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Advancing conservation planning for western chimpanzees using IUCN SSC A.P.E.S. – the case of a taxon-specific database

Stefanie Heinicke[1,2], Roger Mundry[1], Christophe Boesch[1,3], Bala Amarasekaran[4], Abdulai Barrie[5], Terry Brncic[4], David Brugière[6], Geneviève Campbell[7], Joana Carvalho[8], Emmanuel Danquah[9], Dervla Dowd[3], Henk Eshuis[1], Marie-Claire Fleury-Brugière[10], Joel Gamys[11], Jessica Ganas[12], Sylvain Gatti[13], Laura Ginn[14], Annemarie Goedmakers[15], Nicolas Granier[16], Ilka Herbinger[17], Annika Hillers[3,18], Sorrel Jones[18,19], Jessica Junker[1,2], Célestin Y. Kouakou[3,20,21], Vincent Lapeyre[3], Vera Leinert[1], Fiona Maisels[22,23], Sergio Marrocoli[1,2], Mary Molokwu-Odozi[24], Paul K. N'Goran[25], Liliana Pacheco[26], Sébastien Regnaut[3,27], Tenekwetche Sop[1,2], Els Ton[15], Joost van Schijndel[1,15], Virginie Vergnes[3], Maria Voigt[1,2], Adam Welsh[1], Erin G. Wessling[1,2], Elizabeth A. Williamson[23] *, Hjalmar S. Kühl[1,2] *

[1]Max Planck Institute for Evolutionary Anthropology, Leipzig, Germany
[2]German Centre for Integrative Biodiversity Research (iDiv) Halle-Leipzig-Jena, Leipzig, Germany
[3]Wild Chimpanzee Foundation (West Africa Representation), Abidjan, Côte d'Ivoire
[4]Tacugama Chimpanzee Sanctuary, Freetown, Sierra Leone
[5]Bumbuna Watershed Management Authority, Freetown, Sierra Leone
[6]Projets Biodiversité et Ressources Naturelles BRL Ingénierie, Nimes Cedex, France
[7]The Biodiversity Consultancy Ltd., Cambridge, UK
[8]Faculty of Computing Science and Mathematics, University of Stirling, Stirling, UK
[9]Department of Wildlife and Range Management, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana
[10]Independent consultant, Nîmes, France
[11]Conservation International, Monrovia, Liberia
[12]Independent Biodiversity Consultant, Slinger, WI, USA
[13]West African Primate Conservation Action, Accra, Ghana
[14]Anthropology Center for Conservation, Environment and Development, Oxford Brookes University, Oxford, UK
[15]Chimbo Foundation, Amsterdam, Netherlands
[16]Behavioural Biology Unit, University of Liège, Liège, Belgium
[17]WWF Germany, Berlin, Germany
[18]RSPB Centre for Conservation Science, The Royal Society for the Protection of Birds, Sandy, UK
[19] School of Biological Sciences, Royal Holloway University of London, Egham, UK
[20]Université Jean Lorougnon Guédé, Daloa, Côte d'Ivoire
[21]Centre Suisse de Recherches Scientifiques en Côte d'Ivoire, Abidjan, Côte d'Ivoire
[22]Global Conservation Program, Wildlife Conservation Society, Bronx, NY, USA
[23]Faculty of Natural Sciences, University of Stirling, Stirling, Scotland, UK
[24]Fauna & Flora International, Monrovia, Liberia
[25]World Wide Fund for Nature, Regional Office for Africa - Yaoundé Hub, Yaoundé, Cameroon
[26]Jane Goodall Institute Spain, Dindefelo Community Nature Reserve, Kédougou, Senegal
[27]International Union for Conservation of Nature, West and Central Africa Programs, Ouagadougou, Burkina Faso

* shared last author

E-mail: stefanie_heinicke@eva.mpg.de

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Abstract

Even though information on global biodiversity trends becomes increasingly available, large taxonomic and spatial data gaps persist at the scale relevant to planning conservation interventions. This is because data collectors are hesitant to share data with global repositories due to workload, lack of incentives, and perceived risk of losing intellectual property rights. In contrast, due to greater conceptual and methodological proximity, taxon-specific database initiatives can provide more direct benefits to data collectors through research collaborations and shared authorship. The IUCN SSC Ape Populations, Environments and Surveys (A.P.E.S.) database was created in 2005 as a repository for data on great apes and other primate taxa. It aims to acquire field survey data and make different types of data accessible, and provide up-to-date species status information. To support the current update of the conservation action plan for western chimpanzees (*Pan troglodytes verus*) we compiled field surveys for this taxon from IUCN SSC A.P.E.S., 75% of which were unpublished. We used spatial modeling to infer total population size, range-wide density distribution, population connectivity and landscape-scale metrics. We estimated a total abundance of 52,800 (95% CI 17,577 – 96,564) western chimpanzees, of which only 17% occurred in national parks. We also found that 10% of chimpanzees live within 25 km of four multi-national "development corridors" currently planned for West Africa. These large infrastructure projects aim to promote economic integration and agriculture expansion, but are likely to cause further habitat loss and reduce population connectivity. We close by demonstrating the wealth of conservation-relevant information derivable from a taxon-specific database like IUCN SSC A.P.E.S. and propose that a network of many more such databases could be created to provide the essential information to conservation that can neither be supplied by one-off projects nor by global repositories, and thus are highly complementary to existing initiatives.

1. Introduction

In conservation planning there is an increasing need for detailed information on the density distribution of species, population trends, and habitat suitability to support evidence-based decision-making (Schwartz *et al* 2018). To derive these parameters different types of data are needed across large areas, an extent that usually exceeds the scope of individual research projects. Consequently, the curation of existing data has been the focus of various databases, many of them compiling data at a global scale, such as the Global Biodiversity Information Facility (GBIF 2018), Map of Life (Jetz *et al* 2012), and Living Planet Index (Collen *et al* 2009). However, large data gaps remain regarding spatial and taxonomic coverage and type of data, especially for Africa and the Middle East, and occurrence data are more readily available than abundance or trend data (Boakes *et al* 2010, Peterson and Soberón 2018, Kindsvater *et al* 2018).

For many taxa the challenge is not necessarily that data are not available. In contrast, researchers and conservation organizations go to great lengths to collect species survey data, which requires extensive human and financial resources. However, only a fraction of these data are shared, despite their value for broad-scale and comparative analyses (Costello *et al* 2013). Impediments to data sharing include first and foremost a lack of perceived benefit, workload, and concern of losing intellectual property (Thessen and Patterson 2011). In addition, the amount of survey data published in the grey literature greatly exceeds that published in peer-reviewed journals (Corlett 2011). To inform conservation planning, these data need to be centralized, standardized, and quality checked, whilst assuring data collectors of their intellectual property rights (Reichman *et al* 2011, Thessen and Patterson 2011, Costello *et al* 2013).

