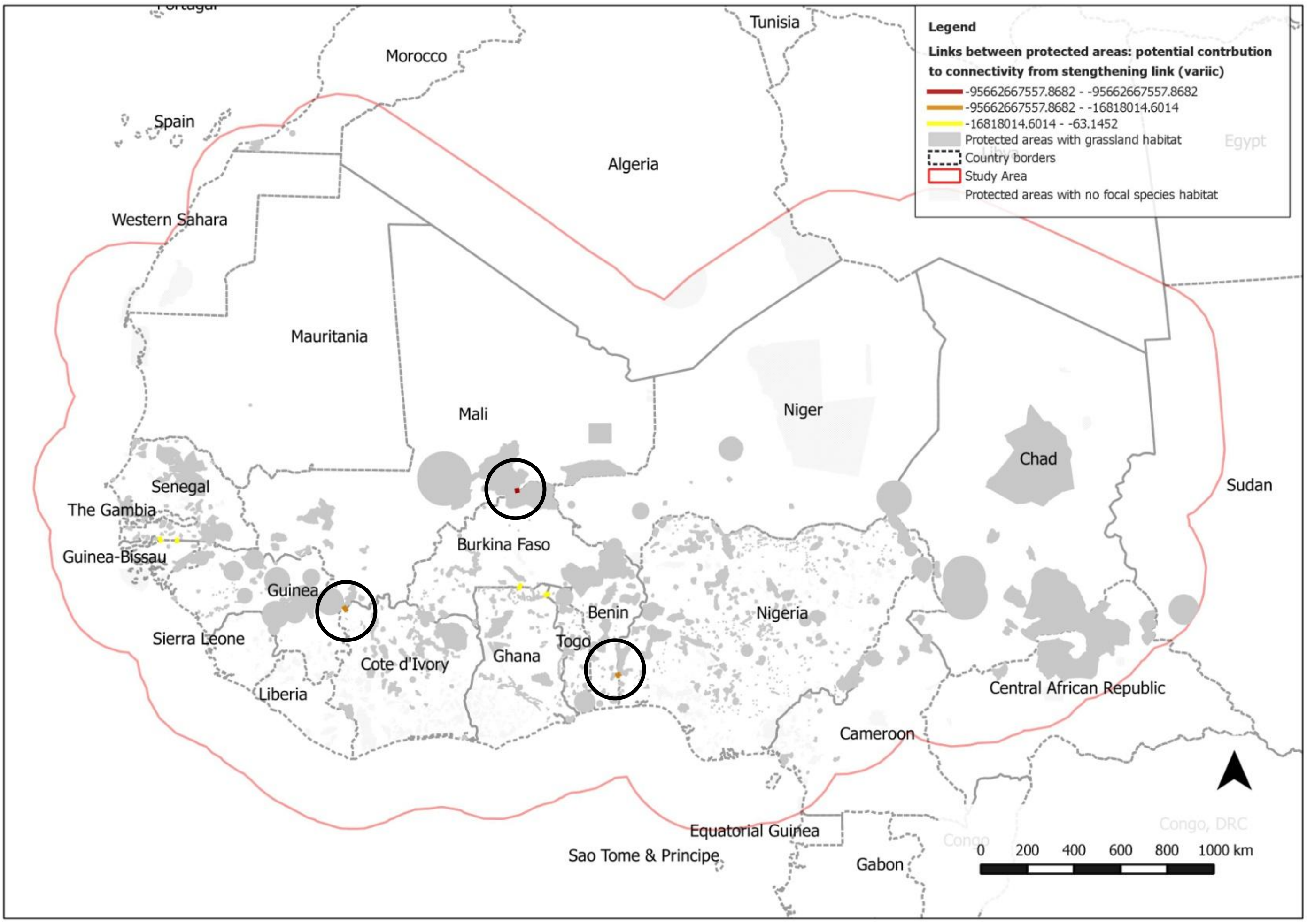

Figure 13. Potential importance of improving links between PAs for generic focal species: **grassland specialists with short range (1km) maximum dispersal abilities.**

The most notable linking opportunities for improving the PA network connectivity for short dispersal grassland species are found:

- Between Sahel Partial Hunting Reserve in Burkina Faso and Gourma Partial Elephant Reserve in Mali (which appears to be the most important link);
- Between Dogo Classified Forest in Benin and Odugebe Forest Reserve in Nigeria; and
- Between Sankarani-Fié Ramsar site in Guinea and Djangoumerila Faunal Reserve in Mali.

