PaleoscapeHerbivoreABM Version 1.0 Full Description (ODD Specification)
(Updated June 2023)

Overview

Purpose

The PalaeoscapeHerbivoreABM is an agent-based model created to investigate how vegetation preference, a need for water, animal speed and lion predation affect the habitation patterns, encounter locations and kill locations of herbivores on the Paleo-Agulhas Plain (PAP). The PAP is a now submerged region of South Africa. The ABM is set upon a map of the PAP (Marean et al. 2020) that includes vegetation types and water locations. Five herbivore types described by Brooke and colleagues (2021) are treated as agent types in the simulation. A sixth agent type, lions, are included as the source of predation. As the herbivores move, they forage for food and move periodically to water sources. Each step of the model represents an hour of time and animal behavior can be affected by the time of day (e.g. lions are less active during the hottest hours of the day). As each hour passes in the model, animals move to nearby locations weighing vegetation preferences and a fear of lions (based on a recent lion kill in a location). Animals move to nearby water sources at a frequency that is based on their herbivore type. At the same time, lions move towards nearby animals and if a lion encounters an animal, then a lion has a probability of making a kill at that location. The amount of time each herbivore agent spends on the various vegetation types and the number of kills by lions in each location are recorded by the model and output after 30 days have passed in the simulation.

Entities, state variables, and scales

- The spatial units of the model are 1km x 1km grid squares. Each square includes a vegetation type based on a map of the PAP from Marean et al. 2020.

- There are six agent types that represent different herbivore classes and one predator type. They are included as individual breeds within Netlogo. SNSBrS refers to small non-social browsers. MSMixS refers to medium-sized social herbivores with mixed diets while LBrS stands for large browsers. WDGrS refers to water-dependent grazers and NRumS includes nonruminants. Each of the herbivore agent types can represent multiple animals moving as a herd. The justification for these five herbivore types can be found at Brooke et al. (2020). To simulate predation in the model, lions are included.

The global state variables are presented in Table 1, the patch state variables in Table 2, and the state variables of the agents in Table 3.

Table 1. Global State Variables.

Variable Name	**Description**
On Interface	
SNSBr-speed	The speed (km/hour) of Small Non-Social Browsers
MSMix-speed	The speed (km/hour) of Medium Sized Social Browsers
LBr-speed	The speed (km/hour) of Large Browsers
WDGr-speed	The speed (km/hour) of water-dependent grazers
Nrum-speed	The speed (km/hour) of non-ruminants
High-Risk-of-Death	The maximum chance of a prey being killed by a lion
Low-Risk-of-Death	The minimum chance of a prey being killed by a lion
lion-density	The number of lions per km2
hours-between-lion-meals	Number of hours between when a lion eats and it begins hunting again
lion-speed	The speed (km/hour) of lion
lions-move-more-at-night	A boolean variable that when True doubles the speed of lions at night
In Code	
patches-vt	patchset of locations with vegetation - everywhere but the ocean
water-patches	Patchset of locations that contain water for animals to drink
herbivores	agentset that includes all herbivores
day-count	The number of days a simulation has run
hour-of-day	The hour of the day
predation-risk1	The risk of predation for Small Non-Social Browsers
predation-risk2	The risk of predation for Medium Sized Social Browsers
predation-risk3	The risk of predation for Large Browsers
predation-risk4	The risk of predation for water-dependent grazers
predation-risk5	The risk of predation for non-ruminants
veg-type1-encountered	Records the number of herbivores encountered by lions at vegetation type 1
veg-type2-encountered	Records the number of herbivores encountered by lions at vegetation type 2
veg-type3-encountered	Records the number of herbivores encountered by lions at vegetation type 3
veg-type4-encountered	Records the number of herbivores encountered by lions at vegetation type 4
veg-type5-encountered	Records the number of herbivores encountered by lions at vegetation type 5
veg-type6-encountered	Records the number of herbivores encountered by lions at vegetation type 6
veg-type7-encountered	Records the number of herbivores encountered by lions at vegetation type 7
veg-type8-encountered	Records the number of herbivores encountered by lions at vegetation type 8
veg-type9-encountered	Records the number of herbivores encountered by lions at vegetation type 9
veg-type10-encountered	Records the number of herbivores encountered by lions at vegetation type 10
veg-type11-encountered	Records the number of herbivores encountered by lions at vegetation type 11
veg-type12-encountered	Records the number of herbivores encountered by lions at vegetation type 12
veg-type13-encountered	Records the number of herbivores encountered by lions at vegetation type 13
veg-type14-encountered	Records the number of herbivores encountered by lions at vegetation type 14

