

ODD Model: Ecological vs. Moving (Initial model).

Purpose and patterns:

1.1 Purpose:

The purpose of this model is to analyze different configurations and scenarios of ecological corridors to simulate the movement of three avoider bird species at a local scale:

***Chondrohierax uncinatus* (Accipitridae)**, a large carnivorous bird; ***Ampelion rubrocristatus* (Cotingidae)**, a species that seeks areas with substantial land cover for refuge and rest; and ***Coeligena bonapartei* (Trochilidae)**, a large hummingbird that prefers areas with a rich and diverse food supply. The model focusses on juvenile bird individuals seeking refuge and food, considering the mobility parameters of each species and the existing land cover types within the study area.

Specifically, the model aims to:

- Simulate the movement of 45 avoider's birds which are considered umbrella species sensitive to urban changes (which were chosen based on their specific biological and ecological requirements and parameters relevant to urban conservation efforts), 15 avoiders' birds per species to cross a two-dimensional world predominant urban.
- To be able to select which corridor scenario would be the most beneficial, to help the mobility of other species affected by urban fragmentation.
- Contributes to urban ecology research and supports decision-making processes by relevant stakeholders.

1.2 Patterns:

The following patterns come from documented ecological observations for the three evasive species included in the model (***Chondrohierax uncinatus*, *Ampelion rubrocristatus*, and *Coeligena bonapartei***). These patterns represent real behaviors related to habitat use, mobility, feeding, and survival, and serve as a reference to assessing whether the model accurately reproduces the spatial dynamics of these birds in a fragmented urban landscape.

Comentado [PM1]: estoy confundida en esto

Pattern 1 – Evasive birds avoid the urban matrix (Urban).

Description:

The selected avoiders exhibit low tolerance to densely urbanized areas, actively avoiding transit or residence in patches dominated by infrastructure.

Verifiable criterion in the model:

Agents must show low probability of occupying urban patches. And avoid them

Pattern 2 – Birds depend on continuous vegetation patches for movement.

Description:

Birds species tend to use corridors with continuous vegetation based in their cover requirements or connected patches (urban forest, shrubs, herbaceous areas), facilitating safe mobility and access to food.

Verifiable criterion in the model:

Agents must show preferred routes through vegetation patches compatible with their requirements.

Pattern 3 – Each species shows specific preferences for certain covers.

Description according to the literature:

Chondrohierax uncinatus → prefers dense forests and urban forests.

Ampelion rubrocristatus → uses shrubs, and urban forest.

Coeligena bonapartei → uses shrubs and urban forest.

Verifiable criterion in the model:

When feeding, birds must gain energy only in suitable covers and lose energy in unsuitable ones same as when the birds move, they lose energy.

Pattern 4 – Mobility is conditioned by energy loss associated with displacement.

Description:

Birds lose energy when moving, and their survival depends on finding covers of suitable patches before energy levels reach critical thresholds.

Verifiable criterion in the model:

Agents must die when their energy is equal or minor to “bird-1: 27.37”; “bird-2: 9.11” and “Bird-3: 1.60”).

Pattern 5 – Juvenile birds show limited daily movements within their local range.

Description:

Diurnal species have restricted movement ranges during a single day, prioritizing remaining in safe, resource-rich areas.

Verifiable criterion in the model:

Within 12 ticks (12 hours), trajectories should be concentrated in appropriate feeding areas and should not cover excessive or unrealistic distances, "Each bird will walk: fd 8", all the birds must walk 8 steps in the model.

Pattern 6 – Ecological corridors facilitate access to key landscape areas (Botanical Garden, Virgilio Barco, Simón Bolívar).

Description:

These areas act as the target of those birds attracting urban wildlife.

Verifiable criterion in the model:

Under suitable connectivity settings, all the birds must be able to reach these target zones from Chapinero without dying in route.

2. Entities, State Variables and scales:

2.1 Entities:

The model includes two types of entities: **Agents (Birds)** and **Patches (Landscape)**.