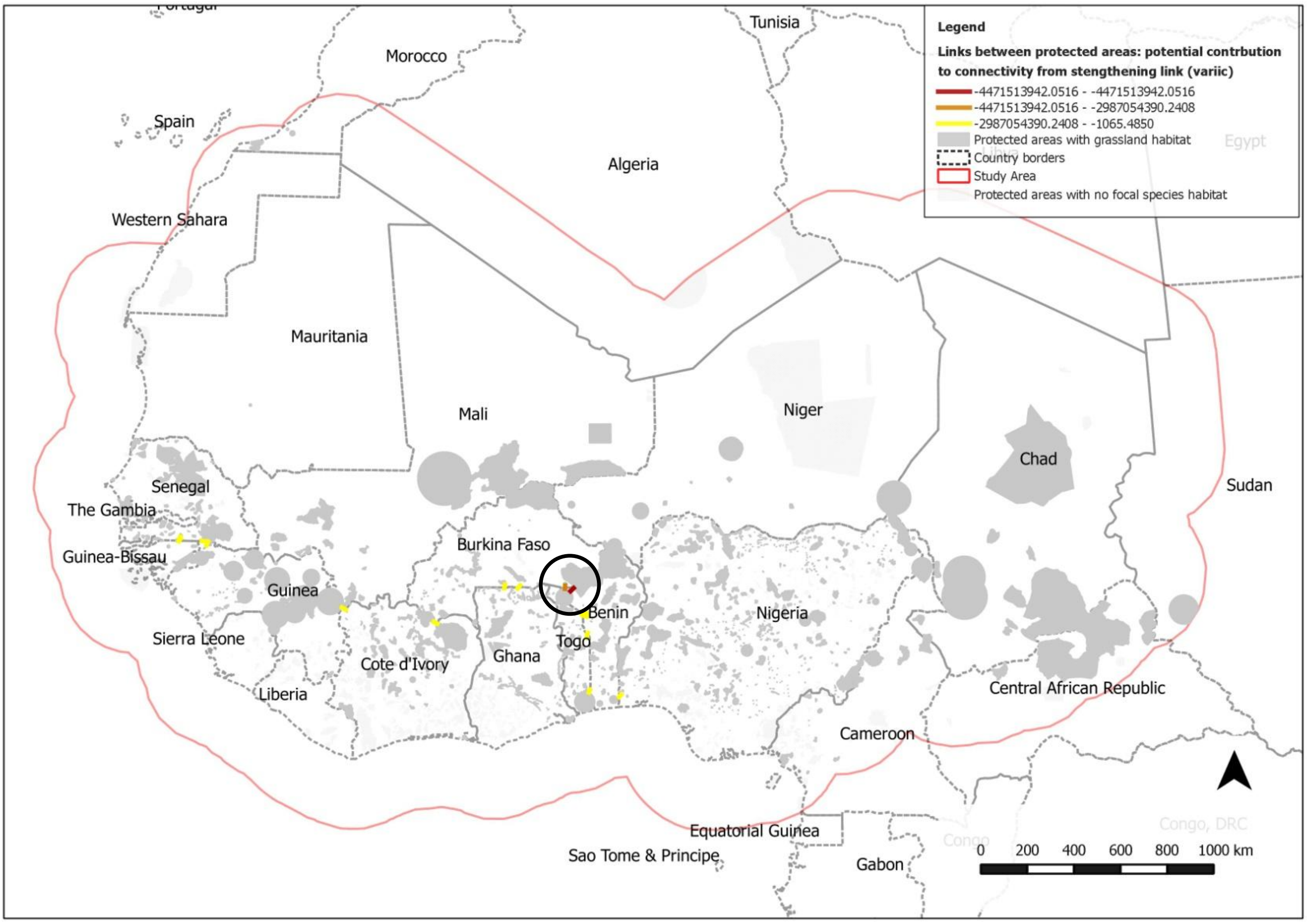

Figure 14. Potential importance of improving links between PAs for generic focal species: **grassland specialists with medium range (10km) maximum dispersal abilities.**

The most important links for medium range grassland species, if improved, appear to be in the vicinity of the WAP transboundary PA complex (mentioned above), between Bassin Versant Oti-Mandouri Ramsar site in Togo, and two other PAs: Pendjari Hunting Zone in Benin, and Barrage de la Kompiega Ramsar Site in Burkina Faso.