Apes are particularly well studied (Wich and Marshall 2016), and western chimpanzees (*Pan troglodytes verus*) are no exception, as illustrated by the IUCN Status Survey and Conservation Action Plan (Kormos *et al* 2003). However, the action plan stated that information available at the time was insufficient because data were only available for specific sites, and large data gaps remained. Consequently, the identification of priority areas for conservation activities was based on expert opinion (Kormos and Boesch 2003). Besides the call for filling data gaps (Kormos and Boesch 2003), conservationists and researchers saw the need of compiling available ape survey datasets and make them accessible through a platform to better inform conservation planning.

The IUCN SSC Ape Populations, Environments and Surveys database (A.P.E.S.; Kühl *et al* 2007) was initiated in 2005, and its creation was facilitated by a collaboration between the Section on Great Apes of the IUCN Primate Specialist Group, ape range country authorities, academic institutions, and conservation organizations. IUCN SSC A.P.E.S. contains geo-referenced survey data of all 14 taxa of extant great apes covering 21 of the 23 ape range countries (data not available for South Sudan, and Cabinda Province in Angola, figure 1). The database holds almost 500 standardized and quality-checked datasets consisting of more than three million records, including information on abundance, density, population trends, presence-absence, and spatial distribution (as of November 2018).

For western chimpanzees, data deposited in IUCN SSC A.P.E.S. have been used to predict the distribution of habitat suitability and its trends (Junker *et al* 2012, Jantz *et al* 2016), and to determine their population trend as well as geographic range (Kühl *et al* 2017). These assessments estimated a population decline of 80% and a range reduction of

20% within 24 years (Kühl *et al* 2017). As a result, western chimpanzees were uplisted to Critically Endangered by the IUCN Red List of Threatened Species (Humle *et al* 2016). Currently, the conservation action plan for this taxon is being updated. As various researchers and conservation organizations conducted surveys on this ape in the past 15 years and shared their data with IUCN SSC A.P.E.S., we were now able to use a dataset representative of the entire range of western chimpanzees, 75% of which had not been published. For the first time, we could thus model the range-wide density distribution for this ape. We then derived information on western chimpanzees important for the update of the conservation action plan, including areas with high chimpanzee densities, or those where population connectivity has been reduced, estimated total abundance, and proportion of chimpanzees occurring in proximity to settlements and infrastructure.

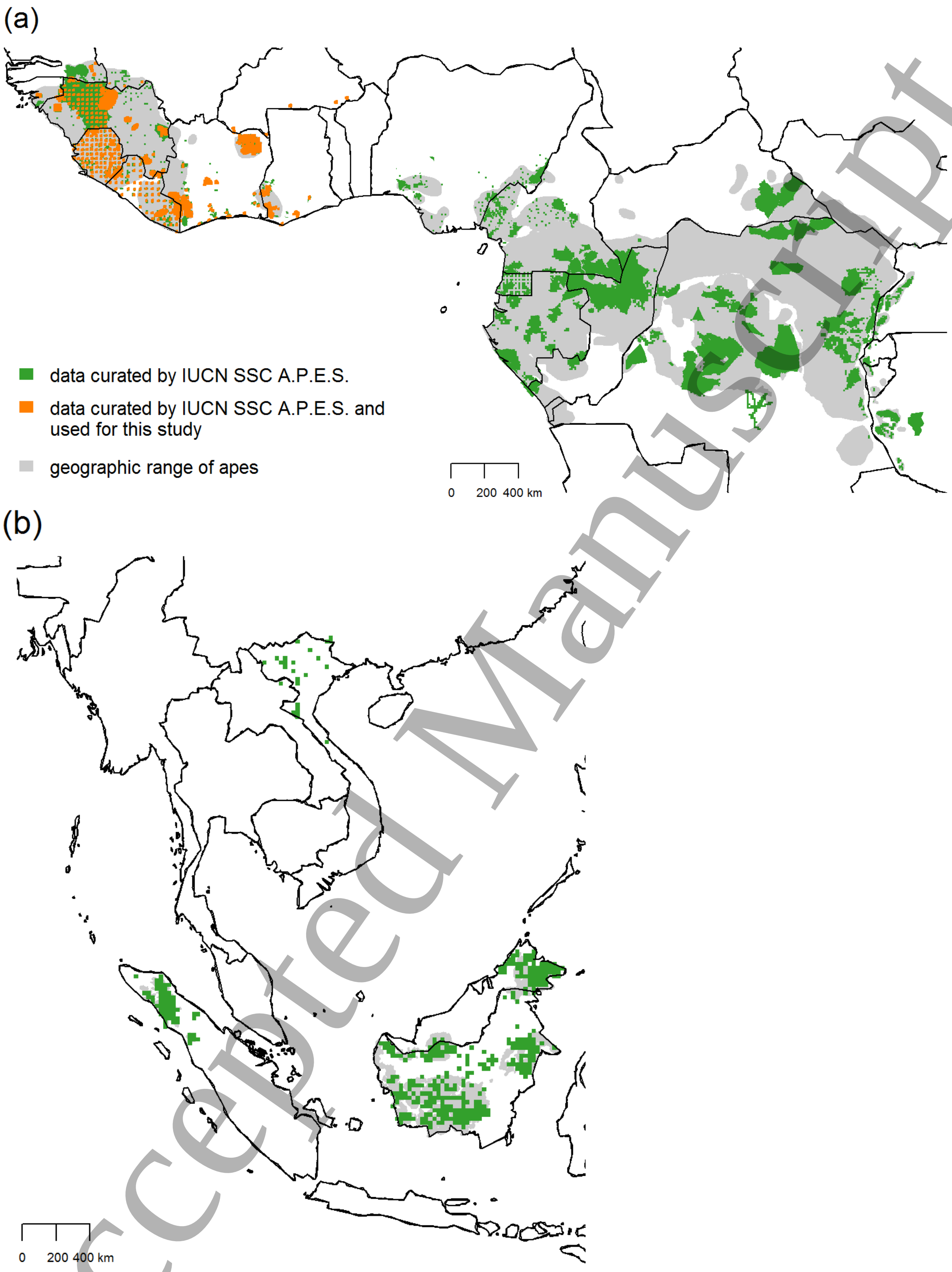

Figure 1. Data contained in IUCN SSC Ape Populations, Environments and Surveys (A.P.E.S.) database with spatial distribution of datasets for (a) African apes, and (b) Asian apes.