Agents (Birds):

Those species are classified as “avoiders”; in other words, they require habitats with minimal urbanization or reduced disturbance, making them suitable indicators for assessing habitat, connectivity in urban areas. These birds have requirements that make them targets for studying movement and survival. Choosing those species allows the model to focus on the most affected species by urban fragmentation, as well as which corridor scenario would be the most beneficial.

a) ***Chondrohierax uncinatus (Accipitridae) - Bird 1:***

It is a carnivore, associated with secondary vegetation and grasslands (VsHz). It mainly inhabits the lower part of the forest canopy and the dense understory of tropical forests, forest edges, and clearings with some degree of disturbance (Pineda-Guerrero, 2014). Likewise, it is found in forests or in mosaics of forest patches and open areas (Hilty and Brown, 1986). Its trophic guild is carnivorous, feeding on insects, crustaceans, amphibians, and reptiles (Ruelas-Inzunza et al., 2010).

b) ***Ampelion rubrocristatus (Cotingidae) - Bird 2.***

It is a bird that seeks areas with good cover for shelter and resting, associated with forested areas, small patches of shrubs and trees in agricultural zones, and tree canopies, primary forests, scrublands, and open areas. It is present on the hills throughout the Bogotá savanna where vegetation is active and conserved, and it has also been recorded in the Botanical Garden, the Arboretum of the National University, and the eastern hills of Bogotá. Its trophic guild is frugivorous, meaning it feeds on fruits from eight plant families, preferably ***Schefflera bogotensis (Araliaceae)*** and ***Hieronyma huilensis (Euphorbiaceae)***.

c) ***Coligena bonapartei (Trochilidae) - Bird 3.***

It is a large hummingbird that seeks vegetation covered with a good supply and variety of food, associated with open areas with scattered shrubs, trees, or thickets. Its trophic guild is nectarivorous.

Patches (Landscapes):

It is highly important to mention that all the turtles in the model must avoid the "urban patch" represented by the color gray. Because those Birds are permeable to certain covers and impermeable to others.

There are five patch types classifying by colors:

(1.2.1) Urban (Grey): Presence of buildings and urban structure, whether continuous or discontinuous, as well as commercial areas.

(1.2.2) Urban Forest (Lime green): This refers to scattered trees, rows of trees, and patches of forest between localities.

(1.2.3) Grassland (yellow): Secondary vegetation, grasslands, and areas with more than 50% grass presence.

(1.2.4) Shrub (orange): Scrubland or small patches of shrubs, plants less than five meters tall, whose branches emerge from the base.

(1.2.5) Dense Forest (Turquoise): Forest edges are present in the town of Chapinero area, or well-wooded areas whose canopy is visible continuously.

2.2 States Variables:

There are two variables:

I. Species type:

- **Chondrohierax uncinatus (Accipitridae) - Bird 1**
- **Ampelion rubrocristatus (Cotingidae) - Bird 2**
- **Coeligena bonapartei (Trochilidae) - Bird 3**

II. Each agent belongs to one of these three species, which determines:

- Its compatible cover
- Its energy expenditure (EMB)
- Its size
- Its feeding behavior

Comentado [PM2]: en búsqueda de las ecuaciones

III. Possible values:

- *Chondrohierax uncinatus* — Bird 1
- *Ampelion rubrocristatus* — Bird 2
- *Coeligena bonapartei* — Bird 3

IV. **Energy:** Which updates when eat or move, as well as determining the state of the agents between alive and dead. The energy expenditure among the agents is different, depending on their requirements for land cover and the size of the bird.

V. Equations EM:

Metabolizable energy equation:

Bird 1: *Chondrohierax uncinatus*.

$$EMB = 70 \times 0.286 \text{ kg}^{0.75} \rightarrow 27.37 \text{ Kcal}$$

- Where 286 g = 0.286 kg.
- The energy gained by *Chondrohierax uncinatus* is 27.37 Kcal if it is “located” in Urban Forest and Dense Forest. Otherwise, it will lose 27.37 Kcal.

Bird 2: *Ampelion rubrocristatus*.

$$EMB = 70 \times 0.066 \text{ kg}^{0.75} \rightarrow 9.11 \text{ Kcal}$$

- Where 66 g = 0.066 kg.
- The energy gained by *Ampelion rubrocristatus* is 9.11 Kcal if it is “located” in Shrubs and Urban Forest. Otherwise, it will lose 9.11 Kcal.

Bird 3: *Coeligena bonapartei*.

$$EMB = 70 \times 0.0065 \text{ kg}^{0.75} \rightarrow 1.60 \text{ Kcal}$$

- Where 6.5 g = 0.0065 kg.
- The energy gained by *Coeligena bonapartei* is 1.60 Kcal if it is “located” in Shrubs and Urban Forest. Otherwise, it will lose 1.60 Kcal.

VI. Equations EMB:

- **Bird 1: Chondrohierax uncinatus.**

$$\text{EMB} = 70 \times 0.286 \text{ kg}^{0.75} \rightarrow 27.37 \text{ Kcal}$$

Where 286 g = 0.286 kg.

The energy gained by *Chondrohierax uncinatus* is 27.37 Kcal if it is “located” in Urban Forest and Dense Forest. Otherwise, it will lose 27.37 Kcal.

