Agent-Based Model of Yellow-Bellied Marmots (*Marmota flaviventris*)

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*Presenters

Motivation

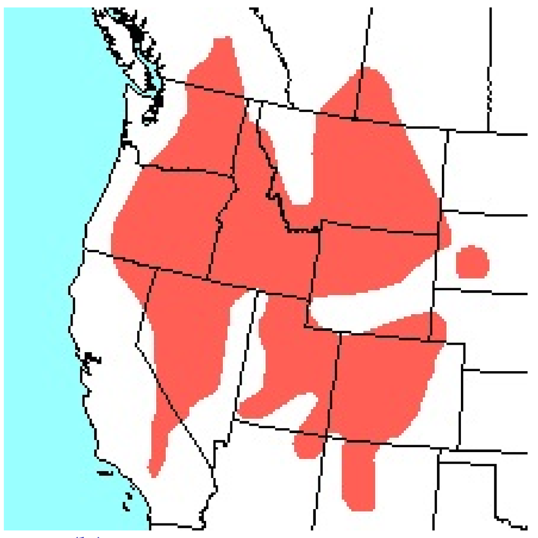
A long-term study (1976-2008) of a yellow-bellied marmot (*Marmota flaviventris*) population in the Upper East River Valley, Colorado revealed a dramatic population increase from 2000 to 2008 (when compared to the growth rate of the population over previous years) [2]. The researchers conducting the study attribute the sharp increase in population size to climate change. Changing climate conditions have lead the marmot population to hibernate for short periods of time allowing them more time to gain weight (and store fat) which causes an increase in their likelihood to survive hibernation. Possibly, a more important effect of the climate change is that more of the females have the necessary fat levels post hibernation for successful reproduction.

In this project we model the Upper East River Valley yellow-bellied marmot population using individual-based modeling techniques, paying specific attention to the link between climate and rates of survival and reproduction. In this poster we present the current state of our model which simulates the yellow-bellied marmot habitat and social structure with networks, along with each marmot's loss of mass over hibernation. The model does not currently include social movement or predation which occur during summers between hibernation periods.

Yellow-Bellied Marmots

The yellow-bellied marmot (*Marmota flaviventris*) is a ground squirrel native to the western United States and southwestern Canada in steppes, alpine meadows, and talus fields above 2000 m of elevation. Yellow-bellied marmots reside in localities with 1–3 reproducing males (typically age $\geqslant 3$ years), 1–12 adult females, 0–8 non-reproducing resident yearlings (mostly female), and 0–36 young (< 1 year). Each reproducing male defends 1-3 (often related) females known as his harem; each breeding season the male produces offspring with the dominant female of the harem. Male offspring typically leave their natal territory when they are yearlings to establish their own harem. However, the death rate of male juveniles and adults is high (47% of male young become yearlings, 36% of male yearlings live to age 3). Female offspring will often stay within their natal territory, sometimes becoming a part of their mother's harem.

(a) Yellow-bellied marmot.



(b) Yellow-bellied marmot range.

Figure: *Marmota flaviventris*

Modeling Space via a Network

In our model we use a network to represent the spatial distribution of marmots burrow sites:

- Each node represents a burrow site
- Colonies have two nodes: a primary burrow site and a secondary burrow site
- Satellites have only one node: a primary burrow site.
- Undirected links (edges) are used to connect nodes, where each link is assigned a weight defined as
  - 0.25 if there are satellite nodes at both ends of the link
  - 0.50 if there is a satellite node at one end of the link and a colony node at the other end
  - 0.75 if there are colony nodes at both ends of the link

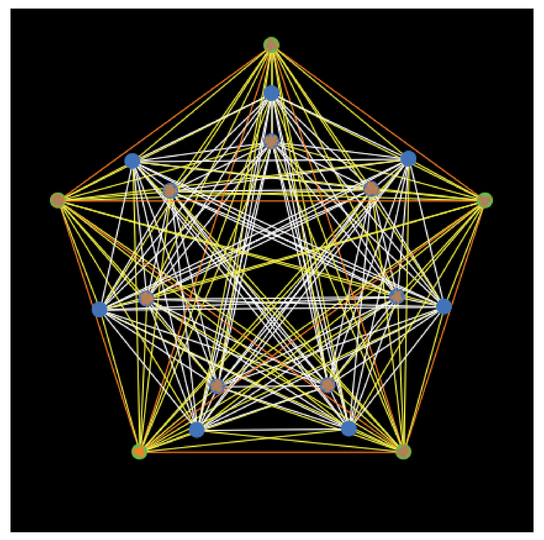


Figure: Network burrow site structure with 7 colonies (blue) and 5 satellites (green)

- Each node has six state variables:
  - locality type (colony or satellite)
  - site type (primary or secondary)
  - site size (randomly sampled from a uniform distribution $\mathcal{U}[0.15, 7.24]$, measured in hectares)
  - direction of slope exposure (randomly sampled from a bimodal distribution where 65% of values come from a normal distribution centered around Southwest slope exposures ($239° \pm 47°$), and remaining 35% of values come from a normal distribution centered around Northeast slope exposures ($77° \pm 33°$))
  - population size (count of the number of marmots at the node at the current time step)
  - carrying capacity (the total number of marmots the node can sustain)

