BID Africa 2017 – Small Grant Final narrative report

Instructions

- Fill the template below with relevant information. **please indicate the reason of the delay and expected date of completion.**
- Use the information included in your project Full proposal (reproduced in annex III of your BID contract) as a baseline from which to complete this template
- The information provided below must correspond to the financial information that appears in the financial report
- Sources of verification are for example direct links to relevant digital documents, news/newsletters, brochures, copies of agreements with data holding institutions, workshop related documents, pictures, etc. **Please provide access to all mentioned sources of verification** by either providing direct link or sending a copy of the documents.
- This report must first be sent as a **Word document** to BID@GBIF.org and be pre-approved by GBIFS
- Once this report is pre-approved in writing by GBIFS, it must be signed by the BID project coordinator and sent by post to:

  The Global Biodiversity Information Facility Secretariat (GBIFS)

  Universitetsparken 15

  DK-2100 Copenhagen Ø

  Denmark

....

Template

1. Table of Contents

This programme is funded by the European Union

2. Project Information

2.1. Project Coordinator: Institution/network/agency name:

Prof. John T.Woods
Department of
Forestry University
of Liberia
Fendall Campus, Montserrado
County Monrovia, Liberia

2.2. Main contact person and role:

Prof. John T.Woods, Lead Partner

2.3. BID proposal identifier:

BID- AF2017-0168- SMA

2.4. Project title:

"BID-AF2017-0168-SMA: Building Capacity for Biodiversity Data Mobilization and Conservation in Liberia" (the 'Action')

2.5. Start date and end date of the reporting period:

01/11/2017-30/10/2018

2.6. Country in which the activities take place:

Liberia, West Africa

3. Overview of results

3.1. Executive summary

Give a short summary of the activities implemented and the outcomes of the project for the reporting period (500 words maximum)

The purpose of this project was to build the capacity of Liberia to mobilize biodiversity information and data for conservation and development. The contract for the implementation of the project was signed on November 1, 2017 but actual implementation did not became untill after the political periods of elections and inuaguration in November 2017 and January 2018. During this period of implementation, data sharing agreements were concluded with a dozen of data holding institutions who designated twenty-six (26) technicians for training in biodiversity data mobilization, processing and publishing. All participants were certificated and a follow up training was conducted to help those who needed more attention. For example, after certificating and accessing their capacity, it was determined that a follow up training was necessary, especially in heavy data holding institution like the Environmental Protection Agency (EPA) to further enhance their capacity to enter and catalog more data. Over the period, we gathered several datasets from data holding institutions, including, the datasets mentioned in our proposal. We mobilized and publised a total of 12 datasets (6,138 record) covering five taxonomic groups (plants, mammals, birds, reptiles, and insects) and some threatened species in each group (see published datasets). Additionally, all other datasets gathered during the period have been cataloged and archived accordingly while we we seek funding to continue data mobilization. Meanwhile, we have developed a bibliograph of the cataloged data to be made available in soft and hard copies as a source of reference for biodiversity information and data researchers and users. We hope that this will aviod the duplications of efforts in generating biodiversity information and data in the future. A center for processing biodiversity information and data has been established at the Forestry Development Authority (FDA) which has become a Voting Member of the GBIF Governing Council (the biggest achievement of this project). The implementation of this project has taught many lessons leading Liberia towards building an institution for biodiversity information and development that will coordinate and manage the mobilization, processing and publishing of biodiversity information and data in Liberia.

3.2. Progress against expected milestones:

Give an overview of all the expected milestones for your project from the beginning until now (see Annex V of your contract)

Expected milestones/activities	Completed? Yes/No	Explanatory notes	Sources of verification
Completed capacity self-assessment questionnaire for data holding institutions https://www.gbif.org/document/82785/self-assessment-guidelines-for-data-holding-institutions (EN) https://www.gbif.org/document/82813/modele-dauto-evaluation-pour-les-institutions-detentrices-de-donnees (FR) (***Early Progress report milestone***)	Yes	This will help with our monitoring and evaluation process.	Reported to GBIF
At least one national data publishing institutions are registered with GBIF.org Guidelines to become a publisher: https://www.gbif.org/become-a-publisher (***Early Progress report milestone***)	Yes	The Forestry Development Authority has been registered.	GBIF
At least one person from the project team has completed the certification process following the BID Capacity Enhancement workshop on Data Mobilization organized as a part of the BID programme Africa 2015 or the BID programme Africa 2017 (***Early Progress report milestone***)	Yes	Ben Freeman of our team attended the workshop	GBIF-BID
Knowledge dissemination activities have been scheduled following the first BID Capacity Enhancement workshop (***Early Progress report milestone***)	Yes	A stakeholders workshop was held where presentations were made about Data Mobilization.	Current report
At least one dataset has been published to GBIF.org (***Midterm report milestone***)	Yes	A total of six datasets were published onto the GBIF network to achieve this milestone.	https://www.gbif.org/dataset/3187332f-77d0-4d34-9840-f26bcdb98a82 https://www.gbif.org/dataset/43f9dcb0-80e1-40ec-906f-93a186e993b2 https://www.gbif.org/dataset/0b394791-e0c5-4f94-bc8e-bbfe5c32920d https://www.gbif.org/dataset/34f447ee-6521-4e05-b7d5-f18540a9648d https://www.gbif.org/dataset/7afcfc1d-b370-4b00-823c-e9308f1fb5ca https://www.gbif.org/dataset/2f0f6f6b-b7dc-4cf0-9ede-

This programme is funded by the European Union

			107627044722
The data users identified in the full proposal have documented their intended use of the mobilized data and provided early feedback (***Midterm report milestone***)	Yes	There is extensive progress being made in Liberia in line with this activity and we are still engaging stakeholders to encourage the use of our datasets. So far one project has used our datasets to answer questions about endangered species distributions, habitat connectivity, and species vulnerability to climate change. A a research article entitled 'Reconstructing endangered mammal species distributions and forest connectivity across the humid Upper Guinea lowland rainforest of West Africa' has been submitted to the journal Biodiversity and Conservation using data from Liberia. Also, our capacity needs assessment showed that many data users identified in this project have limited capacity in analyzing biodiversity data to be used for decision making. Our just ended workshop on biodiversity data mobilization and usage has trained over 20 people in addressing these limitations. We are confident this will motivate more data use.	
All mobilized data have been published to GBIF.org **(Final report milestone)**	Yes	A total of 12 datasets were mobilized (i.e., cleaned, formated and processed) and published onto the GBIF network. However, it should be noted here that the projected gathered more datasets during the period and we are hoping to seek more funding to processed and publish those datasets.	https://www.gbif.org/dataset/3187332f-77d0-4d34-9840-f26bcdb98a82 https://www.gbif.org/dataset/43f9dcb0-80e1-40ec-906f-93a186e993b2 https://www.gbif.org/dataset/0b394791-e0c5-4f94-bc8e-bbfe5c32920d https://www.gbif.org/dataset/34f447ee-6521-4e05-b7d5-f18540a9648d https://www.gbif.org/dataset/7afcfc1d-b370-4b00-823c-e9308f1fb5ca https://www.gbif.org/dataset/2f0f6f6b-b7dc-4cf0-9ede-107627044722 https://doi.org/10.15468/bhb1fv https://doi.org/10.15468/aa6txh https://doi.org/10.

			15468/wucefr https://doi.org/10.15468/grxior https://doi.org/10.15468/3m4dle https://doi.org/10.15468/wtsfsv
All published data meet the minimum requirements outlined in the Data Quality Requirements available at **(Final report milestone)**	Yes	All published datasets were cleaned and standardized in the Darwin format befor publicatipon. We also ensured that all datasets met the minimum requirements before publication. All published data have been approved by the GBIF team.	See published data. https://bid.gbif.org/en/community/data-quality/
The training outcomes of the project have been documented, including the number of people receiving certification through the BID Capacity Enhancement workshops, the number of people trained in nationally organized events, and the evaluation of the impacts of these training activities **(Final report milestone)**	Yes	All training activities were documented and partciparticipants certificated. We also also followed up with participants and provided technical suport where necessary. For example, the project team worked along with staff at the Liberian Environmental Protection Agency (EPA) to help them organize and catalog data gathered from environmental impact assessments. We are still working with the EPA staff and hoping to find funding to digitize all the data they have.	Certificates & photographs
Final capacity self-assessments for national biodiversity information facilities have been completed with sustainability plans. https://www.gbif.org/document/82785/self-assessment-guidelines-for-data-holding-institutions (EN) https://www.gbif.org/document/82813/modele-dauto-evaluation-pour-les-institutions-detentrices-de-donnees (FR) **(Final report milestone)**	Yes	An assessment was carried out and the need to set up biodiversity information facilities have been serious considered. The project has trained people from each responsible government agency to manage any such facilities. At the meager scale of this project a laptop was purchased and relevant software installed to catalog, store, and manage biodiversity. Most importantly, Liberia has become a GBIF Node to sustainably continue the work of the project. There are ongoing plans to establish a Biodiversity Institute at the University of Liberia to manage all biodiversity information in the country.	
All uses of the mobilized data have been documented **(Final report milestone)**	Yes	All mobilized data were archived in our local database before publishing onto GBIF platform. Additional data have been gathered and cataloged additional datasets are yet to be processed and published.	See attached and bibliograph of datasets.
Best practices and lessons learned have been documented **(Final report milestone)**	Yes	Best practices and lessons learned have been documented and will be writen up into a manuscript for publication into a biodiversity informatics journal.	