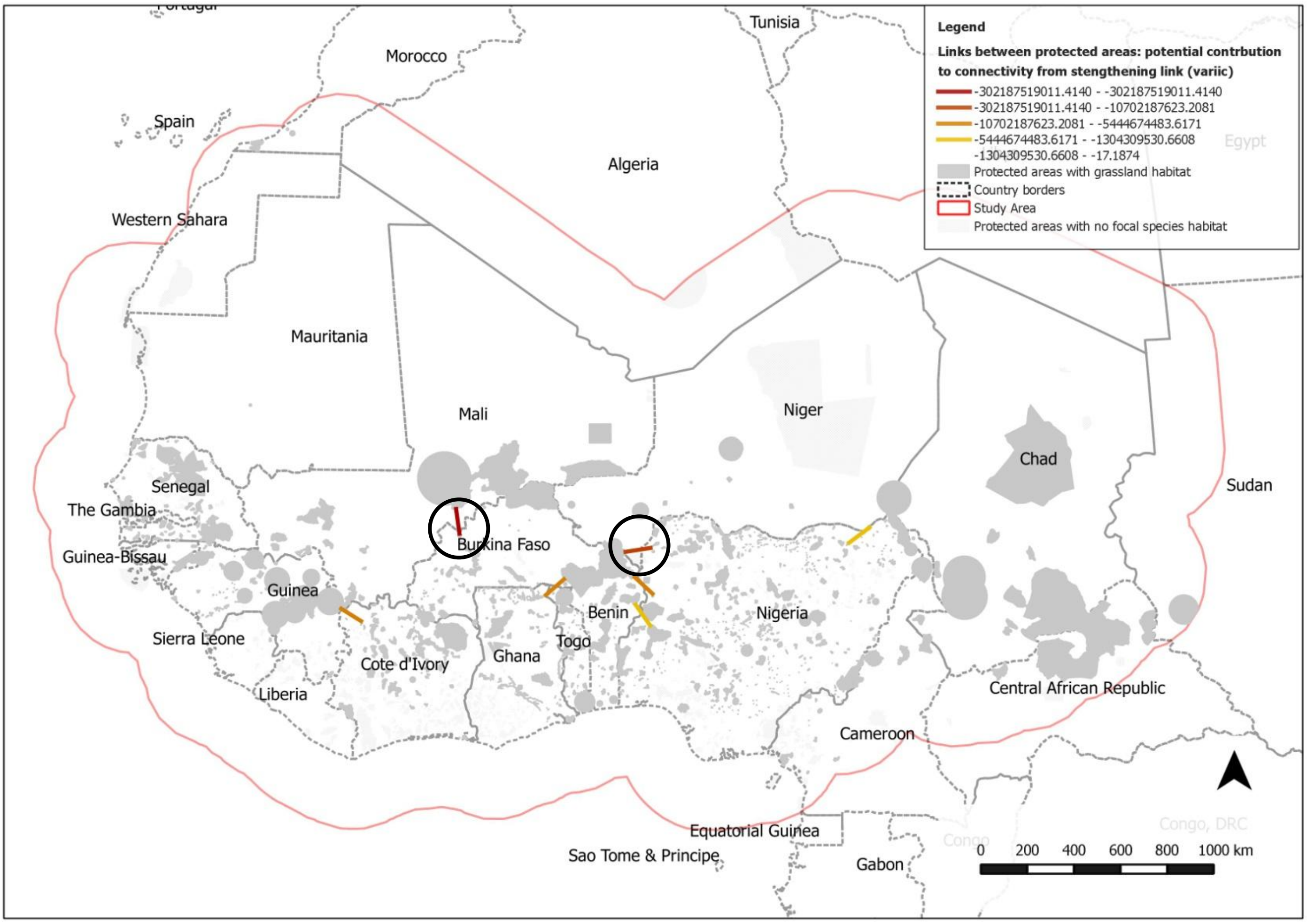

Figure 15. Potential importance of improving links between PAs for generic focal species: **grassland specialists with long range maximum dispersal (100km) abilities.**

Long range dispersal grassland specialists are most likely to benefit from improving the following links:

- Between Cliff of Bandiagara World Heritage site and Source de Mouhoun Classified Forest in Burkina Faso; and
- Between W Park in Benin (which is part of the WAP complex mentioned above) and Bagga Forest Reserve in Nigeria, through Niger.