2. Methods

2.1. IUCN SSC A.P.E.S. database

The IUCN SSC A.P.E.S. database currently holds 498 survey datasets contributed by more than 200 conservation scientists, wildlife authorities, and non-governmental organizations. A dataset is defined as a set of data that was collected for a specific area and time period. Datasets had been collected as part of single or repeated surveys, and range from small scale (20 km^2) to large areas, or even entire countries. The database stores different types of data that are standardized and quality-checked, including point and reconnaissance survey data that can be used to determine presence and absence, line transect data which are the basis for density estimates, and camera trap data. IUCN SSC A.P.E.S. also holds 280 abundance polygons, meaning abundance estimates for various resource management areas such as protected areas or resource concessions. The available data also include 24 spatial layers, for example, species density distribution and range layers, abundance layers, and suitable ecological conditions layers. Additionally, IUCN SSC A.P.E.S. contains nest decay datasets, which are needed to convert counts from ape nest surveys into individual ape density and abundance estimates. Most datasets not only include sightings of the ape taxa targeted in the survey, but also include phenology of ape food plants, records of other taxa, human signs, and records of covariates such as vegetation type and slope. Furthermore, the database stores 950 publications and reports, of which 280 are unpublished field survey reports. For this study we used 58 chimpanzee nest count surveys and nest decay datasets, only 13 of which had been published to date (figure 1, table S1).

2.2. Modeling chimpanzee density distribution

We followed a commonly used procedure to predict ape density distributions (Murai *et al* 2013, Wich *et al* 2016, Strindberg *et al* 2018, Voigt *et al* 2018). Specifically, we first fitted a full model to establish the relationship between chimpanzee densities and several social-ecological predictor variables, and then predicted chimpanzee density distribution based on multi-model inference (Burnham and Anderson 2002).

The response variable in the full model was the number of nests per transect with a sample size of 17,109 transects and a total survey effort of 10,929 km, covering all western chimpanzee range states (figure 1a). For the model output to directly express number of individuals per km^2 and to account for varying transect lengths, we included an offset term comprising transect length, effective strip width, proportion of nest builders, nest production rate, and nest decay time (details Supplementary Material). We then extracted 20 predictor variables for each transect using publicly available satellite and aggregated household-survey data which approximate known drivers of chimpanzee density including both environmental variables and anthropogenic pressure (details in table S2 and table S3). We originally started with a model comprising the same predictors used in an earlier study to identify drivers of chimpanzee densities (Heinicke *et al* 2019), but the initial evaluation of the derived density distribution revealed an underestimation of chimpanzee densities for protected areas. We therefore added 'protected area' as a binary predictor, meaning whether the midpoint of a transect was within the boundaries of a protected area designated as 'national park' or IUCN category I or II based on data from the World Database of Protected Areas (UNEP-WCMC and IUCN 2017). For the full model (table S4), we fitted a Generalized Linear Mixed Model (Baayen 2008) with a negative binomial error distribution (Hilbe 2011). Details on model implementation, namely spatial autocorrelation, random effects, check for multicollinearity and overdispersion can be found in the Supplementary Material.

We then extracted all predictors across the entire range of western chimpanzees by deriving a grid with a resolution of half a minute (ca. 0.9 km) and identifying the coordinates of each cell center. The total area was approximately 523,000 km^2. For each cell we extracted, processed and transformed the predictors using the same procedure and parameters as for the transect data (table S3).

To avoid nuisance parameters, namely parameters with an overestimated contribution, and model selection uncertainty, we based the range-wide density prediction on qAICc-weighted multi-model inference (Burnham and Anderson 2002). Specifically, we first derived all possible models on the basis of the test predictors (5824 models). Six of those models did not converge, and we used the remaining 5818 models to derive a density prediction for each grid cell (n=620,043 cells) for the year 2015. These predictions were made in link space and weighted by the corresponding models' qAICc, summed for each cell, and were finally exponentiated to produce chimpanzee densities (Cade 2015). We calculated 95% confidence intervals based on non-parametric bootstrapping (n=1,000) with the sampling units being the datasets (Manly 1997).

2.3. Identifying populations and low-connectivity areas

To estimate where connectivity between chimpanzee populations might be reduced, we first identified grid cells with a high likelihood of chimpanzee presence based on modeled chimpanzee density and expert opinion (details in Supplementary Material). We then determined patches of connected presence cells. Cells were iteratively assigned to the same patch when they were within a threshold distance or connected via cells separated by no more than the threshold distance. There is little information for dispersal distances between chimpanzee communities, for example when females transfer from their natal group. Published maximum daily travel distances range from 9 km in rainforest habitat (Herbinger *et al* 2001) to 16 km in drier habitat (Humle *et al* 2011), and may be larger in very dry areas where chimpanzees have larger home ranges (Pruetz 2018). However, this is likely only the case within suitable habitat and in the absence of barriers such as areas densely populated by humans. As this is a broad-scale analysis, we did not account for conditions between presence cells. Therefore, we present three scenarios for possible dispersal distances, namely 5 km, 15 km, and 25 km, to identify areas where connectivity might be low or be reduced in the near future in case of land-use change or increase of other threats.

2.4. Spatial distribution of chimpanzees in relation to infrastructure

Large-scale land-use change across West Africa is mainly driven by the expansion of agricultural areas, resource extraction, and development of associated infrastructure (Norris *et al* 2010, Laurance *et al* 2015, Edwards *et al* 2014). While most of the land surface has essentially been divided into mining and timber concessions, as well as areas for renewable energy production, such as hydropower plants, spatial data are not available for the entirety of the western chimpanzee range. We therefore focused on only one of these planned development projects, namely proposed "development corridors" (Laurance *et al* 2015), to illustrate how such developments could affect western chimpanzees if they were implemented. Development corridors center on the expansion of roads, railroads, pipelines, and ports, to improve the movement of people and goods between remote areas and urban centers. The aim is to enable rural communities' access to markets and social services, and ultimately improve agricultural productivity, market integration, and regional trade (Weng *et al* 2013, Laurance *et al* 2015, Mulenga 2013). However, these infrastructure projects could lead to environmental damage by opening up formerly inaccessible areas and intersecting protected areas (Laurance *et al* 2015, Sloan *et al* 2017). Four corridors have been proposed for West Africa: Conakry-Buchanan (Guinea, Liberia, Sierra Leone), Dakar-Port Harcourt (Mali, Senegal), Gulf of Guinea (Côte d'Ivoire, Ghana, Liberia), and Sekondi/Ouagadougou (Burkina Faso, Ghana) (Laurance *et al* 2015). The recent $22.7 Mio agreement between the Economic Community of West African States and the African Development Bank to upgrade roads on the 'Gulf of Guinea' corridor (African Development Bank 2019) and feasibility studies for the upgrade of the Dakar-Bamako railroad on the 'Dakar-Port Harcourt' corridor (PIDA 2018) suggest that these developments might threaten apes and their habitat (Laurance 2018). To estimate how many chimpanzees occur in proximity to these corridors, we overlaid the 50-km wide corridor bands from Laurance *et al* (2015) and Sloan *et al* (2017) with the modeled chimpanzee density distribution.

