# Lemurs in Madagascar: Data Cleaning, Exploration and Webpage

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## Introduction

This report examines lemurs, the reasons they are classified as endangered species, and the unique ecosystem they inhabit on the island of Madagascar. Madagascar is globally recognized for its lemurs—distinctive primates with physical features resembling a blend of cat, squirrel, and dog. Found exclusively on this island, lemurs exhibit extraordinary behaviors, such as the haunting, whale-like songs of the indri and the graceful, dance-like leaps of the sifaka.

Over the past sixty years, Madagascar has lost nearly 44% of its forest cover, primarily due to slash-and-burn agriculture (known locally as *tavy*) and the widespread production of charcoal. This rapid deforestation has led to extensive habitat loss and fragmentation. Today, nearly half of the remaining forest lies within 100 meters (approximately 300 feet) of an exposed edge, leaving wildlife vulnerable to disturbance and diminishing overall ecosystem stability. Additional pressures—such as illegal hunting and the capture of animals for the pet trade—further accelerate biodiversity decline.

These threats have placed Madagascar's wildlife, particularly its lemurs, under severe conservation stress. According to the International Union for Conservation of Nature (IUCN), an estimated 95% of lemur species are now threatened with extinction, making them the most endangered group of mammals in the world. The island's biodiversity crisis has worsened significantly in recent years.

The purpose of this report and its accompanying webpage is to increase public awareness about the critical endangerment of lemurs and to encourage meaningful action to support their protection and the preservation of Madagascar's fragile ecosystems.

## Step 1: Read CSV file

The dataset was retrieved from the website Pandoradata.erth. The CSV fiile name is supplementary-table-s1-3.csv.

```
library(shiny)
library(dplyr)
library(stringr)
library(readr)
library(sf)
library(rnaturalearth)
library(rnaturalearthdata)
library(leaflet)
library(tibble)
library(RColorBrewer)
library(viridisLite)
library(ggplot2)

# 1. Read lemur data
lem_raw <- read.csv("supplementary-table-s1-3.csv", skip = 1)

# Filter variables so it narrows down to only Lemur (not other animals)
lemurs <- lem_raw %>%
  filter(
    Kingdom == "Animalia",
    Class == "Mammalia",
    Order == "Primates"
  ) %>%
  filter(!is.na(Latitude), !is.na(Longitude))
```

#### Step 2: NAs imputation

Because the *Body Mass* variable contained a large number of missing values, imputation was performed separately for each species. Since body mass varies widely across species—and each species has its own biologically appropriate range—using a single overall imputation method would be inappropriate and potentially misleading. Instead, species-specific imputation ensures that the filled values reflect realistic physiological ranges.

For several species in the dataset, all recorded body mass values were missing. In these cases, verified body mass ranges were obtained from reputable external sources, and the missing values were imputed by randomly drawing numbers within the documented range for that species. This approach preserves biological plausibility while allowing these species to be retained in the analysis.

```
# Because variable "Body Mass" has a lot of NAs, I do imputation by species.
# Each species has their own range of body mass so we cannot do mass imputation but imputatio
# There are some species that their entire body mass values were NAs; therefore, I googled th
```