Table 2. Patch State Variables

Variable Name	Description
vt	vegetation or coastal resource type
SNSBr-deaths-here	The number of Small Non-Social Browsers killed here
MSMix-deaths-here	The number of Medium Sized Social Browsers killed here
LBr-deaths-here	The number of Large Browsers killed here
WDGr-deaths-here	The number of water-dependent grazers killed here
NRum-deaths-here	The number of non-ruminants killed here
total-kills-here	The total number of herbivores killed on a patch
vegetation-condition	1-10 scale of the quality of forage in a location

Table 3. Agent State Variables

Variable Name	Description
hours-since-water	Number of hours since animal had water
herbivore?	Records if an animal is a herbivore
hours-without-water	Number of hours since an animal last had water
target-water-patch	Nearby water patch an agent is moving towards
heading-to-water?	True if an animal is moving towards water
population-size	The number of animals represented by an agent
predation-risk	The base predation risk for each herbivore type
time-since-last-meal	(Lion Only) The number of hours since a lion ate last
veg-type1-traversed	Number of times Vegetation Type 1 was crossed by an agent
veg-type2-traversed	Number of times Vegetation Type 2 was crossed by an agent
veg-type3-traversed	Number of times Vegetation Type 3 was crossed by an agent
veg-type4-traversed	Number of times Vegetation Type 4 was crossed by an agent
veg-type5-traversed	Number of times Vegetation Type 5 was crossed by an agent
veg-type6-traversed	Number of times Vegetation Type 6 was crossed by an agent
veg-type7-traversed	Number of times Vegetation Type 7 was crossed by an agent
veg-type8-traversed	Number of times Vegetation Type 8 was crossed by an agent
veg-type9-traversed	Number of times Vegetation Type 9 was crossed by an agent
veg-type10-traversed	Number of times Vegetation Type 10 was crossed by an agent
veg-type11-traversed	Number of times Vegetation Type 11 was crossed by an agent
veg-type12-traversed	Number of times Vegetation Type 12 was crossed by an agent
veg-type13-traversed	Number of times Vegetation Type 13 was crossed by an agent
veg-type14-traversed	Number of times Vegetation Type 14 was crossed by an agent

Process Overview and Scheduling

Each time step represents one hour. After 24 hours have passed the day is incremented and the hours start over again. The animals are randomly chosen and move each hour. Animals move based on the number of kilometers per hour they travel and the move procedure is repeated for each animal based on the speed. If an animal moves 2 km per hour, then it will move twice in a time step. Herbivores may move to the best patch based on the vegetation or they may move towards a nearby water patch if it has been a given number of hours since the last time it had water. Lions move towards herbivores on nearby patches or randomly if no patches are occupied. The speed or even if a lion moves is dependent on the time of day and if a lion has recently had a successful kill.

Herbivore Movement

When moving, herbivores first decide if they have gone too long without water. If so, then the herbivore agent moves towards one of the nearby patches that have water. Each subsequent move step will be to a water patch until it arrives and the animal grazes on the vegetation that happens to be there. If water is not necessary, the herbivores rank the vegetation around them based on the vegetation type. The type and ranking of a vegetation type depends on the type of herbivore. In order to choose between patches of the same vegetation type ranking, herbivores may choose to move to a patch based on the condition of the vegetation. Vegetation is modeled on a 1-10 scale with 10 being the best condition. If an agent has recently browsed at a location, then the condition will be lower. Herbivores also then consider if a lion has recently made a kill on a location. If they have, the patch will be avoided (see Figure 1).