To provide further contextual information for conservation planning we determined the proportion of chimpanzees in three habitat types based on the Global land cover dataset (Friedl *et al* 2010): forest (‘broadleaf forest’, ‘mixed forest’), savanna-mosaic (‘savanna’, ‘woody savanna’, ‘open shrubland’, ‘closed shrubland’), and cropland (‘cropland’, ‘cropland/natural vegetation mosaic’). We also determined the distance of each grid cell to the closest road (FAO 2005) and settlement (Esch *et al* 2012) to estimate how many chimpanzees live within 5 km and 10 km of roads and settlements. All analyses were implemented in R (vers. 3.4.x, R Core Team 2018).

3. Results

3.1. Modeled chimpanzee density distribution

We estimated a total western chimpanzee abundance of 52,811 (95% confidence interval: 17,577 – 96,564), with the highest numbers in Guinea, Liberia and Sierra Leone (table 1). Densities ranged between <0.01 and 6.3 individuals/km^2. The highest densities were predicted for the Fouta Djallon highland region (figure 2). We estimated that 7.66% of western chimpanzees range in high-level protected areas (i.e., national parks and IUCN Cat I + II) as of 2015. Since then several new national parks have specifically been created for the protection of western chimpanzees, e.g., Boé and Dulombi (Guinea-Bissau), and Gola and Grebo-Krahn (Liberia), while Moyen Bafing (Guinea) is currently being created. Consequently, 8.56% of the current range is now a high-level protected area which corresponds to 16.98% of the estimated western chimpanzee population.

3.2. Population connectivity analysis

We estimated that there is one large chimpanzee population across the Fouta Djallon highland region and adjacent areas, extending from Senegal and Guinea-Bissau, across Guinea and Mali and into Sierra Leone (figure 3). This population comprises at least half of the remaining chimpanzees in West Africa (>33,000 individuals, details table S5). The southern population that extends from eastern Guinea across Liberia to Taï National Park in western Côte d’Ivoire comprises the remaining half of western chimpanzees (table S5). Our analysis revealed that connectivity between these two populations might be low in certain areas, specifically across the Upper Niger Basin in Guinea, and where the three countries Guinea, Liberia and Sierra Leone meet (green and blue patch in figure 3a), and in the Zone Forestière in southern Guinea (green and red patch in figure 3b, population estimates for all scenarios in table S5 and results for additional minimum density thresholds in figure S2).

3.3. Spatial distribution of chimpanzees in relation to infrastructure

We estimated that 10.44% of chimpanzees lived within 25 km of the four aforementioned development corridors. The planned Dakar-Port Harcourt corridor in Senegal and Mali would intersect the northernmost distribution of western chimpanzees, while the Conakry-Buchanan corridor would intersect Outamba-Kilimi National Park and the above identified low-connectivity area at the tri-national border of Guinea, Liberia, and Sierra Leone (figure 4). Azagny and Banco National Park in Côte d'Ivoire, which still hold small chimpanzee populations, are entirely within 25 km of the proposed Gulf of Guinea corridor.

For further contextual information relevant for conservation planning, we estimated that 77.93% of western chimpanzees live in savanna-mosaic habitat, 16.38% in forest habitat, and 5.32% in cropland habitat. We also estimated that 38.59% of chimpanzees live within 5 km and 67.43% within 10 km of settlements, while 59.25% live within 5 km and 88.11% within 10 km of roads (figure 5).

Table 1: Estimated western chimpanzee abundance by country (within geographic range delineated by IUCN SSC A.P.E.S. database).

Country	Estimated chimpanzee abundance (95% CI)	% chimpanzees living in national parks and IUCN category I or II protected areas
Guinea	33,139 (8,796 – 68,203)	12.21
Liberia	6,050 (2,902 – 13,690)	14.22
Sierra Leone	5,925 (1,951 – 12,668)	31.20
Senegal	2,642 (1,077 – 13,293)	31.55
Guinea-Bissau	1,908 (923 – 6,121)	34.45[1]
Mali	2,029 (322 – 9,228)	10.00
Côte d'Ivoire	1,093 (329 – 3,299)	46.92[2]
Ghana	24 (1 – 212)	14.40
Total	52,811 (17,577 – 96,564)	16.98

[1] As the spatial outline of Boé and Dulombi National Parks provided by the World Database of Protected Areas is not up to date (A. Goedmakers pers. obs.), we used the outline provided by the "Instituto da Biodiversidade e das Áreas Protegidas" (Agency of Guinea-Bissau government responsible for national parks) for this calculation.

[2] It is noteworthy that while this number seems high, chimpanzees have declined by more than 90% across Côte d'Ivoire including regional extinctions resulting in a strong contraction of their range (Campbell *et al* 2008, Kühl *et al* 2017).