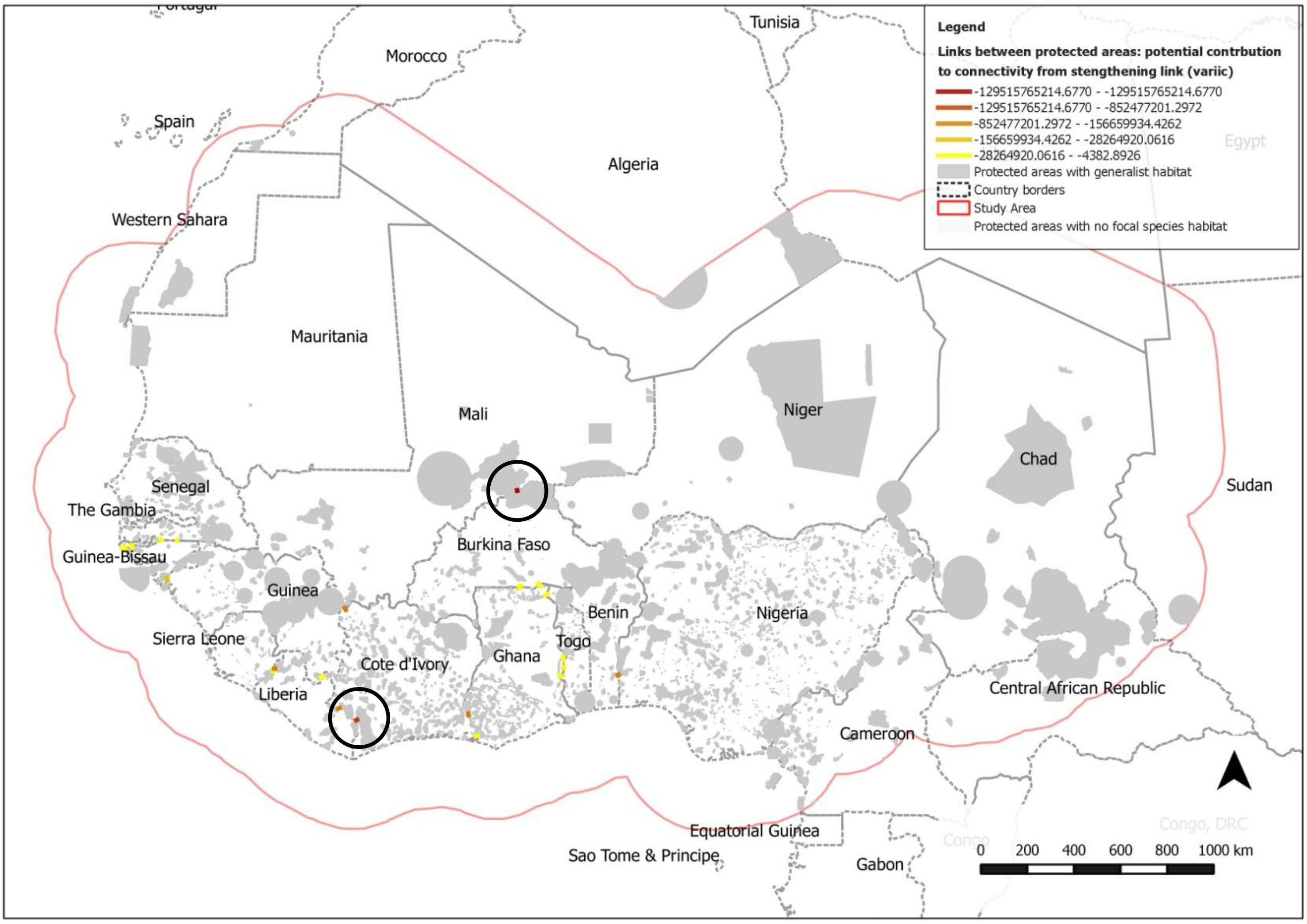

Figure 16. Potential importance of improving links between PAs for generic focal species: **generalists with short range (1km) maximum dispersal abilities.**

The following links represent the highest potential improvement options for generalists with short range dispersal abilities:

- Between in Sahel Partial Hunting Reserve in Burkina Faso and Gourma Partial Elephant Reserve in Mali; and
- Between Grebo National Park in Liberia and Taï national Park World Heritage Site in Cote d'Ivoire.

