Hierarchical Distance Sampling to Estimate Hornbill Densities in Cambodia

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We explore hierarchical distance sampling (HDS) analyses to estimate native wildlife densities in Cambodia. Specifically, we leverage wildlife occurence and distance data collected from line transects to estimate Great hornbill (GH) *Buceros bicornis* densities within Prey Lang Wildlife Sanctuary (PLWS) in central Cambodia. Conservation International-Cambodia (CI) and the Cambodia Ministry of Environment (MoE) collaboratively manage a landscape-wide REDD+ project within the protected area of Prey Lang Wildlife Sanctuary, located in central Cambodia. REDD+ programs require biodiversity monitoring assessments to determine the impact of carbon conservation measures and its impact on deforestation efforts to conserve native flora and fauna. In accordance to this PLWS REDD+ project, CI deployed a baseline assessment of transect line surveysto determine baseline population densities for key biodiversity species inhabiting PLWS. Specifically, our objectives were to explore how HDS methods utilizing environmental covariates such as GH group size, tree canopy height, and human influence, determined GH density estimates within PLWS. Ultimately, we provide the first robust density and population estimates for GH in Cambodia.

Packages

```
library(tidyverse)
library(tidybayes)
library(sf)
library(tmap)
library(rjags)
library(here)
```

Introduction

REDD+

Ongoing global deforestation within and adjacent to tropical forest ecosystems has led to continued decline of wildlife populations and rampant forest habitat degradation, contributing to the loss of critical ecosystem functioning and biodiversity decline affecting critical ecosystem processes such as climate and hydrological regulation. This is especially prominent in Global South countries where a majority of the world's tropical biomes and biodiversity remain.

Reduced Emissions from Deforestation and Forest Degradation (REDD+) is a voluntary global scale climate change mitigation program aiming at creating financial values for carbon stored in forests, and aimed at offerring incentives to reduce greenhouse gas emissions from deforestation and forest degradation [citation].

In many cases, REDD+ provides an avenue for potential forest protection by providing financial-based incentives as conservation projects through reduced forest loss against a defined baseline (Pauly et al., 2022). Through this mechanism, REDD+ proponents have supported the notion that Global North nations can contribute to sustainable development in Global South nations by investing in these carbon markets created through theoretical protection of forests.

In an effort to curtail forest loss and combat deforestation, REDD+ program schemes have been implemented globally in developing tropical regions along with generating carbon credits to be used. Generally, the funds obtained from these voluntary markets are used to better improve deforestation efforts, and promote conservation projects such as improving law enforcement, development alternative incomes for local communities, and research and monitoring of natural resources within protected areas.

> ⚠ Warning
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> Insert sources to make the link between the benefits of managing a REDD+ landscape entails a necessity to monitor biodiversity levels, thus also improving ecosystem functioning for the (tropical forest) region.

Cambodia

Cambodia is known as a global biodiversity hotspot (Myers et al., 2000); however, Cambodia is plagued with deforestation problems due to rampant corruption along with a lack of strong enforcement to safeguard natural resources. High powered companies and individuals are likely to benefit from the selling of land concessions and forest trees from converting land use to large-scale farm plantations and other industrial needs [citation]. Cambodia is also a developing country meeting high demand for a growing population, such as the need to expand infrastructure to support civil society. The main drivers of biodiversity decline are attributed through habitat loss from deforestation along with illegal poaching of wildlife for trade markets.

In collaboration with the Cambodian Ministry of Environment (MoE), Conservation International-Cambodia (CI) has had a long-term partnership with the goal to conserve tropical forest natural resources. Various conservation programs such as protected area management, biodiversity monitoring and community livelihood improvments have been implemented to assess drivers of deforestation and other illegal activities regarding natural resources in PLWS.

To generate carbon credits for sale, CI and MoE initiated the JCM REDD+ program in PLWS to ensure sustainable financing for the program and protection of PLWS. Between 2018 to 2021, the JCM REDD+ Project Phase 1 was implemented in Stung Treng within PLWS, while Phase 2 project proposal was signed by MoE, CI, and Mitsui & Co., Ltd., (Mitsui) in April 2021 to extend the project objectives to include the other three provices of Kampong Thom, Kratie, and Preah Vihear, with a completed end date goal of 2026.

To assess and monitor baseline populations of key taxa, robust and reliable populaton density estimates require robust statistical techniques to seperate observation and ecological processes within surveyed REDD+ landscapes.

Distance Sampling to Estimate Abundance and/or Density

Distance sampling (DS) has been one of the most prominent statistical frameworks used in wildlife science to estimate population abundance and/or densities for vertebrate animals. The benefits of utilizing distance sampling is that data collection methods are relatively logistically simple, as surveys require only counting animals and obtaining the distance the animal occurrence is away from the transect line. Surveys do not have stringent temporal nor spatial requirements, as transect surveys are only conducted once per season and do not require individual animals to be marked or caught.