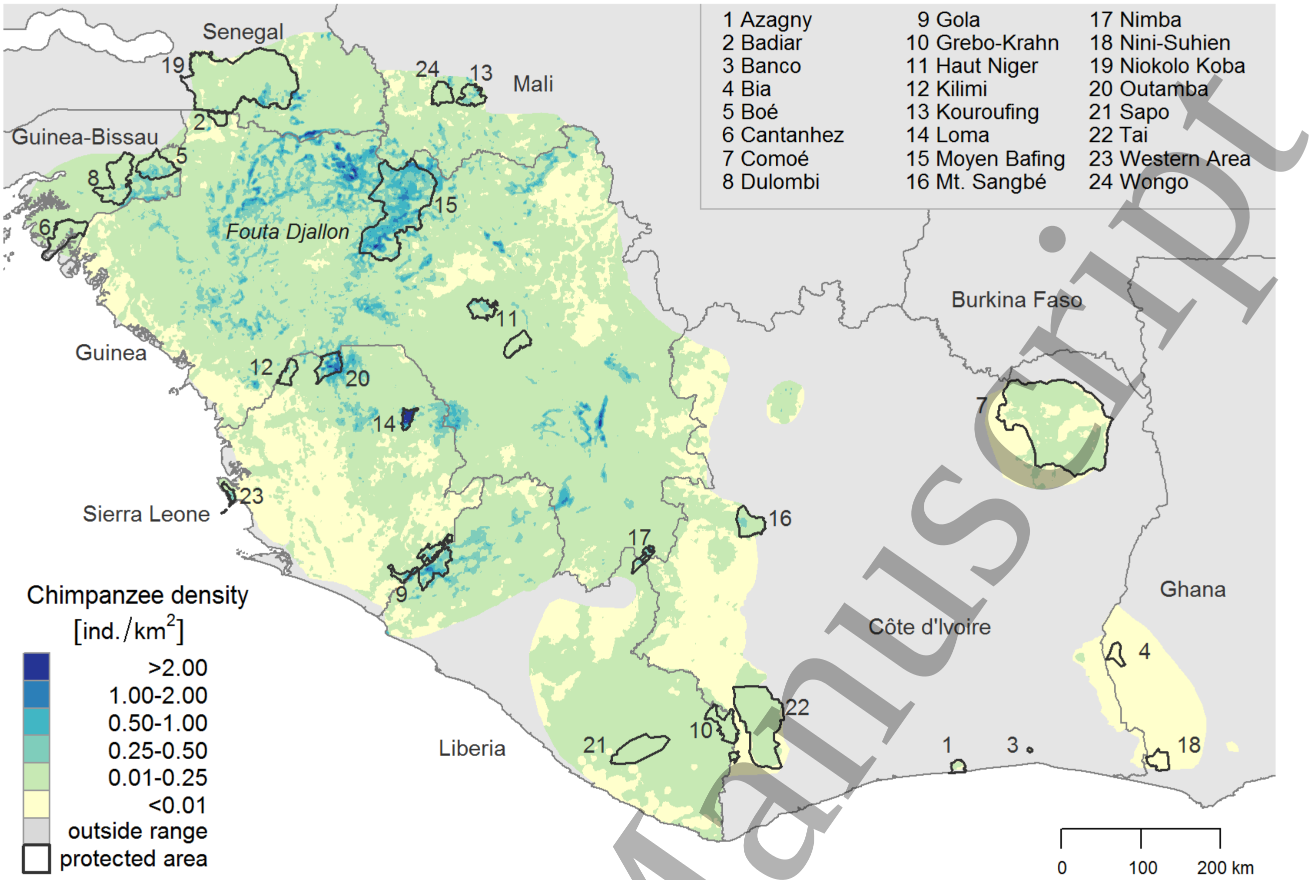

Figure 2. Modeled western chimpanzee density distribution (within geographic range delineated by IUCN SSC A.P.E.S. database, protected area outline from UNEP-WCMC and IUCN 2017, Boé and Dulombi National Parks outline from Instituto da Biodiversidade e das Áreas Protegidas in Guinea-Bissau). For plotting purposes we truncated densities at two because <0.04% of cells had estimated values larger than two, and otherwise low density cells would not be discernible. Maps of lower and upper confidence limit are in the Supplementary Material (figure S1).

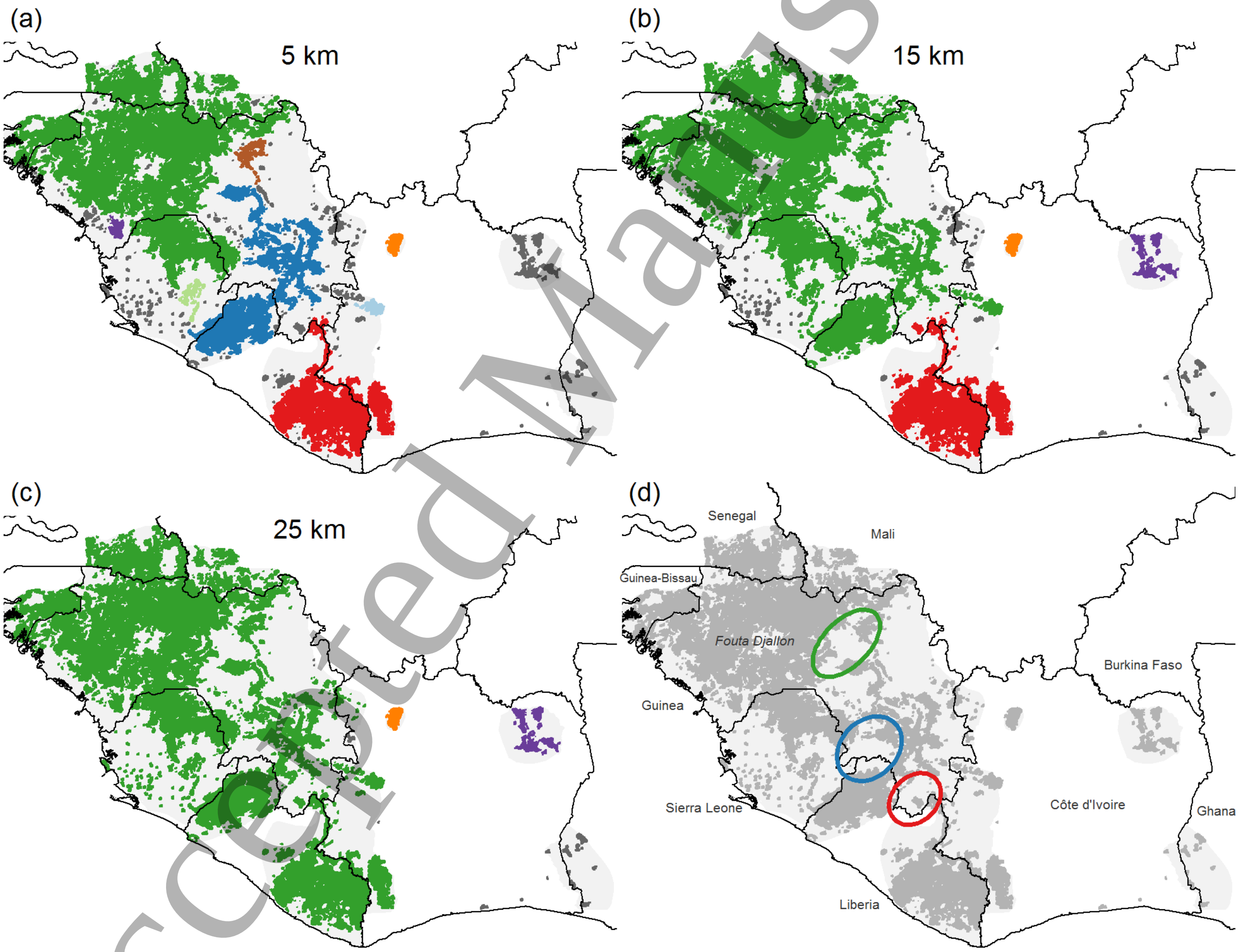

Figure 3. Scenarios for sub-populations based on three minimum distance thresholds (a) 5 km, (b) 15 km and (c) 25 km (i.e., for a larger threshold more presence cells are clustered to the same patch). Large patches are shown in color, smaller ones (typically less than 100 chimpanzees) in gray. (d) Areas with low population connectivity across all three scenarios marked (green: Upper Niger Basin in Guinea, blue: tri-national border of Guinea, Liberia, and Sierra Leone, red: Zone Forestière in southern Guinea).