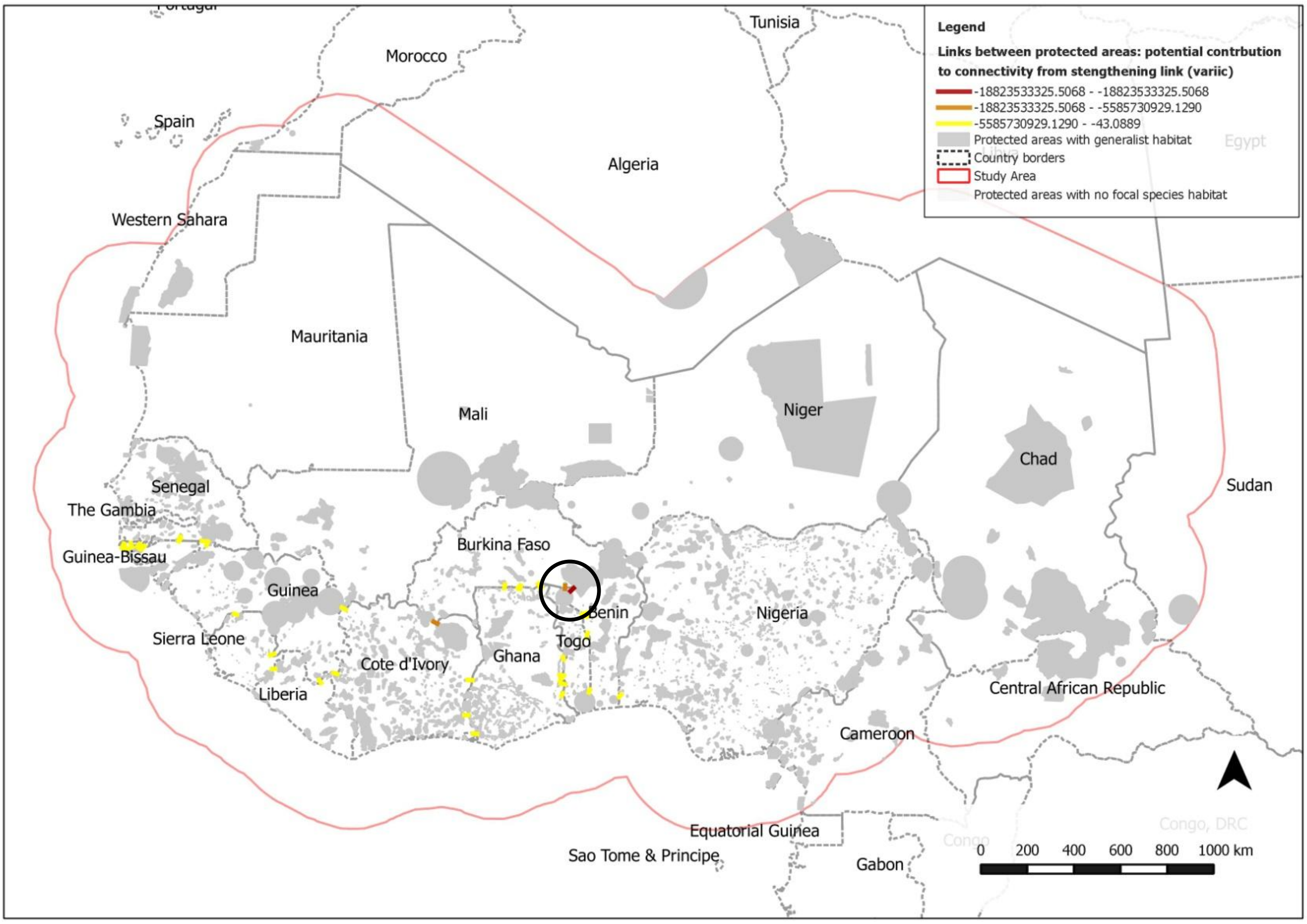

Figure 17. Potential importance of improving links between PAs for generic focal species: **generalists with medium range (10km) maximum dispersal abilities.**

The most important links for medium range generalists, if improved, appear to be in the vicinity of the WAP transboundary PA complex (mentioned above), between Bassin Versant Oti-Mandouri Ramsar site in Togo, and two other PAs: Pendjari Hunting Zone in Benin, and Barrage de la Kompiega Ramsar Site in Burkina Faso.