- **Bird 2: Ampelion rubrocristatus.**

$$\text{EMB} = 70 \times 0.066 \text{ kg}^{0.75} \rightarrow 9.11 \text{ Kcal}$$

Where 66 g = 0.066 kg.

The energy gained by *Ampelion rubrocristatus* is 9.11 Kcal if it is “located” in Shrubs and Urban Forest. Otherwise, it will lose 9.11 Kcal.

- **Bird 3: Coeligena bonapartei.**

$$\text{EMB} = 70 \times 0.0065 \text{ kg}^{0.75} \rightarrow 1.60 \text{ Kcal}$$

Where 6.5 g = 0.0065 kg.

The energy gained by *Coeligena bonapartei* is 1.60 Kcal if it is “located” in Shrubs and Urban Forest. Otherwise, it will lose 1.60 Kcal.

VII. State variables of the PATCHES (spatial units)

- **Cover type:** Which is related to the bird's requirements:

- i. **Values:**

1. Urban
2. Forest
3. Herbage/Grassland
4. Shrub
5. Dense forest

- **This variable:**

- i. Determines whether the bird can feed or not.
- ii. Affects energy expenditure or gain.
- iii. Defines terrain permeability for each species.

2.3 Scales:

A) Temporal scale:

- The selected evasive birds are diurnal (12 hours). Discrete time
1 tick = 1 hour
- One simulation = 12 ticks (12 hours of daily activity)

B) Spatial scale:

- Each patch represents 30 m × 30 m.
- The NetLogo world: 0–800 on X and 0–800 on Y (800 × 800 patches).
- Represents the localities: Chapinero, Teusaquillo, Engativá, and Barrios Unidos.
- The model operates solely at the individual level (the birds).

3. Process Overview and Scheduling:

3.1 Processes executed in each tick:

- In each tick, the model executes the following processes for each of the three species:
 - “move-Bird”:
 - **Movement – move-Bird:**
The bird selects a random patch from the study area (any patch with a valid cover color).
 - It turns to orient toward that patch.
 - It walks 8 units in that direction.
 - It loses a species-specific amount of energy:
 - a. Bird 1: -51.62 (lose EM energy)
 - b. Bird 2: -17.19 (lose EM energy)
 - c. Bird 3: -3.02 (lose EM energy)
 - “eat-Bird”:
 - Feeding – eat-Bird: The bird only gains energy when it is on preferred cover:
 - Bird 1: Urban forest (68) and dense forest (79).
 - Gain: +51.62 EM energy
 - Bird 2: Urban forest (68) and shrub (28).
 - Gain: + 17.19 EM energy
 - Bird 3: Urban forest (68) and shrub (28).
 - Gain: +3.02 EM energy
 - “death-Bird”:
 - The bird dies when:
 - Bird-1: energy ≤ 27.37 according to EMB energy
 - Bird-2: energy ≤ 9.11 according to EMB energy
 - Bird-3: energy ≤ 1.60 according to EMB energy
 - The model stops automatically when there are no more birds.
- **Setup:**
 - **Clean the world.**
 - Load the raster layer of land cover (.asc) using GIS.
 - Assign the color of each land cover type to each patch.
 - Mark the black border (area outside the study area).

- Import the compass rose as an image.
 - Create up to 15 birds.
 - Assign a random initial energy level between 0 and 1000.
 - Place each bird in appropriate land cover types according to its requirements.
 - Reset the clock.
- **Global updates:**
 - **Time:**
 - **At each tick, the model checks if any turtles remain alive.**
 - If none remain, the model stops.

4. Design Concepts

- **Spatial ecology:** In the context of structural ecological corridors, it helps to understand how the availability and quality of these corridors can affect population dynamics and species presence. It also considers the environmental context (Loraamm, 2020).
- **Metabolizable energy** is an important concept in animal nutrition, as it allows estimating how much energy an animal derives from the food it consumes. Accurate determination of metabolizable energy is essential to understand and maximize animal performance in terms of growth, production, and health.
- **Matrix permeability:** It is crucial for the preservation of biodiversity and ecosystem health, as it helps ensure connectivity between protected areas and the movement of species and resources.
- **Habitat:** A place where an organism finds suitable conditions to grow and develop (Di Bitetti, 2012). In other words, it is understood as the physical and biological environment used by the organism.
- **Resource:** Environmental and abiotic factors that are necessary for species to survive (food and shelter). However, **geographical space defined in terms of resources**, it acquires a behavioral dimension for organisms (Begon et al., 2006).
- **Environmental heterogeneity** should be viewed at the scale of the organism, because from its perspective, the environment can be an intolerable mosaic. Understanding the response of organisms to environmental conditions is essential, as it allows for a clearer study of whether a species can survive, grow, and reproduce within the ecosystem (Begon et al., 2006).
- **The ecological niche** refers to all possible resources and geographical spaces that allow a population to exist in a particular system. In other words, the ecological

niche can be understood as the way a species uses available resources and responds to environmental conditions (Begon et al., 2006).