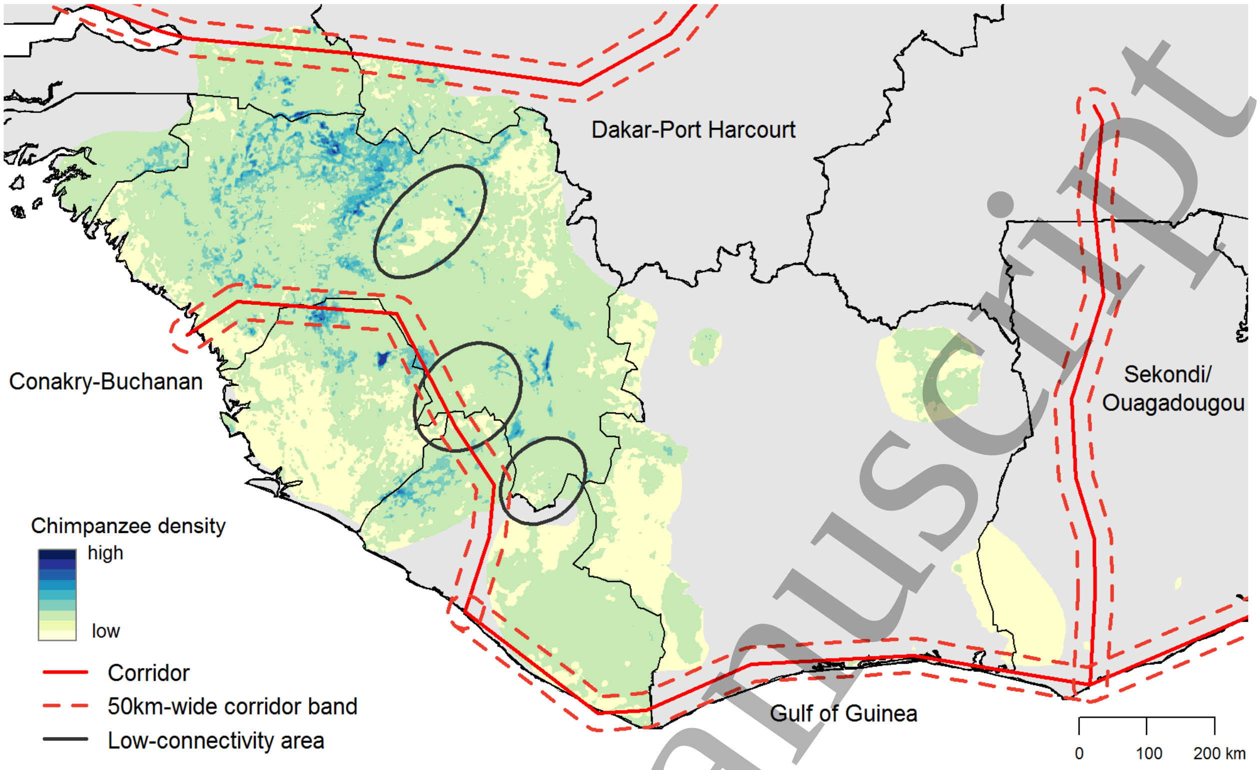

Figure 4. Spatial overlap between the four “development corridors” planned for West Africa (Laurance *et al* 2015, Sloan *et al* 2017) and modeled western chimpanzee density distribution with estimated low population connectivity areas marked.

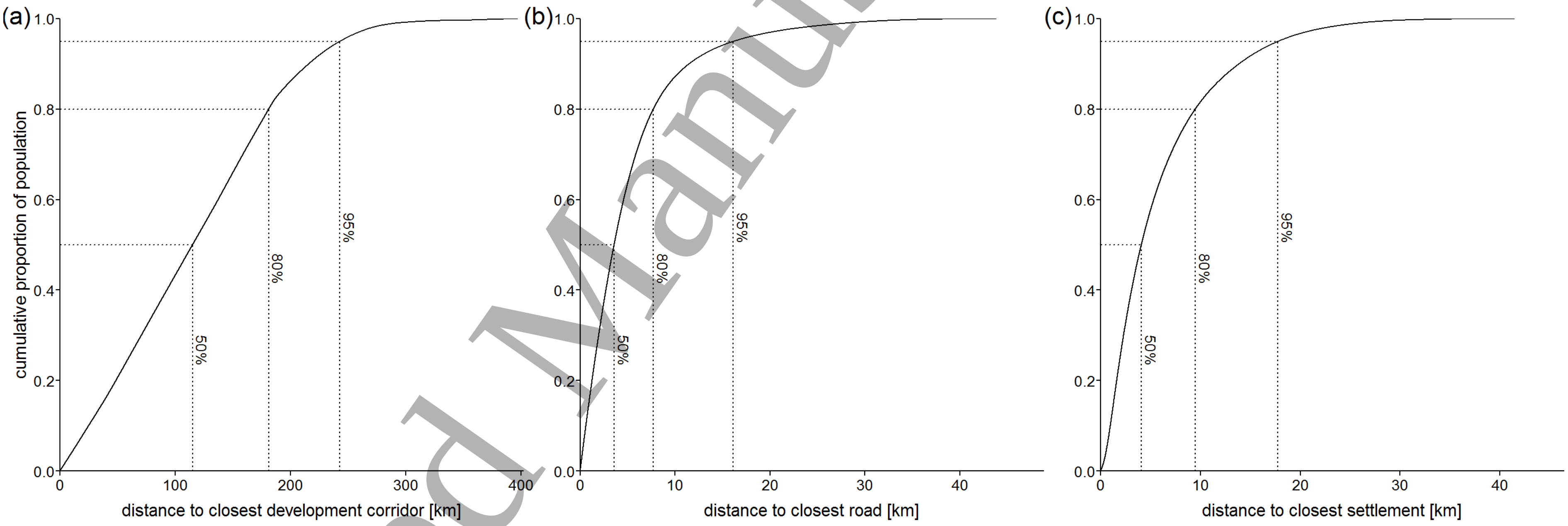

Figure 5. Cumulative proportion of western chimpanzees living within increasing distance to (a) “development corridors”, (b) roads, and (c) settlements. Plot (b) shows, for example, that 80% of western chimpanzees live less than 10 km from the nearest road.