3.3. Project deliverables and activities

Refer to the table in section 2.2 "Deliverables, activities and reporting criteria" of your BID full proposal. Provide updates on the status of each of planned deliverables. In the event of unexpected delay, please provide detailed explanatory notes and indicate planned completion date. Add as many rows as needed.

This programme is funded by the European Union

BID GBIF

Deliverable	Related activity	Completed ? Yes/No	Explanatory notes	Sources of verification
Signed data sharing agreements	Stakeholder workshop	Yes	The worshop was held and 8 stakeholders signed data sharing agreements.	See attached agreement.
Mobilized data for threatened species	Stakeholder workshop Literature review	Yes	We published 12 datasets, consisting of 6,138 records and covering 4 taxonomic groups (birds, mammals, plants, and reptiles) and several threatened species, including, western chimpanzee (CR), pygmy hippo (EN), and African forest elephant (VU). We also note that other than the iconic large mammals species of high conservation priority, little or no data are available on many threatened species across the country.	See published datasets above.
Bibliography of data collectors, sources, databases, and users	Literature review Stakeholder workshop	Yes	We have gathered a bibliography as proposed.	See attachment
Biodiversity information available in desk study report, in hard copy and electronic copy	First evaluation report	Yes	Our results were presented at a national stakeholders meeting bringing together major data collection NGOs and relevant government agencies. At this meeting, findings from a recent study on the status of forest elephants, pygmy hippos, and western chimpanzee in western Africa using our data was presented.	See report attached
At least 20 people trained and capacity-enhanced in biodiversity data mobilization and publishing	Capacity needs assessment Training workshop	Yes	We trained a total of 26 people in biodiversity data mobilization, management, and publishing.	See attendance Photographs Certificates
Checklist of threatened species produced and published	Data mobilization, processing, and publication	Yes	All checklist data (including threateend species) mobilized have been published.	See published data
Distributions of well-studied threatened species identified and published	Data mobilization, processing and publication	Yes	Distribution maps for three threatened species were developed and published.	https://link-springer-com.www2.lib.ku.edu/article/10.1007/s10531-018-01684-6
Occurrence and sample-based data of	Data mobilization, processing and	Yes	All occurrence data (including threateend species) mobilized	See published data

threatened species produced and published	publication		have published.	
Biodiversity database setup at the FDA	Establish facility for data management	Yes	The project trained 3 people from FDA and the UL to manage biodiversity data mobilized over the course of the project. At the meager scale of this project, a laptop was purchased and relevant software installed to catalog, store, and manage biodiversity. Most importantly, Liberia has become a GBIF Node to sustainably continue the work of the project.	Liberia GBIF MOU
Capacity needs of data collectors/users identified	Capacity needs assessment	Yes	An assessment was carried out. Our capacity needs assessment showed marked lack of data mobilization and analytical skills at many agencies to analyse biodiversity data to inform decisions. We see this as a priority for future projects.	This informed many project activities.
Biodiversity data communicated to data users and collectors	Stakeholders seminar	Yes	Presentations were made at different stakeholders meetings.	See report

3.4. Additional data Datasets published on GBIF.org

Refer to the table in section 2.4 "Biodiversity data mobilization plan" of your BID full proposal. If the dataset is not yet published, please indicate the name of the institution that is expected to host the data when published in the column "DOI or URL/Planned hosting institution". Add as many rows as needed.

Dataset title	**Publishing institution**	**DOI or URL/Planned hosting institution**	**Date/expected date of publication**	**Explanatory notes**
Biomonitoring data on threatened species of Sapo National Park	FDA	https://doi.org/10.15468/52ubri	Aug. 14, 2018	Published
Biomonitoring data on threatened species of Grebo National Forest	FDA	https://doi.org/10.15468/bhb1fv	Feb. 23, 2019	Published
Biomonitoring data on threatened species of Gola National Park	FDA	https://doi.org/10.15468/rpmxoz	Aug. 14, 2018	Published
Biomonitoring data on threatened species of East Nimba Nature Reserve	FDA	https://doi.org/10.15468/aa6txh	Feb. 23, 2019	Published
Nation-wide survey data on chimpanzee and other large mammals	FDA	https://doi.org/10.15468/grxior	Feb. 23, 2019	Published

This programme is funded by the European Union

National Pygmy Hippo data	FDA	https://doi.org/10.15468/lmyyxs	Aug. 14, 2018	Published
National Elephant data	FDA	https://doi.org/10.15468/ewe58c	Aug. 14, 2018	Published
Birds of Grand Kru Liberia	UL	https://doi.org/10.15468/hh6ppt	Aug. 14, 2018	Additional data
Exploration of the Carbon Sequestration Potential River Cess, Liberia 2008	FDA	https://doi.org/10.15468/3m4dle	Feb. 23, 2019	Additional data
Birds and plants of Firestone Harbel Plantation	UL	https://doi.org/10.15468/z1qxgu	Aug. 14, 2018	Additional data
Liberian Greenbul Expedition 2013	UL	https://doi.org/10.15468/wucefr	Feb. 23, 2019	Additional data
National forests rapid biological assessment Liberia 2002/03	FDA	https://doi.org/10.15468/wtsfsv	Feb. 23, 2019	Additional data

3.5. Examples of use of biodiversity data available through GBIF

Data mobilised through the BID programme, ultimately, should guide natural resource conservation and management policy. We require you to report on how you have integrated these data into these policy-making processes. You may want to refer to the section 2.5 "Plan to support the integration of biodiversity information into policy and decision-making process" of your original proposal as a reminder of your original commitments.

As part of that process, we request you to provide us with a summary of how you have used these data within the decision-making process and we have included some guiding questions below to help with that process. Please note that if your dataset has been combined with other datasets in analyses that guide the decision-making process, then this should be recorded too.

Description

Has your project been successful in integrating data within the policy-making process? ***Yes***
Where did the demand for these data come from? ***Researchers, Government agencies, NGOs***
If yes, which policies have been developed using your data? Protected Areas establishment and management. ***There are current efforts to establish new protected areas across the country and our data provide some baseline information.***
If no, what were some of the challenges you faced in getting your data into those processes? ***We note that this aspect is the main limitation of this project. Our capacity needs assessment showed marked lack of analytical skills at many agencies to analyse biodiversity data to inform decisions. We see this as a priority for future projects.***
Did you have a biodiversity data integration plan from the beginning of your project? ***Not exactly****. If so, did you have to adapt your plan as the project progressed and why did you have to make those alterations?*
In what format are your data being used i.e. what were the analyses, if any, that you needed to perform on the data to ensure that they was in a format accessible to policy-makers? ***Our data have been used for ecological niche modelling to inform conservation planning. At the national level, our checklist data are used to determine the checklist in areas ear marked for protected area established.***
What level of communication has there been with the relevant policy stakeholders i.e. by which means? With what regularity? And, how critical have these interactions been for the development policy-relevant analyses? ***This is still developing. Project leaders were able to present findings at national stakeholders meetings in biodiversity conservation.***
What additional support (resources, tools, network, training) would be needed for your project to ensure the flow of information from mobilisation to decision-making? ***All supports, particularly more hands-on training in biodiversity data use for decision making harnessing all relevant tools (GIS, Ecological Niche Modelling, etc).***

How would you improve on your own processes in the future to improve data integration in the future? **By building on the initial capacity for the mobilization acquired from this Small EU Grant.**
Data may serve other purposes other than for policy-making and these are as valuable. How was your data used for other purposes e.g. development of training materials, scientific publications, communication activities etc? **We are hoping to improve this, now that Liberia is a GBIF member. However, it should be noted that this new concept in Liberia so we are hoping that with time we will see more uses. Of course, one scientific publication has come out of our work already.**

Supporting materials

As part of our reporting, we request you to provide us with a copy of any materials highlighting data use on your dataset, either on its own or in combination with other datasets. This could be in the form of:

- Reports – governmental, ministerial, non-governmental organisations, international policy-making bodies
- Policy briefs
- Scientific publications
- Outputs from analyses that will be used in the future e.g. species distributions maps and other spatial analyses
- Education/communication materials

Please provide a valid dataset to the doi. Where the doi is not known, please state why.

Name of resource	Type of resource i.e. report, policy brief, scientific publication, analysis output, education materials, communication materials, other (please specify)	Dataset doi	Link to document or publication citation
Modeling endangered mammal species distributions and forest connectivity across the humid Upper Guinea lowland rainforest of West Africa	scientific publication	https://doi-org.www2.lib.ku.edu/10.1007/s10531-018-01684-6	https://link-springer-com.www2.lib.ku.edu/article/10.1007/s10531-018-01684-6

3.6. Events organized as part of the project

List all the events that have been organized as part of your project. Please provide links to any documents or webpages documenting the use in the "Sources of verification" column. Add as many rows as needed.