In traditional conventional DS, population estimates are made by calculating a detection function based on the distribution of distances to individuals observed. All distances and observations are pooled together across the entire study area. With this pooled data, the detection function is based on the distribution of observed distances, and is used to calculate estimated densities of animals. In effect, this estimation is adjusted for non-detection bias. Conventional DS methods do not account for effects of habitat covariates on densities, thus wildlife managers managing on a landscape level scale require further information on habitat-animal relationships.

Hierarchical Distance Sampling (HDS)

However, modern estimates of wildlife populations need to take account imperfect detection and uncertainty when making reliable animal density estimates for the important fact of wildlife conservation management. Hierarchical models through the use of Bayesian statistics provides a robust, flexible framework where we are able to seperate the ecological and detection process through a hierarchical modeling framework through Bayesian statistical methods.

We examine the affect of environmental and human covariates and how this affects localized greater hornbill densities across spatially replicated transects in Prey Lang Wildlife Sanctuary. (Royle et al., 2004) utilized hierarchical distance sampling in order to examine the effect of covariates on abundance.

This analytical framework allows flexibility for rarely collected data, especially in transects that were met with logistical constraints (Sillett et al., 2012).

Great Hornbills

Hornbills are large forest birds classified in the order of Bucerotiformes (Corlett, 2017) consisting of 15 genera, 62 species; with 32 species inhabiting Asia and 25 species in Africa (Poonswad et al., 2013). Prominent characteristics are an oversized, long curved bill with a casque on top. Hornbills are known as the most important single family of seed dispersal agents for large-woody species in the forest canopy (Corlett, 2017).

> ⚠ Warning
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> More information about the status of hornbill species throughout mainland Southeast Asia will be udpated here, with mainly studies from Thailand comprising the majority of the literature for the region.

Greater hornbill (GH) *Buceros bicornis* can be found in Cambodia occurring through their natural habitat of dense tropical evergreen forest.

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> More information about the status of hornbill species in Cambodia will be udpated here.

Previous Hornbill Studies Utilizing Distance Sampling

A number of peer-reviewed studies have incorporated line transect surveys and distance sampling (DS) analyses to estimate hornbill densities from different regions of the world. Sriprasertsil et al. (2024) conducted variable-width line transect surveys and used multi-covariate distance sampling to estimate hornbill densities from June 2021 to June 2022 in two protected areas in Southern Thailand: Hala-Bala Wildlife Sanctuary and Budo Su-Ngai Padi National Park. Pradhan et al. (2024) estimated abundances for four hornbill species: Great Hornbill, Wreathed Hornbill, Rufous-necked Hornbill, Oriental Pied-Hornbill) in the highly-fragmented and highly-modified Buxa Tiger Reserve in northern West Bengal, India. Researchers used line transects and multi-covariate distance sampling to estimate densities recording hornbill species, flock size, time of sighting, activity (perched, foraging, call and flight) and perpendicular distance from the observer to the bird. Predictor variables (elevation, density of fruiting trees, cut logs, total basal area) and hornbill occurrence was explored using a generalized linear model with binomial error structure with all hornbill occurrences pooled together. Pawar et al. (2021) utilized distance sampling methods to estimate abundance of Great Hornbills and Malabar Grey Hornbills in two contrasting habitat types in protected area rainforests versus fragmented habitat consisting of coffee plantations in India. They found that both hornbill species used both habitat types year-round. Their main findings include determining that distance sampling estimates were higher in protected areas for both nesting and non-nesting seasons.

Methods

Study Area: Prey Lang Wildlife Sanctuary (PLWS)

Prey Lang Wildlife Sanctuary (PLWS) is a protected area located in the central plains of Cambodia. As one of the largest areas of contiguous lowland tropical forests left in mainland Southeast Asia, PLWS was established in 2016 and covers four provinces including 1) Kampong Thom, 2) Preah Vihear, 3) Kratie and 4) Stung Treng.

PLWS is notable for its immense biodiversity, providing critical refuge for up to 55 globally threatened vertebrates including gibbons, Asian elephants, and /insert carnivore/, while having up to 538 plant and tree species. PLWS is also critical in that it supports more than 250,000 people inhabiting the forest, including the indigenous Kuy people who reside in and around this protected area. PLWS also serves as an important watershed for the Mekong and the Tonle Sap lake.

While maintaining protected area status, PLWS continues to face enormous natural resource extraction pressure due to weak enforcement of environmental laws and lack of resources. Illegal forest logging, wildlife trade, land encroachment, and unsustainable agricultural practices have led to continued degradation of quality forest habitat.

PLWS is comprised mainly of evergreen and semi-evergreen forest, mixed with some deciduous forests and savanna grasslands.

Line Transects

Transect grids/lines, which could also be noted as "survey sites" were generated in ArcMap 10.8.1 and placed randomly within PLWS outside of farms, degraded areas, human settlement, and other non-forest habitat. Transect grids were composed of four 1-km lines forming a square grid, totaling 4 km in walked transect length (1 km^2).

Before data collection, transect lines were cleared using machetes to create a trail no more than one meter in width to ensure minimum impacts on local vegetaion. Trails were painted blue every 10 to 20 meters, while transect grid corners were painted by applying paint on trees. Field training and practice trials were conducted before implementation of data collection.