4. Discussion

4.1. Implications for western chimpanzee conservation

As IUCN SSC A.P.E.S. provides access to a large number of ape survey datasets, many of which have not been published in peer-reviewed journals, we were able to compile a dataset representative of the entire range of western chimpanzees. For the first time, we could thus model range-wide density distribution of this taxon and derive information on chimpanzee status important for conservation planning.

The analysis showed that two main populations can be distinguished (figure 3). Chimpanzees in the Fouta Djallon and adjacent areas appear to be a large population characterized by savanna-mosaic habitat. Despite challenging ecological conditions (Wessling *et al* 2018), chimpanzees persist here at high densities due to relatively low levels of anthropogenic threats and a high prevalence of hunting taboos (Heinicke *et al* 2019, Boesch *et al* 2017). Chimpanzees in the second largest population live in a habitat mostly characterized by rainforest. Our analysis indicated that these two populations might have low connectivity at present (figure 3). The other chimpanzee populations remaining in Côte d'Ivoire and Ghana are already completely isolated (Kühl *et al* 2017), and due to their small size these populations are particularly vulnerable to stochastic events, such as disease outbreaks, that can cause local extinctions (Knight *et al* 2016).

If implemented as planned, the multi-national infrastructure projects, including development corridors, hydropower plants and powerlines, could pose multiple threats to chimpanzees (Laurance 2018). First, infrastructure development is likely to incur direct loss of chimpanzee communities, because chimpanzees cannot shift their home range to move away from disturbances as they are highly territorial (Morgan *et al* 2018). Large-scale habitat loss can especially ensue from infrastructure developments that entail expansion of settlements and agriculture, one of the explicit objectives of development corridors (Laurance *et al* 2015). For example, large-scale deforestation and wide-spread hunting as a result of industrial agriculture led to strong declines of chimpanzee populations in Côte d'Ivoire and Ghana (Kormos *et al* 2003, Campbell *et al* 2008). Beyond the direct reduction in chimpanzee abundance this may also lead to loss in behavioral diversity, as even neighboring communities can differ in their behavioral repertoire (Luncz *et al* 2012). Second, infrastructure expansions often carry secondary threats, especially an increase in hunting due to the arrival of more people, who potentially also do not adhere to established hunting taboos (Golden and Comaroff 2015). For example, in northern Congo the development of a logging concession with road construction and influx of workers led to a 64% increase in bushmeat supply (Poulsen *et al* 2009). However, a recent study of apes in Western Equatorial Africa underlined that this is context dependent, as central chimpanzee densities were significantly lower close to roads, but this effect disappeared with the presence of law enforcement (Strindberg *et al* 2018). Third, infrastructure projects lead to habitat fragmentation and act as dispersal barriers for a wide range of species (Laurance et al 2009). Although, chimpanzees have been observed to cross unpaved roads (Hockings *et al* 2015), genetic studies demonstrate that habitat fragmentation reduced chimpanzee population connectivity (Knight *et al* 2016, da Silva Borges 2017). A notable example is the case of Bossou, Guinea, where habitat fragmentation led to the isolation of a chimpanzee group, and there has been no female immigration from neighboring groups for the last 30 years (Matsuzawa *et al* 2011). What the impact on western chimpanzees will be remains to be seen and will strongly depend on the context. However, the list of potential negative impacts emphasizes the necessity to apply the mitigation hierarchy during the planning and construction of infrastructure (i.e., avoid, minimize, restore, and offset; BBOP 2013).

4.2. Comparison to previous estimates and data gaps

Overall, our abundance estimates are in line with previous studies that estimated around 7,000 chimpanzees in Liberia (Tweh *et al* 2015), 5,600 in Sierra Leone (Brncic *et al* 2015), and 17,700 in the Guinean part of the Fouta Djallon (WCF 2012). Kühl et al. (2017) compiled abundance data for 35 sites across West Africa, covering 40% of the western chimpanzee range, and estimated a minimum of 35,000 chimpanzees. Our predicted abundance for Senegal is notably higher than previous estimates of 200-400 which were extrapolated from small-scale surveys (Kormos *et al* 2003). Similarly, our estimate is higher than the 600-1,000 estimated for Guinea-Bissau, but that estimate was not based on quantitative data (Kormos *et al* 2003).

Modeled estimates are associated with uncertainties (figure S1) due to the possibility of missing predictors, and differences in spatial scale of different predictor datasets (table S2). Uncertainties are more pronounced for areas with fewer data and those that differ strongly from surveyed areas regarding predictor space coverage. While substantial data are already available for large parts of the western chimpanzee's range, notable data gaps exist (figure 6). Identifying such gaps can inform where further surveys are needed, and shows where results are uncertain and need to be interpreted with care (see also figure S1). In particular, further field surveys are needed for Mali, for which only few data points are available. However, this is difficult due to the on-going political instability there. Considering that our estimates are significantly higher than previous estimates for Senegal and Guinea-Bissau and have large confidence intervals, more intensive and representative future surveys in these countries would be instrumental in verifying our estimates. Similarly, high densities were predicted for the Kourandou and Simandou mountain ranges in eastern Guinea, but considering that this region is very dry, densities might have been overestimated and further surveys would be needed to validate these predictions. The aim of