Lion Movement

Lions move to a neighboring patch that is occupied by a herbivore. Then, based on the vegetation in a patch and the type of herbivore a lion has a probability of a successful encounter. If no neighboring patches are occupied, then a random moves randomly to a nearby patch. Lions may not move based on the time of day (if it is the hottest hours of the day which is set in the interface). Lions may also move at double speed if it is nighttime (set in the interface). Finally, lions may not begin hunting again for a given number hours if they have had a successful kill because they are ‘full’ (see Figure 2).

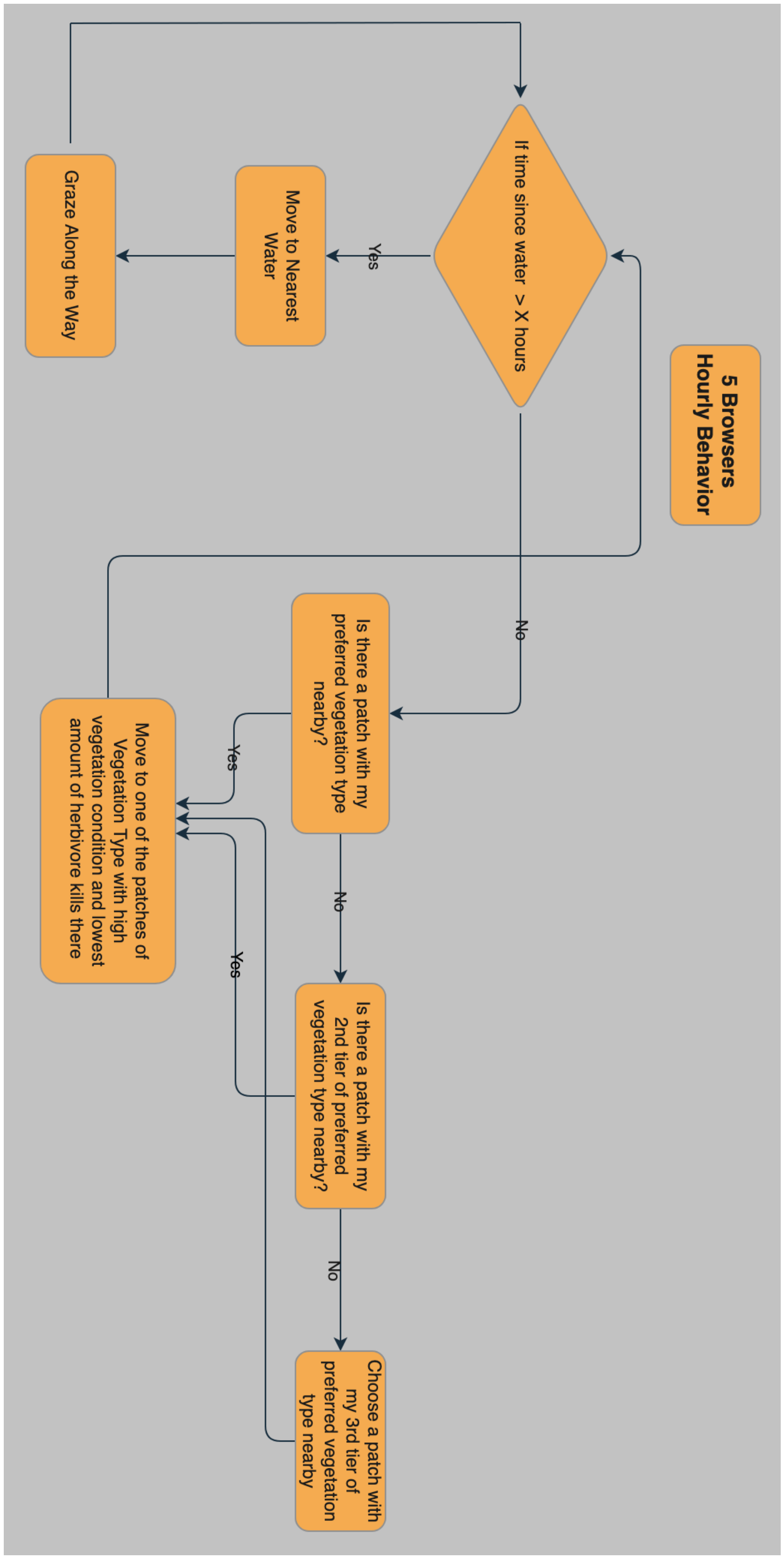

Figure 1. Browsing behavior of herbivores.