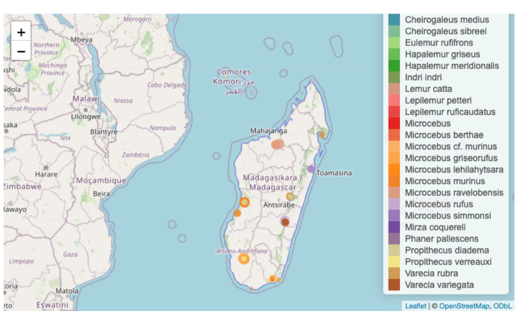
```r
# Body-mass ranges for species with all NAs

mass_ranges <- tribble(
  ~Genus_Species,              ~min_mass, ~max_mass,
  "Avahi laniger",             0.6,       1.3,
  "Cheirogaleus grovesi",      0.4,       0.41,
  "Cheirogaleus medius",       0.12,      0.27,
  "Eulemur rufifrons",         2.2,       2.3,
  "Hapalemur griseus",         0.7,       1.0,
  "Hapalemur meridionalis",    0.965,     1.179,
  "Indri indri",               6.0,       9.5,
  "Lemur catta",               2.2,       3.5,
  "Lepilemur petteri",         0.5,       0.9,
  "Lepilemur ruficaudatus",    0.6,       0.9,
  "Microcebus",                0.03,      0.12,
  "Microcebus cf. murinus",    0.058,     0.067,
  "Mirza coquereli",           0.29,      0.32,
  "Phaner pallescens",         0.3,       0.5,
  "Propithecus diadema",       5.0,       7.0,
  "Propithecus verreauxi",     2.5,       4.0,
  "Varecia rubra",             3.3,       4.1
)

set.seed(123)

# Impute & clean
lemurs_imputed <- lemurs %>%
  mutate(Body_Mass = as.numeric(Body_Mass)) %>%
  group_by(Genus_Species) %>%
  mutate(
    Body_Mass = if_else(
      is.na(Body_Mass),
      median(Body_Mass, na.rm = TRUE),
      Body_Mass
    )
  ) %>%
  ungroup() %>%
  left_join(mass_ranges, by = "Genus_Species") %>%
  mutate(
    Body_Mass = if_else(
      is.na(Body_Mass) & !is.na(min_mass),
      runif(n(), min_mass, max_mass),
```

```
      Body_Mass
    )
  ) %>%
  select(-min_mass, -max_mass)
```

### Step 3: Geospatial map

```
# Fix encoding for character columns
lemurs_imputed <- lemurs_imputed %>%
  mutate(across(where(is.character), ~ iconv(.x, from = "", to = "UTF-8")))

# Aggregate for map
lemurs_counts <- lemurs_imputed %>%
  group_by(
    Genus_Species,
    Site_Name,
    Locality,
    Latitude,
    Longitude
  ) %>%
  summarise(
    n_individuals = n(),
    Elevation     = first(Elevation),
    .groups = "drop"
  )

# sf object
lemurs_counts_sf <- st_as_sf(
  lemurs_counts,
  coords = c("Longitude", "Latitude"),
  crs = 4326
)

# Madagascar polygon
madagascar <- ne_countries(
  scale = "medium",
  country = "Madagascar",
  returnclass = "sf"
)

# Color palette by species
```

```r
species_levels <- sort(unique(lemurs_counts_sf$Genus_Species))
n_species <- length(species_levels)
pal_vec <- colorRampPalette(brewer.pal(12, "Paired"))(n_species)

pal <- colorFactor(
  palette = pal_vec,
  domain  = species_levels
)

if (knitr::is_latex_output()) {
  # PDF: leaflet can't render, so show a static image instead
  knitr::include_graphics("lemur_map_static.png")
} else {
  # HTML: interactive leaflet
  leaflet(lemurs_counts_sf) |>
    addTiles() |>
    addPolygons(data = madagascar, fill = FALSE, weight = 1) |>
    addCircleMarkers(
      radius = ~pmax(3, log10(n_individuals + 1) * 4),
      stroke = FALSE,
      fillOpacity = 0.8,
      color = ~pal(Genus_Species),
      popup = ~paste0(
        "<b>", Genus_Species, "</b><br>",
        "Site: ", Site_Name, "<br>",
        "Locality: ", Locality, "<br>",
        "Elevation: ", Elevation, " m<br>",
        "Individuals: ", n_individuals
      )
    ) |>
    addLegend("bottomright", pal = pal, values = ~Genus_Species,
              title = "Lemur species", opacity = 1)
}
```



**Step 4: Distribution of body mass of lemurs by species**

This visualization shows body mass distributions for each lemur species in the dataset. We can see that species vary widely in their typical body mass.