Full title	Organizing institution	Dates	Number of participants	Sources of verification
Species Working Group Liberia meeting	FFI	December 18, 2018		
BID Collaborators' meeting	Collaborators (FFI, UL, FDA, Kansas)	December 18, 2018		
Species Working Group Liberia meeting	Wild Chimpanzee Foundation (WCF)	**Nov 23, 2018**		
Training & Capacity Enhancement Workshops	UL, FDA, FFI, KU	July 2018 & January 2019		

This programme is funded by the European Union

4. Updated calendar for the BID project implementation and evaluation period

The calendar should be completed in the same way as in the Full Project Proposal, but should include any expected changes. Provide reasons for any expected changes in section 4.1 'Explanatory Notes'.

Implementation period start date and end date (dd/mm/yy) 01 – 06– 18 to 31 – 12 – 18																			
Activity	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	**16**	**17**	**18**	**Notes**
Training workshop									X										Scheduled for July 16 – 20, 2018
Data mobilization, processing and publication								X	X	X	X	x							Data processing and publication
Establish facility for data management										X	X	X							
Stakeholder seminar												X				.			These seminars will be used to communicate project results to stakeholders
Final report																x	x	x	Extenuating circumstances in the country (political and administrative)

This programme is funded by the European Union

Evaluation period start date and end date (01 – 11– 18 to 01 – 02 – 19)				
Activity	1	2	3	**Notes**
Final financial and narrative reporting		X	X	Complete
Literature review (Bibliography of data collectors, sources, databases, and users; mobilized data)	X	X		Complete
Training workshop (capacity enhancement)	X	X		Complete
Establish facility for data management		X		Complete
Data mobilization, processing and publication (checklist, distribution maps, etc)	x	x		Complete

4.1. Explanatory notes:

5. Sustainability plans

Explain the approach that will be taken to ensure the sustainability of the project's results after the end of your project (500 words maximum)

This project was considered the pilot in building capacity for the mobilization of biodiversity information and data in Liberia. We emphasize pilot project because there has never been an attempt to mobilization the enomurse biodiversity information and data in a cohesive and coordinated way to digitize, store, and manage for research and decision making. The Liberian biodiversity information and data are located all over the globe, in private possessions, universities, museums and research centers. This project has opened windows of opportunity for Liberia to start the initiative of building capacity to mobilize its biodiversity information and data in an organized method with confidence and control over the process. Therefore, lessons learned point to the following directions:

1. *First, Liberia has become an official GBIF member as a result of this project, an opportuinty to continue mobilizing data, finding funding to continue project activities.*
2. *An institution will have to be established name and styled as a "Liberian Biodiversity Information and Data Institute (LBIDI)) samilar to that in South Africa.*
3. *The Forestry Development Authourity (FDA), the government agency which is responsible for capturing all biodiversity information and data in Liberia will have to be robust in requiring that copies of reports generated within the borders of Liberia be filed with the agency.*
4. *The FDA will turn such reports over to LBIDI for strategy, digitization, publishing, curation and archival.*
5. *LBIDI will need to robustly be funded to aggresively retrieve or mobilize all Liberian biodiversity information and data from anywhere in the world and bring them to be treated in the process of the strategy, digitization, publishing, curation and archival.*

This is a huge task given Liberia has two-third of the tropical rainforest block in the Upper Guinea region and characterized as biodiversity hotspot.

6. Beneficiaries/affiliated entities and other cooperation

6.1. Relationship with project partners

Please describe the relationship between your project coordinating team/institution and your project partners, and with any other organisations involved in implementing your BID project.

Our project partners were supportive throughout the implementation of this project. Since they are mainly conservation NGOs in the country, to support their work in Liberia they need information and data on biodiversity.

6.2. Links to other projects and actions

Where applicable, outline any links and synergies you have developed with other actions, e.g. GBIF nodes, other BID funded projects, etc. If your organization has received previous grants in view of strengthening the same target group, to what extent has your BID project been able to build upon/complement the previous project(s) ?

Our BID project has built link with the Ghana and the USA (University of Kansas) nodes based on their long years of experience in data digitization. They provided the training needs for our participants in the training workshops. We are linked also with the Species Working Group in Liberia, where we give them regular updates of our progress in building capacity for mobilizing biodiversity information and data. They are very impressed that this project is taking off to a good start. They are providing leads for funding sources for this project to succeed. We are also working with the Steering Committee on capacity building for young conservationists in Liberia. Our role in this committee is to inform this group that conservationists in the future will have to rely on biodiversity information and data to make policy for development purposes and to exercise options regarding species, habitat and ecological management.

7. Visibility

Please refer to the BID guidelines.

7.1. Visibility of the BID project

How is the visibility of your BID project being ensured?

The project visibility has been meanly in the form of display of logo on letterheads, reports, meetings, presentations etc.

Short summary

All communications and presentations followed recommended guidelines for visibility.

This programme is funded by the European Union

Sources of verification

BID templates.

7.2. Visibility of the EU contribution

How is the visibility of the EU contribution being ensured within your project implementation?

Short summary

All communications and presentations followed recommended guidelines for visibility.

Sources of verification

BID templates.

Signature ________________________________
Name of the contact person for the BID Project: **John T. Woods**
Date report sent by email in Word format to bid@gbif.org for pre-approval: **February 27, 2019**
Date report sent by post to GBIF Secretariat: ________________

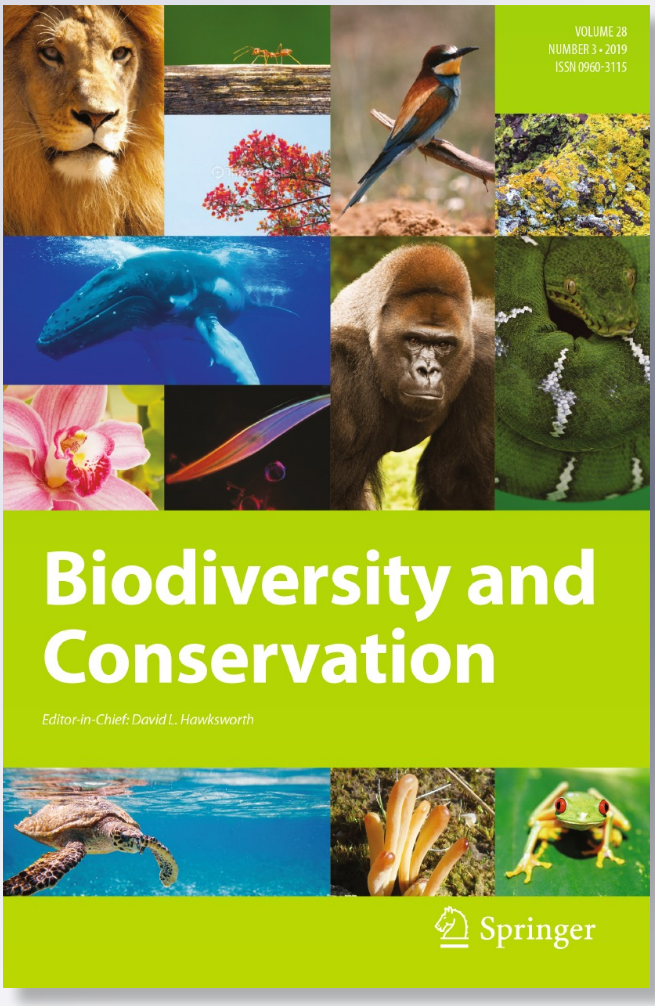
Modeling endangered mammal species distributions and forest connectivity across the humid Upper Guinea lowland rainforest of West Africa

Benedictus Freeman, Patrick R. Roehrdanz & A. Townsend Peterson

Biodiversity and Conservation

ISSN 0960-3115
Volume 28
Number 3

Biodivers Conserv (2019) 28:671-685
DOI 10.1007/s10531-018-01684-6



Springer

Biodiversity and Conservation (2019) 28:671–685
https://doi.org/10.1007/s10531-018-01684-6

ORIGINAL PAPER

Modeling endangered mammal species distributions and forest connectivity across the humid Upper Guinea lowland rainforest of West Africa

Benedictus Freeman[1] · **Patrick R. Roehrdanz**[2] · **A. Townsend Peterson**[1]

Received: 26 June 2018 / Revised: 25 October 2018 / Accepted: 11 December 2018 /
Published online: 17 December 2018

Abstract

Species distribution data provide critical baseline information for conservation planning and decision making. However, in many of the Earth's most biodiverse regions, such data are lacking for many species. Here, we used ecological niche modeling and connectivity analyses to model distributions of endangered species and protected area connectivity across the Upper Guinea Forest (UGF) Global Conservation Hotspot of West Africa. We estimated the current distributions of African forest elephant *Loxodonta cyclotis* (Vulnerable), western chimpanzee *Pan troglodytes verus* (Critically Endangered), and pygmy hippopotamus *Choeropsis liberiensis* (Endangered) across the region and optimized connectivity in two main forest complexes in the region. We used occurrence data for the period 2010–2016 for the three species from two well-sampled national parks in Liberia (Sapo National Park and Gola National Park), and remotely sensed MODIS enhanced vegetation index data for the period 2010–2015. Our models predicted a total of 75,157 km^2 of suitable habitat for chimpanzees in the region, 79,400 km^2 for elephants, and 290,696 km^2 for hippos. Of these areas, for chimpanzees, 30% of the area predicted falls within the boundaries of proposed or designated protected areas, and likewise 30% for elephants, and 19% for hippos. Liberia had the largest blocks of contiguous forest suitable for these species compared to other countries in the region but this forest was largely unprotected. This study identifies priority areas for biodiversity conservation and forest connectivity in the region, and reemphasizes the practicality of these tools to optimize conservation planning and implementation.