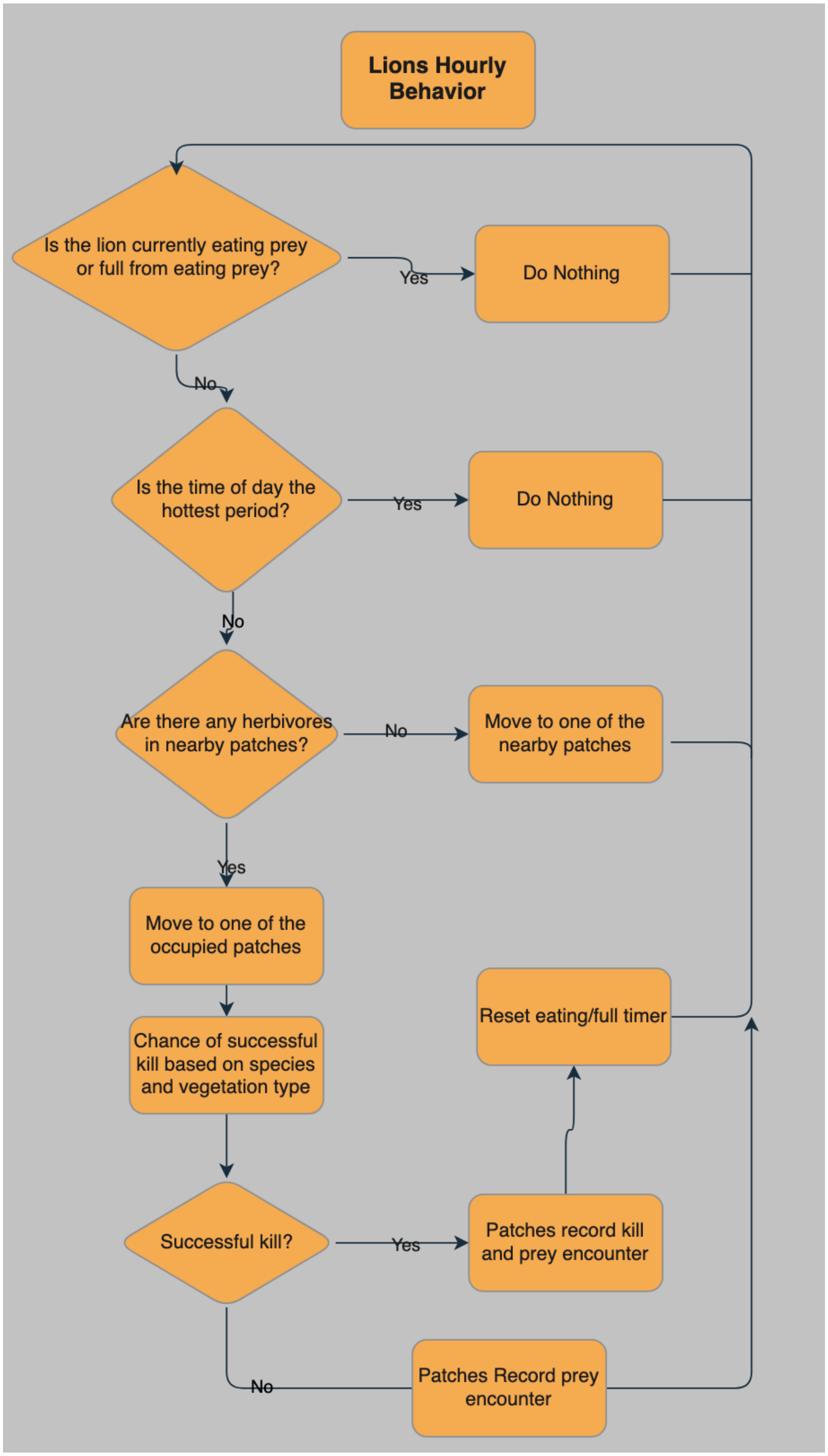

Figure 2. Lion movement and decision making.

Design Concepts

Basic principles

The model attempts to mimic herbivore occupation of the PAP by incorporating vegetation type, predation risk, water usage and vegetation conditions.

Emergence

Lions may occupy the area around watering holes as they encounter animals in these areas while herbivores may avoid these areas unless water is necessary.

Adaptation

By avoiding areas that lions have made successful kills, animals stay in safer locations.

Objectives

Each herbivore attempts to find the best vegetation types depending on the type of herbivore while avoiding being eaten by a lion. Lions attempt to eat herbivores.

Learning

Not Applicable

Prediction

Not Applicable

Collectives

Not Applicable

Sensing

Herbivores can detect the vegetation type and condition of the patches surrounding them. They can also sense if a lion has made a successful kill in a location so that they can avoid the area. Herbivores can sense the closest patch with water as well. Lions can sense if a nearby patch is occupied by a herbivore.

Observation

Within the interface, animal movement can be observed and patches with recorded kills are indicated. The number of herbivores of each type is also displayed in a histogram. The model also outputs a CSV with numbers related to each simulation run. The numbers output include the number of herbivores of each type that are killed by lions on each of the vegetation types; the number of animals encountered on each vegetation type by lions and the time each herbivore spent on patches of each vegetation type.

Details

Initialization