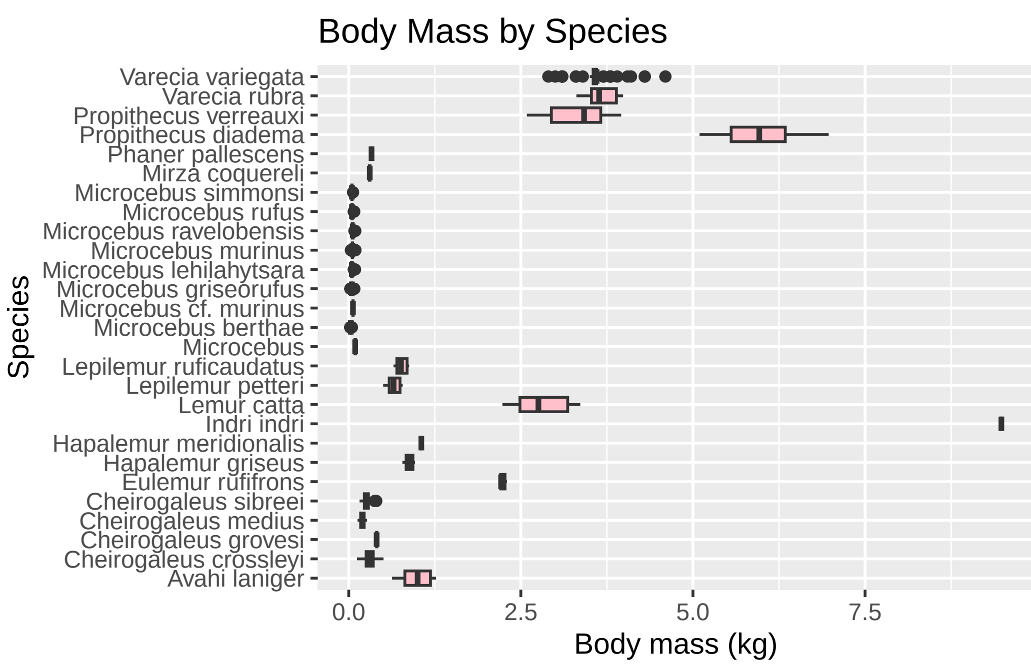
Some species (e.g., *Varecia*, *Propithecus*) have higher body mass, often above 3–4 kg. Many *Microcebus* species appear near 0.05–0.1 kg, reflecting their extremely small size.

Larger-bodied species are mainly in genera like Varecia, Propithecus, Indri.

Small-bodied species (mouse lemurs) in genus Microcebus cluster at extremely low weights.

Variability differs: Some species (e.g., *Lemur catta*) show wide ranges, meaning individuals differ substantially in mass. Others show tight clusters, suggesting more consistent body size.

```
ggplot(lemurs_imputed, aes(x = Genus_Species, y = Body_Mass)) +
  geom_boxplot(fill = "pink") +
  coord_flip() +
  labs(
    title = "Body Mass by Species",
    x = "Species",
    y = "Body mass (kg)"
  )
```