Keywords Conservation · African forest elephant · Western chimpanzee · Pygmy hippopotamus · Protected area connectivity · Ecological niche modeling

Communicated by Samuel Cushman.

This article belongs to the Topical Collection: Forest and plantation biodiversity.

Benedictus Freeman
benedictusfreeman@gmail.com

Extended author information available on the last page of the article

Introduction

Biodiversity conservation is a global priority, yet garnering resources to meet global conservation priorities is challenging, in largest part owing to escalating threats to biodiversity, particularly in biodiversity-rich regions of the world (Squires 2014). These threats, including forest fragmentation, habitat degradation and destruction, overhunting, disease associated with human activities, and a myriad of negative impacts of climate change, are pushing endangered species to the brink of extinction (Thomas et al. 2004; Pimm et al. 2014).

To optimize biodiversity conservation and reduce threats in the wake of limited resources, conservation biologists have employed conservation triage (i.e., prioritize investments for maximum returns, given limited resources (Wilson et al. 2007; Bottrill et al. 2008, 2009), ecosystem/landscape level conservation, in situ species-level conservation, and ex situ captive breeding programs (Primack 2010). The debate over whether species-level strategies versus ecosystem/landscape-level approaches may lead to greater success continues unabated (Lindenmayer et al. 2007; Franklin 1993). Whereas Franklin (1993) argued that ecosystem/landscape level conservation is cost-efficient and holistic in species coverage (e.g., including microbes), Lindenmayer et al. (2007) argued that species-level strategies provide useful baseline information for policy and management, particularly for threatened species, keystone species, and invasive species, that have specific impacts on the environment. Carignan and Villard (2002), however, cautioned that, whatever the case may be, conservationists should select indicators carefully, to optimize biodiversity conservation.

Several habitat connectivity modeling approaches have been used in biodiversity science to optimize species and ecosystem conservation in a combined effort (Ball et al. 2009; McRae et al. 2008; Brás et al. 2013; Lehtomäki and Moilanen 2013; Cushman et al. 2018; Hearn et al. 2018; Khosravi et al. 2018; Zacarias and Loyola 2018). These approaches are generally based on least-cost analysis of resistance surfaces (e.g., habitat suitability, topography) to assess connectivity between distributional areas, but vary in input data requirements, scale of analysis, and conservation goals. Here, we explore the use of correlative ecological niche modeling to build resistance surfaces (niche models) for habitat connectivity analysis to identify spatial patterns of connectivity in the humid rainforest of West Africa. Correlative ecological niche modeling (ENM) uses known occurrences of a species and associated environmental data (e.g., temperature, precipitation) to identify areas of similar suitable environments for the species (Peterson et al. 2011). Ecological niche models are usually developed using machine-learning algorithms to characterize current and potential distributions of species in geographic and environmental spaces, and has been adopted widely in the scientific community, with notable applications in conservation, climate change, biogeography, and zoonotic disease research (Jennings and Veron 2015; Peterson et al. 2017; DeMatteo et al. 2017). A landscape connectivity approach, implemented in the Circuitscape program, which uses electronic circuit theory to predict patterns of animal movement between fragmented or heterogonous landscapes (e.g., connecting protected areas; McRae et al. 2008, 2016). Circuitscape uses resistance surfaces between fragmented range areas to map corridors with greater connectivity. Like ENM applications, several studies have applied Circuitscape to diverse challenges in large mammal conservation (Beier et al. 2011; Roever et al. 2013; Dickson et al. 2013).

Over the last 200 years, West Africa has been identified to rank among the world's most heavily deforested regions, leaving its unique biota severely threatened (Allport 1991; Darwall et al. 2015). The remaining portions of the region's well-known humid Upper

Guinea lowland rainforest are highly fragmented; the exception is Liberia, currently possessing ~ 42% of its original forest in a relatively well-preserved, extensive, and continuous state (Liu et al. 2016). However, an increasing wave of investments from the agricultural and mining sectors raises concerns about threats to the remaining biodiversity (Primack 2010). Regional efforts have begun to address these threats, but little is known about the ecology and distributions of most West African species. If better documented and analyzed, distributional data could be leveraged to inform conservation programs and at least partially mitigate development-associated habitat fragmentation.

In this study, we integrated these two techniques to address questions about endangered species distributions, and protected area connectivity across the Upper Guinea Forest (UGF) of West Africa. Specifically, we aimed to (1) use correlative ENM to predict the current distributions of African forest elephant (*Loxodonta cyclotis;* Vulnerable), western chimpanzee (*Pan troglodytes verus*; Critically Endangered), and pygmy hippopotamus (*Choeropsis liberiensis*; Endangered) (hereafter referred to as chimpanzee, elephant, and hippo) across the humid lowland UGF of West Africa. Then, (2) we use the resulting models as surrogates to explore landscape connectivity and identify ideal movement corridors to connect protected areas across Liberia and neighboring countries (Guinea, Côte d'Ivoire, and Sierra Leone) using Circuitscape. We identified 14 suitable corridors to connect protected areas within two main forest complexes (Gola-Ziama and Sapo-Tai); these corridors likely represent practical candidate regions for applied conservation action.

Materials and methods

This study was conducted in the UGF, one of the two major humid tropical lowland rainforests blocks of western and central Africa (Fig. 1). We fitted ENM models in the portion of UGF from western Ghana to western Guinea to characterize suitable habitats for our target species, while forest connectivity analysis covered the portion of UGF within the Manor River Basin (Guinea, Sierra Leone, Liberia, and Côte d'Ivoire; Fig. 1). We used three severely threatened, but well-sampled/documented species (chimpanzee, elephant, hippo) to answer our questions. These species were selected because they are known to be flagship/umbrella species with large home ranges, have high ecological importance, well-sampled, and are of high global conservation priority.

Input data

Ecological niche modeling requires two types of input datasets: environmental data and georeferenced species occurrence data. Environmental data typically include layers summarizing aspects of temperature, precipitation, and/or vegetation, all of which may influence the survival of a species. Species occurrence data consist of unique, georeferenced locations where a species has been recorded (Peterson et al. 2011). Occurrence data were split into calibration and evaluation subsets (Peterson et al. 2011). The geographic space was divided into a calibration area (M), the area that has been accessible to the species over relevant time periods (we further reduced this area to the area from which we had available detailed sampling, Sapo National Park or Sapo NP), and a projection area (see below), a larger area of interest to which models are transferred in space or time (Peterson et al. 2011).

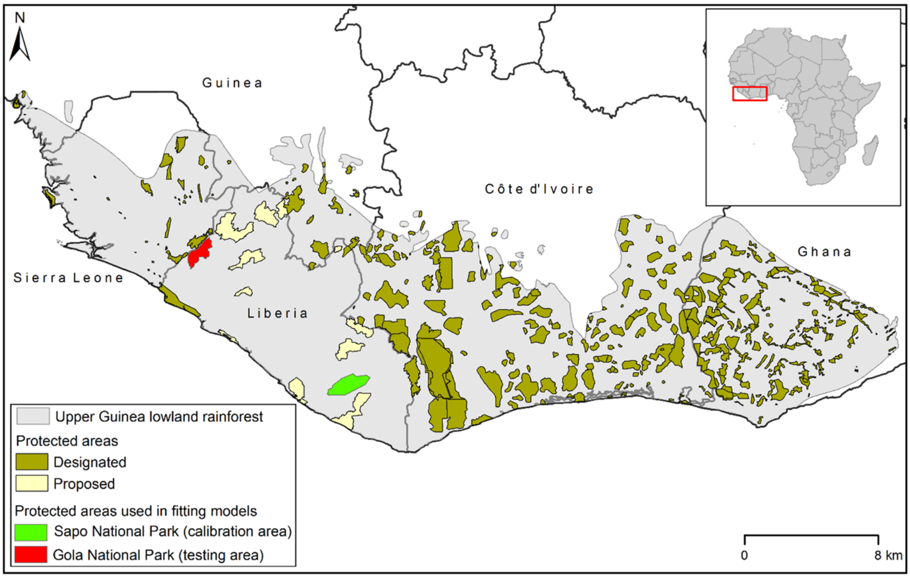


Fig. 1 The extent of Upper Guinea lowland rainforest in West Africa, proposed and protected areas across the region, including, Sapo National Park and Gola National Park in Liberia where our ecological niche models were calibrated and tested respectively

We used the NASA Moderate-resolution Imaging Spectroradiometer (MODIS) enhanced vegetation index (EVI) dataset at 250 m spatial and 16-day temporal resolutions to characterize the environmental landscape for the species (www.modis.gsfc.nasa.gov). MODIS vegetation indices have high spatial resolution and provide a realistic characterization of place and time specific environmental conditions (Bodbyl-Roels et al. 2011; Feilhauer et al. 2012; Peterson 2014). We downloaded 16-day composite MODIS Terra Satellite EVI data for the period 2010–2015- for West Africa. We chose EVI over Normalized Difference Vegetation Index (NDVI) because of EVI's improved sensitivity over dense vegetation conditions, which is the case in our study region. Further processing of these data is described below.