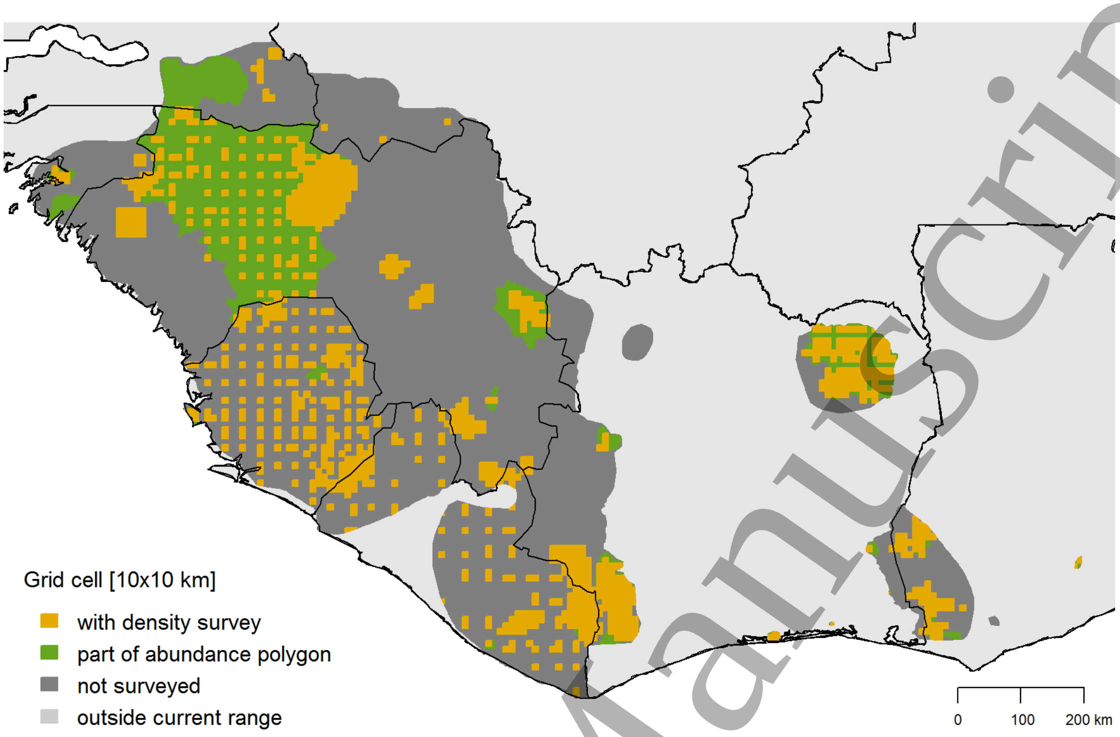

Figure 6. Surveyed areas and survey gaps for western chimpanzees. For each grid cell of 10x10 km we determined whether a survey was conducted in that cell. Abundance polygon is the spatial outline of an area for which an abundance estimate was available from the IUCN SSC Ape Populations, Environments and Surveys (A.P.E.S.) database.

the model was thus to predict general patterns in chimpanzee density distribution across its range. However, its usefulness is limited at the local scale, for which site-based surveys are clearly superior.

4.3. Contribution of a taxon-specific database

Our study exemplifies the multi-facetted advantages of the IUCN SSC A.P.E.S. database. First, it can design data sharing policies reflecting the data sharing culture of its research field (Thessen and Patterson 2011), and by building trust and collaborations with a variety of data collectors, it can compile data in greater depth and provide access to unpublished datasets for a wider community. It also provides contextual information on the data, such as ecological and anthropogenic variables. Second, IUCN SSC A.P.E.S. not only ensures data attribution to data collectors so that their efforts are credited (Thessen and Patterson 2011), but it can also provide direct benefits to data collectors, for example, by collaborating on research projects and sharing authorship. In addition, database staff can support data collectors during study design and data analysis. Third, IUCN SSC A.P.E.S. hosts different types of data which can be used to derive different population parameters, including species abundance, density distribution, population trend, population connectivity, and habitat suitability (table 2). Fourth, databases can pool expertise and technical skills to process data to be directly fed into conservation decision-making. For example, data contained in IUCN SSC A.P.E.S. had been used for a range of applications, including assessments for the IUCN Red List (e.g., Humle *et al* 2016, Fruth *et al* 2016, Maisels *et al* 2018), conservation action plans (e.g., IUCN and ICCN 2012, IUCN 2014), CITES, UNEP, and funding organizations (e.g., GRASP and IUCN 2018). Fifth, due to their knowledge of the field, database staff can also convey contacts to relevant experts and thereby improve information flow between different stakeholders, for example for the verification of study results. Thereby, research efforts can be streamlined and duplication avoided. Lastly, funders and journals increasingly require that research results are made publicly available. Accordingly, study results based on IUCN SSC A.P.E.S. data are also stored in the database (table 2). IUCN SSC A.P.E.S. thus enables a two-way information and knowledge exchange and functions as an intermediary to bridge the gap between stakeholders collecting data and those basing their research or decision-making on that data.

Taxon-specific databases already exist for different taxonomic groups and regions, for example the North American Breeding Bird Survey (Sauer *et al* 2013), African Elephant Database (Thouless *et al* 2016), Biological Records Centre in the UK (Pocock *et al* 2015), or Entomofauna Germanica (Bleich *et al* 2019). Despite their fundamental role in curating data relevant for conservation planners and policy makers, databases face severe funding shortages. We suggest that their contribution to filling data gaps for underrepresented taxa and regions needs to be recognized, and that many more databases could be established. Similar to initiatives in the biomedical sciences that set up database networks, such as bioDBnet (Mudunuri *et al* 2009) and BioMart Central Portal (Guberman *et al* 2011), a network of taxon-specific databases could be grown incrementally to complement global data repositories. Within such a network each database would pool data and expertise of the respective research field, while data users can retrieve data available across the entire network, for example, for a specific country or region. Taxon-specific databases can thus fill the niche between local data collectors and global data repositories.

Table 2: Information on western chimpanzees that has been or could be derived from datasets archived in IUCN SSC A.P.E.S.

type of analysis	results for western chimpanzees	example studies
abundance	52,811 (17,577 – 96,564) individuals	this study
climate change	to be investigated	
density distribution	figure 2 this study	this study
ecosystem service provision through habitat protection (e.g., carbon storage, watershed protection, human cultural traditions associated with the habitat)	to be investigated	
geographic range	524,100 km^2	Kühl *et al* 2017
IUCN Red List assessment	Critically Endangered	Humle *et al* 2016
landscape-scale metrics	figure 5 this study	this study
land-use across species range	77.93% in savanna-mosaic, 16.38% in forest habitat, 5.32% in croplands	this study
population trend	annual decline of 5.96%, decline of 80.2% between 1990-2014	Kühl *et al* 2017

population connectivity	figure 3 this study	this study
presence estimation for individual grid cells	figure 3 this study	this study
protected area coverage	16.98% of chimpanzees occur in high-level protected areas	this study
species co-occurrence	to be investigated	
suitable environmental conditions	decline of area with suitable environmental conditions from 1990 to 2000	Junker *et al* 2012, Jantz *et al* 2016
survey gaps	figure 6 this study	this study

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density distribution for western chimpanzees will be made available via the IUCN SSC A.P.E.S. database (http://apesportal.eva.mpg.de).

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