### Step 5: Build webpage - UI + Server

This code builds an interactive Shiny web app that educates users about lemurs and their conservation in Madagascar. The `ui` defines a styled layout with global CSS to enlarge and bold tab titles, color main headings dark red and subheadings dark blue, and then creates a banner at the top with a full-width lemur image and an overlaid title, "Endangered Species – Lemurs in Madagascar." Below the banner, content is organized into four tabs: **Introduction**, which embeds a YouTube video and presents narrative text on lemur biology, evolution, behavior, threats, and conservation; **Endangered Species**, which combines explanatory text with another video to describe forest loss, impacts on ruffed lemurs, and current conservation actions; **Characteristics**, which provides two interactive tools—a "dictionary" lookup table that shows genus and family for a selected common name, and a body-mass histogram that visualizes the distribution of body mass for a chosen species; and **Map of Distribution**, which displays an interactive leaflet map where colored circle markers show species locations, with bubble size indicating the number of individuals and popups reporting site details. The `server` function powers the app's interactivity: it renders the leaflet map with Madagascar's polygon and species-specific markers, generates the dictionary table based on the selected common name, and draws the body-mass histogram for the selected species, updating outputs dynamically whenever the user changes their selections.

```
## ---------- UI ----------
if (!knitr::is_latex_output()) {
ui <- fluidPage(
  # Global styles
  tags$head(
    tags$style(HTML("
      /* Make tab titles bigger and bold */
      .nav-tabs > li > a {
        font-size: 18px;
        font-weight: bold;
      }

      /* Main headings (e.g., 'Lemurs of Madagascar') */
      h2 {
        color: #8B0000;        /* dark red */
      }

      /* Subheadings (e.g., 'Evolutionary Background') */
      h3 {
        color: #003366;        /* dark blue */
        text-align: center;    /* centered */
      }
    "))
```

```r
),
# Banner with image + title on top of it
tags$div(
  style = "position: relative; margin-bottom: 20px;",

  # banner image
  tags$img(
    src = "lemur_banner.jpg",  # file inside www/
    style = "width: 100%; max-height: 300px; object-fit: cover;"
  ),

  # title overlaid on the image
  tags$h1(
    "Endangered Species - Lemurs in Madagascar",
    style = paste(
      "position: absolute;",
      "bottom: 20px;",
      "left: 30px;",
      "color: white;",
      "font-size: 42px;",
      "font-weight: bold;",
      "text-shadow: 0 0 8px rgba(0,0,0,0.8);",
      "margin: 0;"
    )
  )
),

# ---- Tabs ----
tabsetPanel(
  tabPanel(
    "Introduction",
    br(),

    # --- YouTube video ---
    tags$div(
      style = "text-align: center;",
      tags$iframe(
        width = "800",
        height = "450",
        src = "https://www.youtube.com/embed/6eaTBoqpNEg",
        frameborder = "0",
        allow = "accelerometer; autoplay; clipboard-write; encrypted-media; gyroscope; pic
```

```
      allowfullscreen = TRUE
    )
  ),

  br(), br(),

  # --- Introduction Text ---
  tags$h2("Lemurs of Madagascar"),
  tags$p("Madagascar is renowned for its lemurs-unique primates that look like a blend o
          Found nowhere else on Earth, these animals display remarkable behaviors, from
          indri to the elegant, dance-like leaps of the sifaka. The sections below intro
          behavior, and conservation."),

  tags$h3("Evolutionary Background"),
  tags$p("Unlike other parts of the world, Madagascar lacks the dominant primate group k
          which includes monkeys, apes, and humans. Instead, this ecological space is oc
          of the more ancient Strepsirhini lineage, which also includes lorises, bush ba
          primates were generally small, nocturnal, insect-eating animals with large eye
          long geographic isolation allowed lemurs to survive and evolve relatively undi

  tags$p("About 160 million years ago, Madagascar was still attached to Africa as part o
          Gondwanaland. When the landmass split, Madagascar drifted eastward and became
          primates arose in Africa around 60 million years ago and eventually reached Ma
          emerged roughly 17-23 million years ago, the island was already cut off, preve
          Because monkeys were more adaptable and social, they outcompeted lemur relativ
          else-except on Madagascar."),

  tags$p("Freed from such competition, lemurs diversified extensively, adapting to a wid
          large predators. They eventually developed many traits similar to monkeys, inc
          activity, and plant-based diets."),

  tags$p("Humans arrived much later, about 2,000 years ago, bringing dramatic ecological
          the extinction of at least 15 lemur species, including giants as large as mode
          living lemur-the indri-is tiny in comparison. Nearly all species now face exti
          deforestation and hunting."),

  tags$h3("Social Behavior"),
  tags$p("Lemur societies vary greatly across species. Ring-tailed lemurs (Lemur catta)
          of up to 30 members, where females have priority access to resources. In contr
          (Daubentonia madagascariensis) are mostly solitary and meet only to reproduce.
          more complex social groups, while nocturnal species tend to live alone or in s
          critical role in strengthening social bonds and maintaining hygiene."),
```

```
  tags$h3("Diet and Feeding Strategies"),