We used primary occurrence data collected over the period 2010–2016, as part of ongoing systematic biomonitoring projects and other surveys across Sapo NP in southeastern Liberia and Gola National Park (Gola NP) in northwestern Liberia (e.g., Tweh et al. 2015; Fig. 1). All models were calibrated in Sapo NP and tested in Gola NP (Fig. 1). Sapo NP was chosen as our calibration area (M) because it is well-sampled and contains high-quality primary occurrence data for each of our species of interest; Gola NP was well-sampled and independent of Sapo NP. All data were collected as part of systematic surveys that used GPS for establishing geographic coordinates. Occurrence data for both Sapo NP and Gola NP were imported into ArcGIS and converted to point shapefiles. We used SDM Toolbox to subsample high-density cells and remove duplications in occurrence data (Brown 2014). At the end of the cleaning exercise, we calibrated our models with a total of 40 occurrence points for hippo, 120 for chimpanzee, and 59 for elephant.

Data processing and analysis

The original set of MODIS EVI data layers was mosaicked and cleaned in ArcGIS version 10.3. Cloudy images or artifacts were removed and excluded from further analysis, leaving images for 105 time periods that were included in model fitting. We applied principal components analysis (PCA) to the remaining 105 images to reduce dimensionality and correlation among data layers. PCA extracts the major axes of variation in a dataset and compresses them into fewer orthogonal variables or principal components, with the first PC explaining the most variation in the dataset (Abdi and Williams 2010). In our case, the first 46 PCs accounted for 95% of the variation in the data. These 46 PCs were converted to ASCII file format for ENM. We used the extract by mask (batch) tool in ArcGIS to extract Sapo NP (the model calibration area) from the 46 PCs which were used in calibrating models.

Ecological niche modeling

To estimate the current distribution of our focal species, we used Maxent version 3.3.3 k, a machine-learning software platform widely used to model ecological niches of species (Phillips et al. 2006; Phillips and Dudík 2008). Before fitting our models, we further reduced the 46 PCs for each species using the delete-one jackknife approach in Maxent with each species' occurrence data and the 46 PCs (Wold et al. 1987; Abdi and Williams 2010; Shcheglovitova and Anderson 2013). To do this step, we set the random test percentage to 50%, output format to logistic, and left all other features at default. Once the variable set was reduced, we desired to assess many calibration conditions to be able to choose optimal models. As a result, we used six combinations of feature classes (Linear, Quadratic, Product, Threshold and Hinge) and five regularization multiplier values (0.1, 0.5, 1, 2, and 5) in Maxent (Phillips and Dudík 2008; Shcheglovitova and Anderson 2013; Muscarella et al. 2014). We further explored two environmental data sets for each species: one set using the jackknife-selected PCs, and another using the first nine PCs (1–9) that accounted for 85% of the variation in our dataset from the 46 PCs. We used these nine PCs separately because we observed that most of the PCs selected by the jackknife approach were not within the first ten PCs for all the species. We also used transects surveyed in Sapo NP as bias surfaces for each model to reflect survey effort (Fourcade et al. 2014), which constituted another variable in the model selection process.

To choose optimal models, we assessed model significance, performance, and complexity, in candidate models for each species. We used ENMtools (Warren et al. 2010) to generate scores for sample-corrected Akaike Information Criterion (AICc) for each model to assess complexity. We used Niche Toolbox for partial ROC significance test (http://shiny.conabio.gob.mx:3838/nichetoolb2/; Peterson et al. 2008) and we calculated an omission rate for each species (based on a 5% training presence threshold). Also, we calculated the proportion of areas predicted by each model and used this quantity in a subsequent binomial significance test. Best models for each species were selected based on (1) partial ROC and binomial significance tests, (2) minimum omission rates, and (3) model complexity (Table 1), in that order. Best models were projected across the region to predict suitable habitats for each species, both with and without clamping and extrapolation. We then took the median of the medians of the final models for each species and applied a 5% minimum training presence threshold to produce a binary distribution map. Finally, we used Mobility

Table 1 Best fitted models for each species (rows), including their parameterizations, measures of model complexity (AICc), significance test (partial ROC and Binomial test), performance (omission rate), and proportion of area predicted by each model

Species	Feature class	Regularization multiplier	Log likelihood	Parameters	Sample size[a]	AICc score	Partial ROC pvalue	Binomial test pvalue	Omission rate	Prop. of area predicted
Western chimpanzee	L	2	-1228	8	120	2474	0.007	0.005	0.28	0.51
Western chimpanzee	L	2	-1228	8	120	2474	0.001	0.003	0.00	0.84
Western chimpanzee	L	5	-1228	7	120	2471	0.007	0.005	0.25	0.54
Forest elephant	L	5	-599	5	59	1209	0.068	0.918	0.33	0.61
Forest elephant	LQHP	5	-600	4	59	1209	0.072	0.907	0.29	0.65
Forest elephant	LQHP	5	-600	4	59	1209	0.084	0.710	0.05	0.94
Pygmy hippo	L	0.1	-398	5	40	808	0.009	0.003	0.15	0.60
Pygmy hippo	LQ	0.5	-397	6	40	808	0.033	0.000	0.15	0.50
Pygmy hippo	LQ	0.5	-397	6	40	808	0.003	0.000	0.10	0.59
Pygmy hippo	L	0.5	-398	5	40	808	0.008	0.001	0.15	0.55
Pygmy hippo	LQ	1	-398	5	40	808	0.014	0.011	0.15	0.65
Pygmy hippo	LQ	1	-398	5	40	808	0.008	0.000	0.15	0.43
Pygmy hippo	LQ	0.1	-394	7	40	803	0.006	0.029	0.25	0.57
Pygmy hippo	LQHPT	2	-391	8	40	798	0.049	0.017	0.25	0.54

L Linear, *Q* quadratic, *H* hinge, *P* product, *T* threshold

[a]Number of occurrence records for each species used in the analysis

Oriented-Parity (MOP) analysis based on 10% sampling of the reference region to test for extrapolation in transfers of model predictions (Owens et al. 2013).

To identify suitable corridors for connectivity between suitable protected areas for our species of concern identified in our ENMs, we used 15 proposed and designated protected areas in the two major forest complexes in Liberia, Guinea, Sierra Leone, and Côte d'Ivoire (Fig. 3). These forest complexes together comprise > 60% of remaining forest in the UGF region. We used Circuitscape version 3.5 and its auxiliary software, Linkage Mapper (which uses least-cost corridor analysis to identify and map linkages between core areas) and Pinchpoint Mapper (which uses Circuitscape to identify pinch-points or bottlenecks in corridors produced by Linkage Mapper; McRae et al. 2016, 2008) to model connectivity between proposed and protected areas for each species within these forest complexes. Circuitscape uses electronic circuit theory concept to predict patterns of animal movement between fragmented or heterogeneous landscapes (McRae et al. 2008). To do this, it requires a resistance surface layer(s) and layers of the areas to be connected or core areas. We rescaled the continuous versions of our individual best models for each species from 250 m spatial resolution to 1 km resolution to reduce processing time, summed them using raster calculator tool in ArcGIS, and took the additive inverse (i.e., subtracting from unity) of each sum to recreate resistance surfaces. Our resistance values range between 1 and 100, representing low to high resistance. We used these resistance layers together with shapefiles of proposed and designated protected areas in the two forest complexes to build connectivity models (Fig. 3). To build networks and linkages between our core areas, we used pairwise analysis between core areas in each forest complex separately. We set the cut-off distance (cost-weighted corridor width) at 20 km.

Results

We calibrated a total of 120 models (5 values of regularization multiplier × 6 combinations feature classes x 2 sets of environmental variables x bias/no bias surface) for each species. Of the 120 models fitted for chimpanzees, three were selected as best. These models were significantly different from random and had relatively low omission rates < 28% (Table 1).

For elephants, three models were selected; however, none of the three models met our criteria for model selection. They had reasonable omission rates, but were not statistically significant, and were the most complex models of all species (Table 1). Eight models were selected for hippo, all of which were significantly different from random, less complex, and had low omission rates. All the best models for chimpanzees and elephants were models derived from the first PC variables, whereas the best models for hippos were those from jackknife-selected variables.