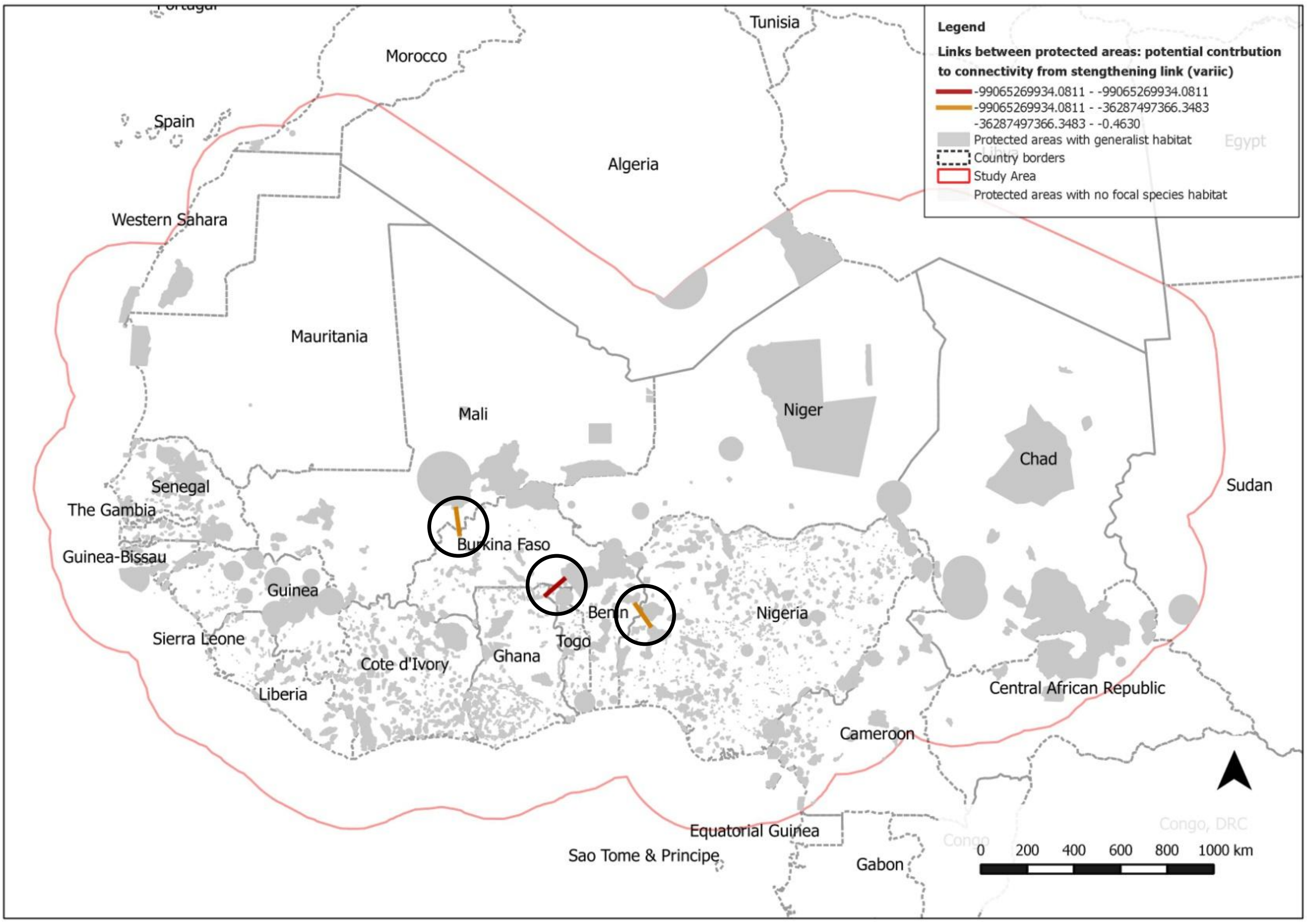

Figure 18. Potential importance of improving links between PAs for generic focal species: **generalists with long range maximum dispersal abilities.**

Long range dispersal generalists are most likely to benefit from improving the following links:

- Between the 'W' Park in Benin (which is part of the WAP complex mentioned above) and Bagga Forest Reserve in Nigeria, through Niger;
- Between Cliff of Bandiagara World Heritage site and Source de Mouhoun Classified Forest in Burkina Faso; and
- Between *Trois Rivières* Forest Reserve in Benin and Vobera Forest Reserve in Nigeria.

4. Discussion

By modeling characteristics from a hypothetical set of generic focal species, we have highlighted a number of protected areas (PA) and links where practical conservation efforts, such as habitat restoration or corridor creation, may be useful to improve connectivity for species with similar characteristics. As this approach intends to target areas for further investigation, not all will be relevant due to aspects not incorporated here, such as geographic barriers and the matrix composition between PAs.