  tags$p("Lemur diets shift according to species and seasonal food availability. Many rel
          are flexible omnivores that eat leaves, flowers, seeds, nectar, and insects. Ba
          specialize in eating bamboo that contains cyanide levels lethal to most animals
          elongated middle finger, extracts insect larvae from wood, filling a niche simi

  tags$h3("Predators and Threats"),
  tags$p("Natural predators include the fossa (Cryptoprocta ferox), a tree-climbing carni
          of prey like the Madagascar harrier-hawk. However, the most significant threats
          habitat loss, fragmentation, and hunting have caused severe population declines
          are listed as endangered or critically endangered."),

  tags$h3("Conservation Efforts"),
  tags$p("Because lemurs are found only in Madagascar and play key ecological roles, they
          initiatives. Protected areas such as Ranomafana, Andasibe-Mantadia, and Masoala
          habitat. Conservation groups are also working to restore forests, reduce poachi
          practices, and expand ecotourism. Zoos worldwide maintain breeding programs for
          survival still depends on protecting Madagascar's forests."),

  tags$h3("Why Madagascar's Lemurs Matter Globally"),
  tags$p("Despite being just one of many countries with native primates, Madagascar conta
          of primate diversity. As noted by primatologist Russell Mittermeier, the island
          (14 of 65) and 36% of primate families (5 of 14)-the highest concentration worl

  tags$p("Because of this, Madagascar is recognized as a distinct fourth biogeographic re
          from the usual three: the Americas, Asia, and mainland Africa. Lemurs represent
          endured environmental change and human pressure for millions of years."),

  tags$p("Protecting lemurs is essential not only for preserving Madagascar's natural her
          scientific knowledge about primate behavior, evolution, and ecology. Lemurs pla
          pollination, and forest renewal, making their conservation a global priority.")
),

tabPanel(
  "Endangered Species",
  br(),

  tags$h2("Threats to Madagascar's Lemurs"),

  tags$p("Madagascar, located off the southeastern coast of Africa, contains extraordinar
      with an estimated 12,000 plant species and 700 vertebrate species, of which 80-90%
      After being geographically isolated for approximately 88 million years, and spannin
```

```
      northeastern United States, the island has become one of the most significant biodi
      While species diversity is high across the island, the biodiversity of its tropical

    tags$p("Despite this ecological importance, Madagascar’s forests-much like tropical fo
      rapid degradation. Fragmentation, unsustainable harvesting of timber and forest pro
      species, pollution, and climate change have all contributed to declines in native s
      is often emphasized because of its widespread impacts, recent research indicates th
      primary factor driving current species losses. Instead, human-induced habitat destr

    tags$h3("Forest Loss and Its Consequences"),

    tags$p("Nearly 44% of Madagascar’s forests have disappeared in the past six decades, la
      agriculture (locally known as tavy) and charcoal production. The pace and extent of
      have been severe. Almost half of all remaining forest now lies within 100 meters (a
      non-forested edge, exposing wildlife to ongoing disturbance and reducing ecosystem
      the capture of wildlife for the pet trade further exacerbate biodiversity decline.'

    tags$p("As a result, Madagascar’s fauna faces extreme conservation pressure. According
      Conservation of Nature (IUCN), 95% of lemur species-including some of the most icon
      threatened with extinction. Madagascar’s biodiversity crisis has intensified over t

    # ---- Video BEFORE the Impact on Ruffed Lemurs section ----
    tags$div(
      style = "text-align: center; margin-top: 25px; margin-bottom: 25px;",
      tags$iframe(
        width = "800",
        height = "450",
        src = "https://www.youtube.com/embed/TxUPMzI14WY?start=19",
        frameborder = "0",
        allow = "accelerometer; autoplay; clipboard-write; encrypted-media; gyroscope; pict
        allowfullscreen = TRUE
      )
    ),

    tags$h3("Impact on Ruffed Lemurs"),

    tags$p("Two recent scientific studies have examined how human activities influence ruff
      endangered primates that play a key ecological role as major seed dispersers and in
      Modeling that incorporated a range of climate and deforestation scenarios suggests
      two ruffed lemur species could decline by up to 93% over the next century. Under un
      all remaining eastern rainforest habitat could disappear, effectively eliminating i
      analyses demonstrate that habitat loss is likely to have more immediate and severe
```

```
        climate change."),

    tags$p("However, projections also indicate that if protected areas maintain their curre
        suitable habitat could be reduced to approximately 62%, highlighting the importance
        the integrity of existing reserves."),

    tags$p("A separate genetic study published in late 2019 examined how landscape features
        crucial process that maintains genetic diversity and supports population resilience
        natural barriers and human-caused constraints on movement, including rivers, elevat
        quality, and human population density. Human activity emerged as the strongest pred
        exchange, with deforestation near human settlements forming significant barriers to

    tags$p("Collectively, the evidence demonstrates that deforestation represents an urgent