Our models predicted a total of 75,157 km^2 of suitable habitats for chimpanzees in the region, 79,400 km^2 for elephants, and 290,696 km^2 for hippos (Fig. 2). Of these areas, for chimpanzees, 30% of the area predicted falls within the boundaries of proposed or designated protected areas, and likewise 30% for elephants, and 19% for hippos (Fig. 4). For both chimpanzees and elephants, Liberia held the largest area of suitable habitats (51 and 53% of total areas, respectively), followed by Côte d'Ivoire (33% for chimpanzees and 32% for elephants), and Ghana (12 and 11%; Fig. 4). Thirty-nine percent of suitable habitat for both species predicted in Liberia was within proposed or designated protected areas, whereas in Côte d'Ivoire, 48% was within the boundaries of protected areas; in Ghana, 14% fell within the boundaries of protected areas. Guinea and Sierra Leone had the least area of

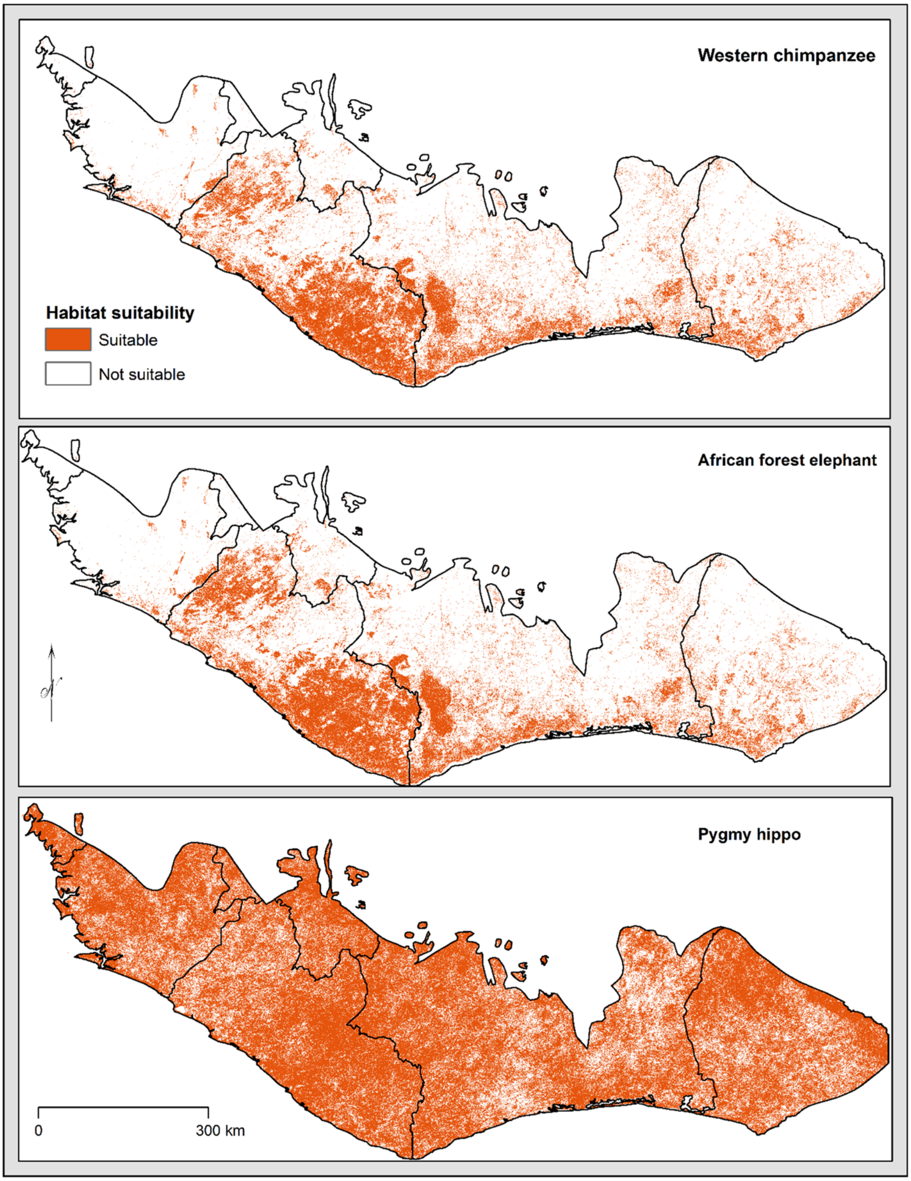


Fig. 2 Distribution maps within the Upper Guinea lowland rainforest for western chimpanzee, African forest elephant, and pygmy hippopotamus as predicted by ecological niche modeling

suitable habitats for both species, with Guinea hosting 1.3% for chimpanzees and 1.6% for elephants, and Sierra Leone hosting 2.7% for chimpanzees and 2.3% for elephants (Fig. 4). Côte d'Ivoire held the largest predicted area for hippos (35%), followed by Liberia 25%, and Ghana (19%; Fig. 4). Connectivity analysis showed that Liberia has the largest blocks of suitable contiguous forest compared to Côte d'Ivoire, Guinea, and Sierra Leone, which had much more fragmented forest landscapes (Fig. 3). The forest blocks are concentrated in

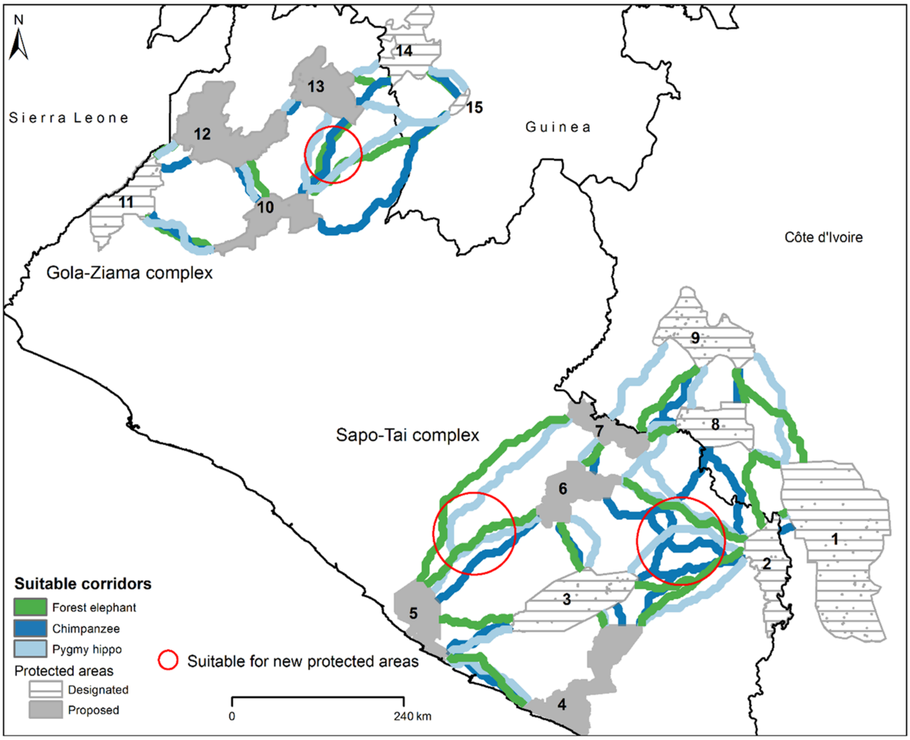


Fig. 3 Suitable corridors for connectivity of proposed and protected areas predicted within the Sapo-Tai and Gola-Ziama forest complexes in West Africa based on least cost path. 1. Tai National Park 2. Krahn-Grebo National Park 3. Sapo National Park 4. Grand Kru Proposed Protected Area (PPA) 5. Senkwen PPA 6. Gbi PPA 7. Zwedru PPA 8. Gouin Park 9. Scio Park 10. Kpo PPA 11. Gola National Park 12. Foya PPA 13. Wologizi PPA 14. Ziama Forest Park 15. Mt. Yonon

southeastern Liberia, with Sapo NP connecting to Tai National Park in southwestern Côte d'Ivoire to the northwest, and in northwestern Liberia, with Gola NP connecting to Gola Rainforest National Park in Sierra Leone to the west, and Ziama Forest in Guinea to the north. Our connectivity analysis in the two forest complexes identified a total of 14 suitable corridors to connect proposed and designated protected areas in the two forest complexes, many of which overlapped among the three species (Fig. 3, Table 2).

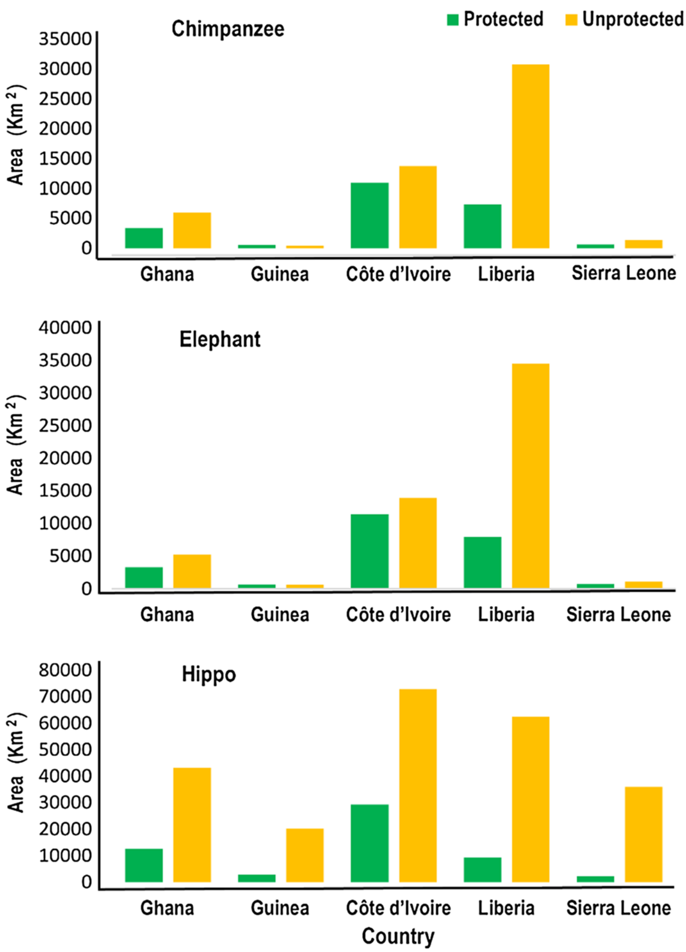


Fig. 4 Estimated protected and unprotected suitable areas for each species in Upper Guinea Forest across each country. Note the different vertical scale used for the hippo models, which suggests and reflects the overly general nature of the models for this species