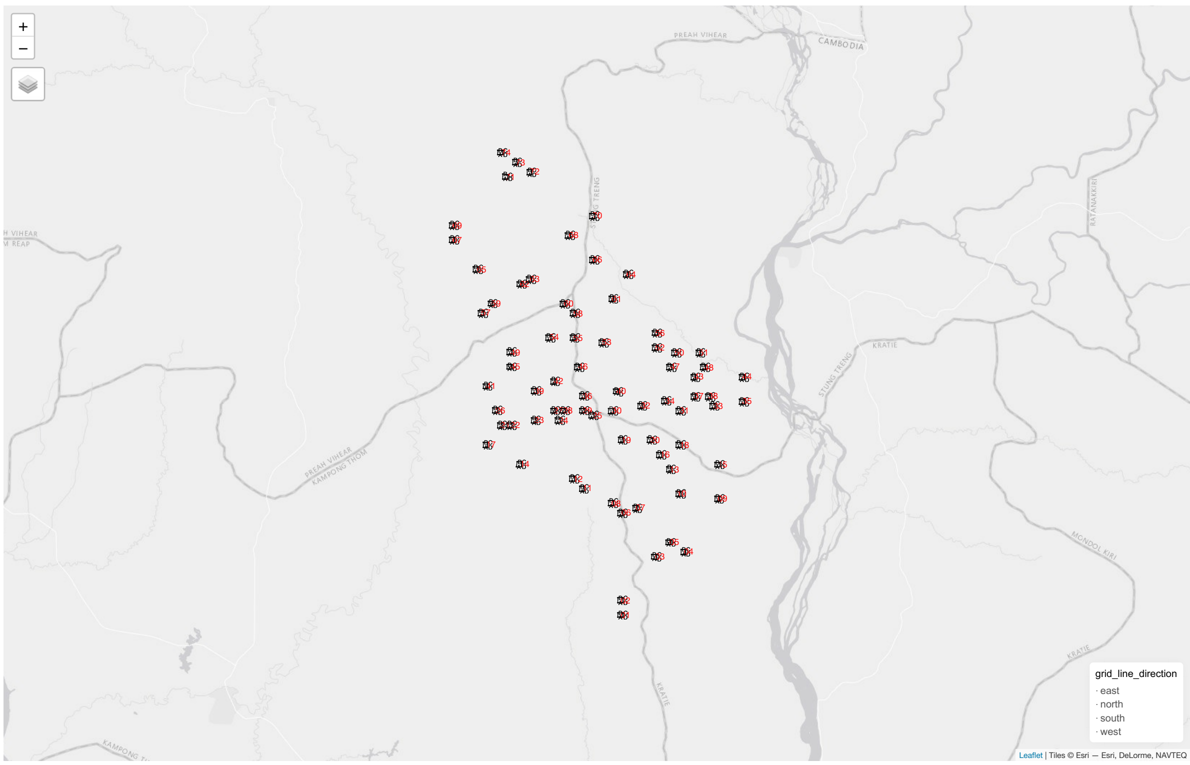
Fifteen key biodiversity species were selected and targeted for biodiversity monitoring at PLWS.

Data collection occurred during January to May 2023 during Cambodia's dry season. Transect grids were mainly completed in evergreen and semi-evergreen forest, with a few transect lines conducted in dry deciduous forest habitat. Each transect grid was surveyed twice per day, with a morning and afternoon session.

Here is a map of transects:

```r
# load data
plws_transect <- read_csv(here("data","2023-plws-line-transect-data-nn.csv"))
#plws_transect |> glimpse()
# extract transect grid data
grid <- plws_transect |>
  select(grid_id, grid_line, grid_line_direction,
         x_mid, y_mid, x_transect, y_transect, province) |>
  drop_na() |>
  st_as_sf(coords=c("x_transect","y_transect"), crs=32648)
# extract midpoint grid data
grid_midpt <- grid |>
  group_by(grid_id) |>
  distinct(x_mid, y_mid) |>
  ungroup() |>
  st_as_sf(coords=c("x_mid","y_mid"), crs=32648)
# create grid polygons
grid_polygon <- grid |>
  group_by(grid_id) |>
  summarise(do_union=FALSE) |>
  st_cast("LINESTRING")
# map
tmap_mode("view")
```

```r
tm_shape(grid) +
  tm_dots(col="grid_line_direction", size = 0.075) +
  tm_text("grid_line", size=0.7) +
  tm_shape(grid_midpt) +
  tm_text("grid_id", col="red", size=1) +
  tm_shape(grid_polygon) +
  tm_lines()
```



Google Earth Engine

We leverage open source remote sensing datasets collected from Google Earth Engine to use as landscape covariates.

We utilize a digital elevation model dataset to obtain elevation at _____ resolution.

We utilize LIDAR derived datasets to gain estimates on global tree canopy heights. Hornbills are often

Statistical Analyses

HDS Models

Data Augmentation & Covariates

Three Part Multinomial Conditional Model & Cobvariates

Results

Discussion

Conclusions

Management Implications

References

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