        survival, surpassing the short-term impacts of climate change. This threat extends
        forest-dependent plants and animals face similar risks. Globally, over one-third (a
        species are extremely rare and disproportionately vulnerable to human land use. Reg
        concentration of rare species often coincide with areas experiencing the greatest h

    tags$h3("Opportunities for Conservation Action"),

    tags$p("Madagascar's natural heritage stands at a critical juncture. Strengthening prot
        reforestation initiatives, and improving forest management remain essential strateg
        loss while broader efforts address global climate change. Several nonprofit organiz
        these efforts. For example, the Madagascar Biodiversity Partnership, in collaborati
        Foundation's Plant Madagascar project, has planted nearly three million trees in th
        as a priority zone for ruffed lemur conservation. The Centre ValBio, based near Ran
        conducting extensive reforestation work to support local ecosystems."),

    tags$p("At the policy level, Madagascar's president, Andry Rajoelina, announced an init
        (99,000 acres) annually for five consecutive years, a scale equivalent to approxima
        While the pledge is promising, the plan currently lacks detailed implementation str

    tags$p("Spatial projections from recent studies identify areas where habitat is likely
        facing high risk of near-complete habitat loss or genetic isolation for ruffed lemu
        strongly correlates with overall biodiversity, protecting lemur habitats will also
        communities. These research findings provide a roadmap for prioritizing conservatio
        Madagascar's exceptionally rich but increasingly threatened biodiversity.")
  ),

  tabPanel(
    "Characteristics",
    br(),
```

```
# ---- Section 1: Dictionary ----
tags$h2("Dictionary"),
tags$p(
  "Use this table to look up the genus and family for any lemur common name.",
  style = "font-size: 18px; margin-top: 5px; margin-bottom: 10px;"
),

tags$label(
  "Choose a common name:",
  style = "font-size: 14px; font-weight: bold;"
),
br(),

selectInput(
  inputId = "dict_common",
  label   = NULL,
  choices = sort(unique(lemurs_imputed$Common_Name)),
  selected = sort(unique(lemurs_imputed$Common_Name))[1]
),

tableOutput("dict_table"),

hr(),

# ---- Section 2: Distribution of Body Mass by Species ----
tags$h2("Distribution of Body Mass by Species"),
tags$p(
  "To explore the distribution of body mass for a particular species, please choose a s
  style = "font-size: 18px; margin-top: 5px; margin-bottom: 10px;"
),

tags$label(
  "Choose a species:",
  style = "font-size: 14px; font-weight: bold;"
),
br(),

selectInput(
  inputId = "bm_species",
  label   = NULL,
  choices = sort(unique(lemurs_imputed$Genus_Species)),
  selected = sort(unique(lemurs_imputed$Genus_Species))[1]
```

```
      ),

      plotOutput("bm_hist", height = "400px")
    ),

    tabPanel(
      "Map of Distribution",
      br(),

      tags$h2("Map of Lemur Distribution"),
      tags$p(
        "This map illustrates the geographic distribution of lemur species across Madagascar
     Each bubble represents a specific observation site, and the size of the bubble reflects
     the number of individuals recorded at that location. By exploring this map, you can
     identify where each species resides, compare population sizes across regions, and view
     additional ecological information such as locality names and elevation. This visualizat
     highlights Madagascar's remarkable biodiversity and the unique habitats that support
     different lemur species.",
        style = "font-size: 18px; margin-bottom: 15px;"
      ),

      leafletOutput("lemur_map", height = "650px")
    )
  )
)

## ---------- SERVER ----------

server <- function(input, output, session) {

  output$lemur_map <- renderLeaflet({
    leaflet() %>%
      addProviderTiles("Esri.WorldImagery") %>%
      addProviderTiles("CartoDB.PositronOnlyLabels") %>%
      addPolygons(
        data   = madagascar,
        weight = 1,
        color  = "grey40",
        fillColor = "transparent"
      ) %>%
      addCircleMarkers(
        data = lemurs_counts_sf,
```

```
        radius = ~2 + n_individuals,
        stroke = FALSE,
        fillOpacity = 0.8,
        color = ~pal(Genus_Species),
        popup = ~paste0(
          "<b>Species:</b> ", Genus_Species, "<br>",
          "<b>Individuals at this site:</b> ", n_individuals, "<br>",
          "<b>Site:</b> ", Site_Name, "<br>",
          "<b>Locality:</b> ", Locality, "<br>",
          "<b>Elevation:</b> ", Elevation
        ),
        label = ~paste0(Genus_Species, " (n = ", n_individuals, ")")
      ) %>%
      addLegend(
        "bottomright",
        pal = pal,
        values = lemurs_counts_sf$Genus_Species,
        title = "Species",
        opacity = 1
      )
  })

# ---- Dictionary table ----
  output$dict_table <- renderTable({
    req(input$dict_common)

    lemurs_imputed %>%
      filter(Common_Name == input$dict_common) %>%
      select(Common_Name, Genus_Species, Family) %>%
      distinct() %>%
      arrange(Genus_Species)
  })

  # ---- Body-mass histogram ----
  output$bm_hist <- renderPlot({
    req(input$bm_species)

    df <- lemurs_imputed %>%
      filter(Genus_Species == input$bm_species, !is.na(Body_Mass))

    hist(
      df$Body_Mass,
```

```
      main = paste("Body Mass Distribution for", input$bm_species),
      xlab = "Body mass (kg)",
      col  = "lightblue",
      border = "white"
    )
  })

}
}
```