Discussion

Model predictions

ENM provides a framework for estimating geographic distributions of species; however, ENMs are cast on geographic extents, and as such do not and cannot take into account finer-scale phenomena such as land use and land cover distributions. In ENM, the best models are those that meet set criteria of statistical significance, model complexity, and performance. However, in this study, we found no agreement between AICc and the other two criteria. Even though the AICc metric has been widely adopted in the field of ENM as a criterion (Shcheglovitova and Anderson 2013; Warren et al. 2013; Muscarella et al. 2014), we caution that it should be used with care and along with other criteria as used in

Table 2 Fourteen suitable corridors identified in this study including their respective distances between core areas

Forest complex	Corridor		Distance (km)
Gola-Ziama	Kpo Proposed Protected Area	Gola NP	39
Gola-Ziama	Foya Proposed Protected Area	Kpo Proposed Protected Area	21
Gola-Ziama	Kpo Proposed Protected Area	Wologizi Proposed Protected Area	44
Gola-Ziama	Foya Proposed Protected Area	Gola NP	13
Gola-Ziama	Foya Proposed Protected Area	Wologizi Proposed Protected Area	6
Gola-Ziama	Ziama Forest	Wologizi Proposed Protected Area	14
Sapo-Tai	Senkwen Proposed Protected Area	Gbi Proposed Protected Area	73
Sapo-Tai	Senkwen Proposed Protected Area	Sapo NP	37
Sapo-Tai	Gbi Proposed Protected Area	Sapo NP	28
Sapo-Tai	Gbi Proposed Protected Area	Zwedru Proposed Protected Area	13
Sapo-Tai	Zwedru Proposed Protected Area	Gouin Park	17
Sapo-Tai	Grand Kru Proposed Protected Area	Sapo NP	8
Sapo-Tai	Krahn-Grebo National Park	Sapo NP	60
Sapo-Tai	Krahn-Grebo National Park	Tai National Park	4

this study. In particular, the best models selected for elephants did not meet our criteria, perhaps for two reasons. First, the species as sampled here within Sapo NP only, is a classic example of a "Wallace's Dream species," as described in Saupe et al. (2012). In this situation, a species' distributional area is constrained by dispersal capabilities, and models for such species will not be significantly different from random because all habitats in the species' calibration area are suitable. The second related reason could be attributed to our selection of Sapo NP as a calibration area, which was influenced by the availability of high-quality data. We recognize that this feature was a limitation of this study that should be carefully considered in future studies (Barve et al. 2011).

However, in spite of the statistical uncertainty in the elephant models, their biological explanation is relevant. Areas of suitable habitats predicted by the elephant models are similar to those predicted by chimpanzees, as we expected given the broader distribution of these species in the region. Unlike the related African elephant *Loxodonta africana*, African forest elephants inhabit the dense humid tropical rainforest of west and central Africa and have overlapping ranges with western chimpanzees. In Sapo NP, for example, these species inhabit the same sites, as evident by camera trapping records (Vogt 2012). In addition, we tested our chimpanzee models using independent data from several chimpanzee projects across the region. We found that our predictions strongly correlated with areas currently occupied by chimpanzees, including areas in Sierra Leone and Guinea, which are known important sanctuaries for chimpanzees and elephants in the region. A notable example is the Western Area Peninsula National Park in Sierra Leone, a designated World Heritage Site that hosts 80–90% of Sierra Leone's terrestrial biodiversity, including chimpanzee (UNESCO World Heritage 2018), which was identified as a disjunct, but highly suitable area for chimpanzees.

In contrast, and perhaps of greatest concern in this study, hippo models met all of our criteria for statistical significance, model complexity, and performance, and yet the models seemed to be underfit and overly general. Of the three species, hippos use the most restricted habitats (aquatic forest habitats); as such, the widespread distributional potential of the species across the region compared to elephants and chimpanzees was unexpected. This could be attributed to the spatial bias in our dataset as articulated above and explained by Warren et al. (2013). Thus, we caution that the hippo models should be interpreted with care.

Overall, an important consideration in interpretation of ENM results is the movement capability (mobility) of a species. That is, uninhabited suitable areas predicted in these models can only be occupied if dispersal barriers do not prevent these species from colonizing them (Peterson et al. 2011). Therefore, providing suitable corridors that connect suitable habitats will enhance these dispersal abilities of these species to colonize uninhabited habitats.

Species distributions and forest connectivity

Using ENM to inform conservation planning is a relatively novel approach in Africa, particularly for West Africa (Iloh and Ogundipe 2016). This study predicted areas of suitable habitat for each of the three focal species across the western sector of the Upper Guinea Forest block, highlighting priority areas inside and outside of protected areas. One notable result was the congruence between predicted suitable habitats and the distribution of the remaining forest in the region, as reported in other studies (Allport 1991; Liu et al. 2016). Our models clearly showed that Liberia retains the largest contiguous portions of suitable habitats for these species, followed by Côte d'Ivoire. However, most Liberian forest areas remain unprotected, far short of its neighbors, which have all major forest patches designated as protected areas. Since 2006, the Liberian Government set a goal of protecting 30% of the country's forest in a network of protected areas (NFRL 2006); this goal is yet to be realized, with just ~ 10% of the country's forest presently designated as protected areas.

Our connectivity analysis identified 14 corridors and three potential sites for establishment of new protected areas in both Gola-Ziama and Sapo-Tai forest complexes, several of which coincide and at least partially agree with results of previous analyses (Junker et al. 2015), reinforcing the importance of these areas as putative habitat corridors. The southeastern block of forest (in Liberia) connecting to southwestern Côte d'Ivoire (Sapo-Tai forest complex) should be considered a particularly significant regional priority. This forest block holds > 50% of the contiguous forest suitable for our focal species in the region. Interestingly, the Liberian side of this forest is largely unprotected, and is under increasing threats from oil palm (*Elias guinesis*) plantation expansion, artisanal mining, and logging (Freeman et al. 2018). We emphasize here that the potential to preserve this forest block should focus on these areas with urgency. We acknowledge current regional initiatives aimed at this forest block, one of which led to the recent (2017) designation of the Krahn-Grebo National Park. However, even though we applaud these efforts, they should be expanded to reflect the proportional significance of this area. Additionally, the Gola-Ziama forest complex, in northwestern Liberia (bordering Sierra Leone and Guinea), is notable for its potential conservation urgency, given that it is also largely unprotected and equally threatened. We recognize efforts of the last decade resulting in designation of Gola National Park in Liberia and Gola Rainforest National Park in Sierra Leone; the northern portion of this forest block, extending north to Ziama in Guinea, is characterized by highly heterogeneous natural landscapes (e.g., submontane forest, semi-deciduous forest), and many unique, high-value species for conservation. Additionally, it should be noted here that to optimize biodiversity conservation, conservation efforts should not only be focused on forest protection but should also address other major drivers of biodiversity loss, particularly hunting, a major threat to West African biodiversity to avoid the empty forest syndrome (Wilkie et al. 2011).

We show that the integration of ENM and connectivity analysis studies provides powerful practical tools to optimize conservation planning and identify priority areas objectively for implementation (conservation action), with the goal of optimizing connectivity among distributional areas of species. These tools, when adopted and applied appropriately, will accelerate knowledge of species distribution and conservation efforts in incompletely-known but highly biodiverse regions of the world. We emphasize that connecting suitable habitats for these species will enhance their dispersal abilities and survivability in the region.

Acknowledgements This study was made possible by the contribution of data from Fauna & Flora International, Liberia (FFI) for Sapo NP; the Society for Conservation of Nature in Liberia (SCNL), Conservation Society of Sierra Leone (CSSL), and the Royal Society for the Protection of Birds (RSPB) for Gola forest in Liberia and Sierra Leone; and Wild Chimpanzee Foundation and the Pan African Programme at the Max-Planck Institute for other parts of the region. We are also very grateful to developers of the APES database (http://apesportal.eva.mpg.de/database) for providing access to these datasets. Finally, we are thankful to the participants of KU-EEB's spring semester (2018) scientific writing working group class for critical reviews of previous drafts of this manuscript, Daniel Jiménez-Garcia and Lindsay Campbell for their advice on processing remote sensing data, and Luis Osorio for writing the R script used in the MOP analysis.