Contribution of connector component to overall habitat availability (IIC)

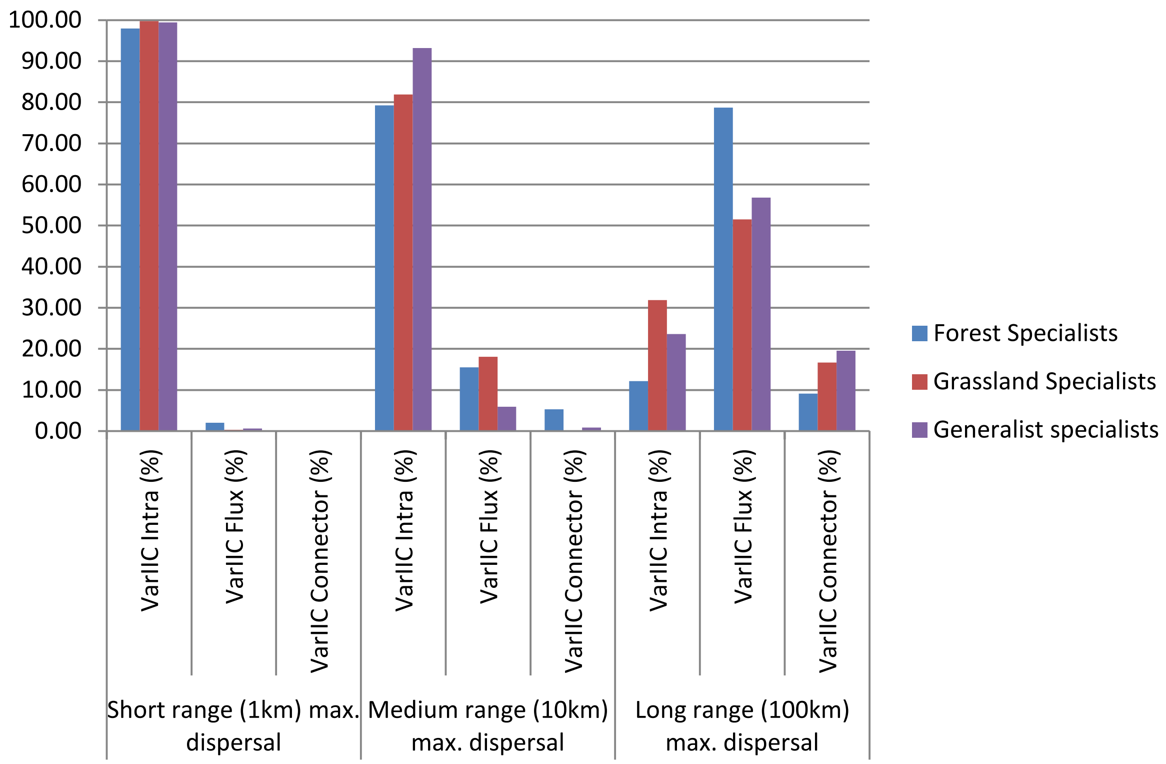

Figure 19. Chart showing the contribution of the three components of the IIC index (intra, flux and connector), for each of the generic focal species in this study. Values for each component for the PAs were summarised and compared to the total habitat availability index (IIC), producing percent contribution to overall habitat availability.

Through exploring the overall contribution of the IIC (intra, flux and connector) components for PAs (Figure 19), it can be seen that the connector component contributes little overall to habitat availability for short dispersal species. Through this component, medium dispersal forest specialists and all long dispersal species were able to contribute to a reasonable degree (i.e., at least 5%). These results suggest that a specific connectivity intervention, such as focusing on stepping stone connectors, if applied throughout the study area, will likely benefit some species more than others, depending on their dispersal abilities and habitat preferences. This is in accordance with Hodgson *et al.* (2009) who suggests that improving connectivity between PAs, such as through the restoration of corridor habitat, is one strategy, but that habitat availability may be ensured more effectively for some species, especially those with short dispersal abilities, by expanding or improving existing PAs.

Short dispersal generic focal species

The network appears to be poorly connected for short dispersal species (max. dispersal 1km) that are least able to disperse between PAs and for which consequently few functional stepping stone connector PAs exist (see Figures 1, 4 and 7 and Annex 1). Such species, however, generally have lower home range and habitat requirements and may therefore require smaller PAs than larger species. The modeling approach of defining PAs as patches and weighting habitat suitability by the area of focal habitat contained is least realistic for such species due to their limited dispersal ability. The connectivity of forest or grassland habitat within such PAs should be addressed before focusing on links between PAs, and should be the most effective use of resources for ensuring their persistence (Hodgson *et al.*, 2009; Saura and Rubio, 2010).