### Step 6: Run app.R

The command `shinyApp(ui = ui, server = server)` launches the Shiny application by combining the user-interface layout (`ui`) with the server logic (`server`), allowing all interactive features, visualizations, and outputs defined in the code to run as a fully functioning web app.

```
## ---------- RUN APP ----------

if (!knitr::is_latex_output()) {
  shinyApp(ui = ui, server = server)
}
```

### Step 7: Conclusion

In conclusion, effective protection of Madagascar's lemurs depends on conserving their forest habitats and strengthening the capacity of local communities to safeguard both wildlife and natural resources. A key strategy involves working collaboratively with communities living near critical lemur areas, such as the Amoron'i Onilahy Protected Area, by training local forest patrols (polisin'ala) to monitor lemur populations, document habitat conditions, detect illegal activities, and help enforce protections. These community-based patrols, equipped with modern tools like smartphone reporting systems, have contributed to reduced deforestation and increasing lemur numbers in targeted zones. Education and outreach are also essential. Together, these approaches demonstrate that protecting lemurs requires not only habitat conservation, but also community engagement, environmental education, and economic support that align human well-being with long-term biodiversity protection.

### Step 8: Click this icon to visit to the webpage

**Step 9: Reference**


https://pandoradata.earth/dataset/isomad-modern-biological-material

https://www.wildmadagascar.org/wildlife/lemurs.php

https://leakeyfoundation.org/lemurs-are-the-worlds-most-endangered-mammals-but-planting-trees-can-help-save-them/