References

Abdi H, Williams LJ (2010) Principal component analysis. Wiley Interdiscip Rev Comput Stat 2:433–459

Allport G (1991) The status and conservation of threatened birds in the Upper Guinea forest. Bird Conserv Int 1:53–74

Ball IR, Possingham HP, Watts M (2009) Marxan and relatives: software for spatial conservation prioritisation. In: Spatial conservation prioritisation: quantitative methods and computational tools, pp 185–195

Barve N, Barve V, Jiménez-Valverde A et al (2011) The crucial role of the accessible area in ecological niche modeling and species distribution modeling. Ecol Model 222:1810–1819

Beier P, Spencer W, Baldwin RF, McRAE BH (2011) Toward best practices for developing regional connectivity maps: regional connectivity maps. Conserv Biol 25:879–892

Bodbyl-Roels S, Peterson AT, Xiao X (2011) Comparative analysis of remotely-sensed data products via ecological niche modeling of avian influenza case occurrences in Middle Eastern poultry. Int J Health Geogr 10:1–21

Bottrill MC, Joseph LN, Carwardine J et al (2008) Is conservation triage just smart decision making? Trends Ecol Evol 23:649–654

Bottrill MC, Joseph LN, Carwardine J et al (2009) Finite conservation funds mean triage is unavoidable. Trends Ecol Evol 24:183–184

Brás R, Cerdeira JO, Alagador D, Araújo MB (2013) Linking habitats for multiple species. Environ Model Softw 40:336–339

Brown JL (2014) SDMtoolbox: a python-based GIS toolkit for landscape genetic, biogeographic and species distribution model analyses. Methods Ecol Evol 5:694–700

Carignan V, Villard M-A (2002) Selecting indicator species to monitor ecological integrity: a review. Environ Monit Assess 78:45–61

Cushman SA, Elliot NB, Bauer D et al (2018) Prioritizing core areas, corridors and conflict hotspots for lion conservation in southern Africa. PLoS ONE 13:e0196213

Darwall W, Polidoro B, Smith K, Somda J (2015) Ecosystem profile Guinean Forests of West Africa biodiversity hotspot. Critical Ecosystem Partnership Fund Report

DeMatteo KE, Rinas MA, Zurano JP et al (2017) Using niche-modelling and species-specific cost analyses to determine a multispecies corridor in a fragmented landscape. PLoS ONE 12:e0183648

Dickson BG, Roemer GW, McRae BH, Rundall JM (2013) Models of regional habitat quality and connectivity for pumas (*Puma concolor*) in the southwestern United States. PLoS ONE 8:e81898

Feilhauer H, He KS, Rocchini D (2012) Modeling species distribution using niche-based proxies derived from composite bioclimatic variables and MODIS NDVI. Remote Sens 4:2057–2075

Fourcade Y, Engler JO, Rödder D, Secondi J (2014) Mapping species distributions with MAXENT using a geographically biased sample of presence data: a performance assessment of methods for correcting samplingbias. PLoS ONE 9:e97122

Franklin JF (1993) Preserving biodiversity: species, ecosystems, or landscapes? Ecol Appl 3:202–205

Freeman B, Danjuma DF, Molokwu-Odozi M (2018) Status of globally threatened birds of Sapo National Park. Ostrich-J Afr Ornithol, Liberia. https://doi.org/10.2989/00306525.2018.1502694

Hearn AJ, Cushman SA, Goossens B et al (2018) Evaluating scenarios of landscape change for Sunda clouded leopard connectivity in a human dominated landscape. Biol Conserv 222:232–240

Iloh AC, Ogundipe O (2016) Using ecological niche modelsto plan conservation in a changing environment: a case for the plant *Chasmanthera dependens* Hochst (Menispermaceae) in West Africa. J Ecol Nat Environ 8:1–8

Jennings AP, Veron G (2015) Predicted distributions, niche comparisons, and conservation status of the spotted linsang and banded linsang. Mammal Res 60:107–116

Junker J, Boesch C, Freeman T et al (2015) Integrating wildlife conservation with conflicting economic land-use goals in a West African biodiversity hotspot. Basic Appl Ecol 16:690–702

Khosravi R, Hemami M-R, Cushman SA (2018) Multispecies assessment of core areas and connectivity of desert carnivores in central Iran. Divers Distrib 24:193–207

Lehtomäki J, Moilanen A (2013) Methods and workflow for spatial conservation prioritization using Zonation. Environ Model Softw 47:128–137

Lindenmayer DB, Fischer J, Felton A et al (2007) The complementarity of single-species and ecosystem-oriented research in conservation research. Oikos 116:1220–1226

Liu Z, Wimberly MC, Dwomoh FK (2016) Vegetation dynamics in the Upper Guinean Forest Region of West Africa from 2001 to 2015. Remote Sens 9:1–5

McRae BH, Dickson BG, Keitt TH, Shah VB (2008) Using circuit theory to model connectivity in ecology, evolution, and conservation. Ecology 89:2712–2724

McRae B, Shah V, Edelman A (2016) Circuitscape: modeling landscape connectivity to promote conservation and human health. Nat Conserv

Muscarella R, Galante PJ, Soley-Guardia M et al (2014) ENMeval: an R package for conducting spatially independent evaluations and estimating optimal model complexity for Maxent ecological niche models. Methods Ecol Evol 5:1198–1205

NFRL (2006) National Forestry Reform Law of 2006. http://www.fao.org/forestry/16151-05fd47b845599b5d3a594a9b0240dacff.pdf. Accessed 1 May 2018

Owens HL, Campbell LP, Dornak LL et al (2013) Constraints on interpretation of ecological niche models by limited environmental ranges on calibration areas. Ecol Model 263:10–18

Peterson AT (2014) Mapping disease transmission risk: enriching models using biogeography and ecology. Johns Hopkins University Press, Baltimore

Peterson AT, Papeş M, Soberón J (2008) Rethinking receiver operating characteristic analysis applications in ecological niche modeling. Ecol Model 213:63–72

Peterson AT, Soberón J, Pearson RG et al (2011) Ecological niches and geographic distributions. Princeton University Press, Princeton

Peterson AT, Campbell LP, Moo-Llanes DA et al (2017) Influences of climate change on the potential distribution of *Lutzomyia longipalpis* sensu lato (Psychodidae: Phlebotominae). Int J Parasitol 10–11:667–674

Phillips SJ, Dudík M (2008) Modeling of species distributions with Maxent: new extensions and a comprehensive evaluation. Ecography 31:161–175

Phillips SJ, Dudík M, Schapire RE (2006) A maximum entropy approach to species distribution modeling. In: Proceedings of the twenty-first international conference on Machine learning. ACM, p 83

Pimm SL, Jenkins CN, Abell R et al (2014) The biodiversity of species and their rates of extinction, distribution, and protection. Science 344:1246752

Primack RB (2010) Essentials of conservation biology. Sinauer Associates, Sunderland

Roever CL, van Aarde RJ, Leggett K (2013) Functional connectivity within conservation networks: delineating corridors for African elephants. Biol Conserv 157:128–135

Saupe EE, Barve V, Myers CE et al (2012) Variation in niche and distribution model performance: the need for a priori assessment of key causal factors. Ecol Model 237–238:11–22

Shcheglovitova M, Anderson RP (2013) Estimating optimal complexity for ecological niche models: a jackknife approach for species with small sample sizes. Ecol Model 269:9–17

Squires D (2014) Biodiversity conservation in Asia. Asia Pac Policy Stud 1:144–159

Thomas CD, Cameron A, Green RE et al (2004) Extinction risk from climate change. Nature 427:145–148

Tweh CG, Lormie MM, Kouakou CY et al (2015) Conservation status of chimpanzees Pan troglodytes verus and other large mammals in Liberia: a nationwide survey. Oryx 49:710–718

UNESCO World Heritage (2018) Western Area Peninsula National Park. In: UNESCO World Herit. Cent. https://whc.unesco.org/en/tentativelists/5741/. Accessed 18 Apr 2018

Vogt M (2012) Biomonitoring & research programme, Sapo National Park: updated plan for research opportunities and priorities in and around Sapo National Park. Fauna Flora Int Liberia

Warren DL, Glor RE, Turelli M (2010) ENMTools: a toolbox for comparative studies of environmental niche models. Ecography 33:607–611

Warren DL, Wright AN, Seifert SN et al (2013) Incorporating model complexity and spatial sampling bias into ecological niche models of climate change risks faced by 90 California vertebrate species of concern. Divers Distrib 20:334–343

Wilkie DS, Bennett EL, Peres CA, Cunningham AA (2011) The empty forest revisited. Ann N Y Acad Sci 1223(1):120–128

Wilson KA, Underwood EC, Morrison SA et al (2007) Conserving biodiversity efficiently: what to do, where, and when. PLoS Biol 5:e223

Wold S, Esbensen K, Geladi P (1987) Principal component analysis. Chemom Intell Lab Syst 2:37–52

Zacarias D, Loyola R (2018) Distribution modelling and multi-scale landscape connectivity highlight important areas for the conservation of savannah elephants. Biol Conserv 224:1–8. https://doi.org/10.1016/j.biocon.2018.05.014

Affiliations

Benedictus Freeman[1] · **Patrick R. Roehrdanz**[2] · **A. Townsend Peterson**[1]

[1] Biodiversity Institute and Department of Ecology and Evolutionary Biology, University of Kansas, Lawrence, KS 66045, USA

[2] Conservation International, Betty and Gordon Moore Center for Science, Arlington, VA 22202, USA