- **Ecological trap** is defined as a “habitat, under the perception of the organism, that appears equally or more attractive compared to others” (Zuñiga-Palacios et al., 2021), but these are low-quality habitats that reduce species’ survival.
- **Metapopulation**: is defined as “a population whose dynamics occur both within and between subareas, in fragmented environments” (Begon et al., 2006).
- **General Systems Theory (GST)**: It is an interdisciplinary approach that studies systems, rather than analyzing only their individual parts. According to Von Bertalanffy (1968), systems must be understood through their interrelationships and dynamics, since their components are connected and function in an interdependent manner. This perspective allows for a better understanding of complex phenomena, such as urban landscapes or ecosystems, by considering the relationships, interactions, and processes that shape them, rather than focusing solely on isolated elements.
- **Umbrella species** are selected to protect other species and their habitats. They are usually chosen because they require large, intact habitats and are crucial for the overall health of the ecosystem (Lambeck, 1997). The concept of an umbrella species has a degree of application in conservation planning, with the purpose of using the “requirements of demanding species to encompass other less demanding ones” (Roberge & Angelstam, 2004; Lambeck, 1997). Fleishman et al. (2000) define umbrella species as “species that, when conserved, protect many coexisting species in the area”.
- **Ecological fitness** refers to a species’ ability to persist and survive in an environment, contributing to its adaptation and success (Ginnobili, 2013).

5. Initialization

Setup:

- **Clean the world.** Included loading the raster layer of land cover (.asc).
- Create up to 15 bird-agent colors coded differently.
- Assign a random initial energy level between 0 and 1000. The birds have randomly assigned energy. Set initial energy (random from 0 to 1000).
- Place each bird in appropriate land cover types in Chapinero area according to its requirements.
 - Bird-agent 1: set xcor (503 + random 5) and set ycor (269 + random 5).
 - Bird-agent 2: set xcor (510 + random 5) and set ycor (276 + random 5).

- Bird-agent 3: set xcor (591 + random 5) and set ycor (342 + random 5).
- Reset the clock.

6. Input Data

The study area (raster) has a total area of 19,350 meters * 12,130 meters. Mobility scenarios were based on the USGS Earth Explorer tool (Lc09_L2sp_008057_20230203_20230311_02_T1 image), which features a 30-meter resolution Landsat image, spanning from February 1, 2022, to February 15, 2023. Random Forest image processing was used for semi-supervised land cover classification (Poveda-Sotelo et al., 2022). The study area represents the areas: Chapinero, Teusaquillo, Engativá, and Barrios Unidos.

• Global updates:

Different scenarios were generated to increase the overall cover of preferred land-covers by bird-agents, with scenario 1 involving specific greening of few points, and running to scenario 5 with a total cover of Forest patches. As such, each scenario loaded with different land-cover coverage (as .asc files) raster layer will be loaded.

0. **Current scenario:** Raster layer named “mapa-coberturas”.
1. **Scenario 1:** Raster layer named “mapa-coberturas”. Modification of the scenario, on file “CPuntos4022.asc”.
2. **Scenarios 2:** Raster layer named “mapa-coberturas”. Modification of the scenario, on file “AVARBOLESVerdes4.asc”
3. **Scenario 3:** Raster layer named “mapa-coberturas”. Modification of the scenario, on “AVARBOLESVerdes4.asc” and “CPuntos4022.asc”
4. **Scenario 4:** Raster layer named “mapa-coberturas”. Modification of the scenario, on “Viaverde.asc”
5. **Scenario 5:** Raster layer named “mapa-coberturas”. Modification of the scenario, on “ArboladoUrblinea.asc”

• Spatial Global Updates:

- Mark black borders around the study area

✿ Current scenario:

- Global Initialization
- Upload raster layer coverage (first .asc)
- Hierarchical classification of Coverages based on colors.
- Delimitation of the boundaries of the study area (to prevent that those avoiders' birds move to the black area).
- Upload compass rose in the black area which belonging to the agent model but not to the study area.

♣ Scenario 1 to 5:

- Global Initialization
- Upload raster layer coverage (first .asc)
- Upload raster trees modified layer coverage (second .asc)
- Hierarchical classification of Coverages based on colors.
- Delimitation of the boundaries.
- Ecological buffering based on scenario modifications
- Upload compass rose.

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