The model is initialized by loading a raster map of the PAP (see Figure 3). The map is based on a number of previous studies including mapping of terrestrial vegetation types, bathymetric data and paleoclimate models (see Marean et al. 2020). It is loaded at a 1 km x 1 km resolution so each patch represents an area of $1km^2$. Herbivores are distributed on the landscape based on the herbivore type and the vegetation type. Lions are distrusted randomly without regard for vegetation based on lion-density, which is set in the interface.

Figure 3. The Paleo-Agulhas Plain map used in the simulation.

Submodels

Vegetation Growth
A simple qualitative value of vegetation-condition is used to help herbivores judge the best location to browse. Each patch starts at a value of 10 and this number is decreased by 1 each time

herbivores graze on a patch. The value does not go below 0. Each step of the model the vegetation is increased by 0.5, and does not exceed 10.

Population

Each agent has its own population that records how many animals it represents. This can be a value of 1 in the case of small non-social browsers, but it can also represent a herd. If a lion successfully kills an animal, the population is decreased by 1, but the agent does not die unless the population gets to 0. If a population of an agent decreases to 0 it is removed from the simulation and a new animal agent is added. Agent number remains constant throughout the simulation.

References

Brooke, Christopher F., Curtis W. Marean, Colin D. Wren, Hervé Fritz, and Jan A. Venter. 2021. Retrodicting large herbivore biomass for the last glacial maximum on the Palaeo-Agulhas Plain (South Africa) using modern ecological knowledge of African herbivore assemblages and rainfall. *Quaternary Research* 104:136–150. DOI:10.1017/qua.2021.23.

Marean, Curtis W., Richard M. Cowling, and Janet Franklin. 2020. The Palaeo-Agulhas Plain: Temporal and spatial variation in an extraordinary extinct ecosystem of the Pleistocene of the Cape Floristic Region. *Quaternary Science Reviews* 235. The Palaeo-Agulhas Plain: a lost world and extinct ecosystem:106161. DOI:10.1016/j.quascirev.2019.106161.