Focusing such efforts on PAs that have high connector values, such as **Gola Rainforest National Park in Sierra Leone** or **Niokolo-Koba National Park in Senegal** (Figures 1, 4 and 7), could therefore provide additional conservation benefits. Some of the most important links between PAs, if improved, for short ranges species are those **between Foya national Park in Liberia and Gola Rainforest National Park in Sierra Leone**, and **between Grebo National Park in Liberia and Taï National Park World Heritage Site in Cote d'Ivoire** (Figures 10, 13 and 16).

Medium dispersal generic focal species

From the medium dispersal species those with forest preferences have the highest connector contribution (~5%) to the total habitat availability index (see Figure 19). For such species focusing on preserving high scoring stepping stone PAs (such as in Figure 2) and their associated links, would be most useful.

The connector PAs that seem to be the most important for medium range species (forest or grassland specialists or generalists) appear to be **Grebo National Park in Liberia** and the **PAs found along the Ghana-Cote d'Ivoire border** (Figures 2 and 8), as well as **Niokolo-Koba National Park in Senegal** and Badiar National Park in Guinea (Figure 5). The most important link to be created, or restored, between PAs in order to enhance their connectivity for medium range species appears to be the one linking the **Pendjari Hunting Zone in Benin** (which is part of the WAP complex) to the ***Bassin Versant*** **Oti-Mandouri** and **Kéran National Park in Togo** (Figures 11, 14 and 17).

Long dispersal generic focal species

The assumption that the matrix outside PAs contains homogenous and barrier-free habitat is least appropriate for those species that move larger distances between patches, as is demonstrated by Minor and Lookingbill (2010). For this reason, and because larger patches are normally required for species with such characteristics (Sutherland, 2000), it may be more useful to increase the size of individual PAs or to designate additional ones.

The following connector PAs were identified as those most important for long range dispersal species: the **large PA complex in Guinea** (however these PAs are only represented by buffered points), **Comoé National Park** in Cote d'Ivoire, **Sahel Partial Faunal Reserve in Burkina Faso** (adjacent to Mali's Gourma Partial Elephant Reserve), and PAs which are part of, or adjacent to, the **WAP complex in Benin, Niger and Burkina Faso** (Figures 3, 6 and 9).

Attempting to improve connectivity over large distances (such as the links in figures 15, 18 and 21) without a further detailed study is unlikely to be very cost effective. However, it is worth noticing that links to the **WAP complex in Benin, Niger and Burkina Faso** appear to be one of the most important again for both forest and grassland specialists and generalist species (Figures 12, 15 and 18).

Methodological considerations

Some of the PAs that are based on buffered points, such as the large PA complex in Guinea, appear as highly important connectors to multiple generic focal species, however, such conclusions are preliminary until accurate boundaries are available. The figure in Annex 5 shows the difference in varIIC connector values for PAs between a scenario in which buffered point PAs are included and a scenario in which they are omitted. As might be expected, the difference in contribution as a connector is largest for PAs nearest to areas where buffered point PAs were removed. To fully understand the impact of this data limitation, further comparisons between network scenarios could be carried out, such as replacing known polygons PAs with buffered points of exactly the same area.

The IIC index in this study uses a binary approach to modeling links between PAs, which we chose due to increased processing speed. The use of dispersal kernels, however, such as used in the PC index (Saura and Torné, 2009), would provide probabilistic connections that decrease with increasing distance between patches. Furthermore, there are various extensions to graph theory, focusing on modeling the movement in the matrix between patches, such as (i) calculating least cost paths (LCPs) or (ii) isolation by resistance (IBR). The latter is based upon Circuit theory and currently gains interest as an alternative, or complementary, approach to LCPs, and correlates well to gene flow (McRae and Beier *et al.,* 2007). These require the use of resistance to movement layers, for which calibration can be difficult and subjective, but could be useful for specific species models or determining fine-scale connections between PAs.

Climate gradients could also be taken into account, but were beyond the scope of this analysis (Noss *et al.,* 2001; Beier and Brost, 2010). However, using an efficient and repeatable index, this study does provide a detailed cross-border prioritisation of PAs and links, as well as context to any further fine-scale assessments within the PARCC West Africa countries.

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