Hibernation Submodel

- Yellow-bellied marmots hibernate during from late August to early May.
- Marmots lose body mass over the winter at a rate of 2.20 ± 0.93 grams per day. If a marmot loses too much mass over the winter (mass falls below 580 grams) it dies during the hibernation.
- The hibernation submodel simulates the entire hibernation period (229.6 ± 8.19 days) in one time step.
- Data for daily mass loss rate and hibernation period from [1] and are representative of the juvenile age class.
- Lacking data for mass loss rates for any marmot age category other than juveniles, we assume that all marmot age classes have similar mass loss rates, though it is suggested in [3] that this is not the case.

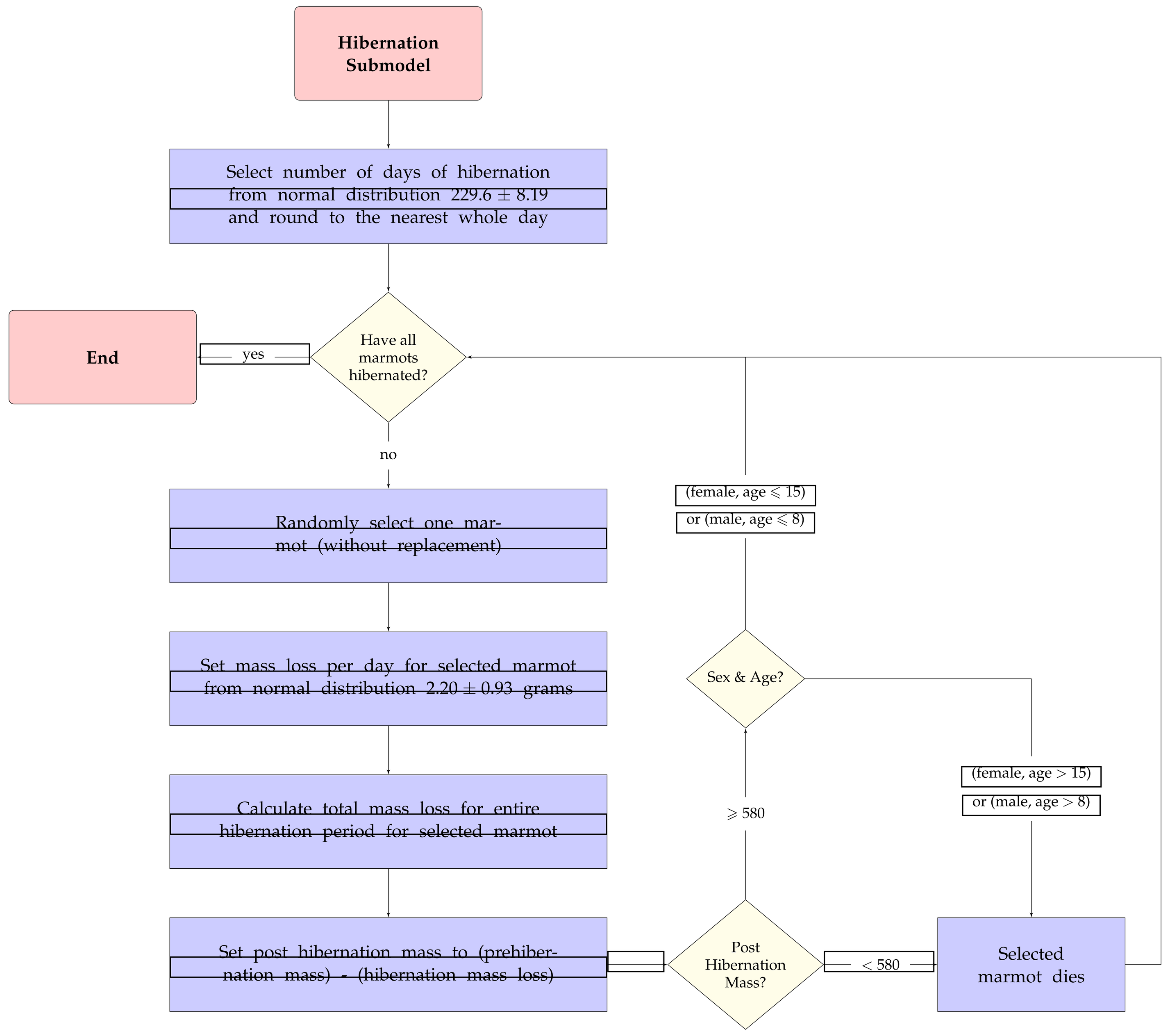


Figure: Flow diagram of modeling hibernation

- The total mass loss is the product of mass loss per day and number of hibernation days.

Numerical Results of Hibernation Submodel

- Data generated from our Hibernation Submodel gives the total mass loss as 502.6 ± 206.6 grams per hibernation period.
- Data from [1] gives the total mass loss of juveniles as 530 ± 219 grams per hibernation period.

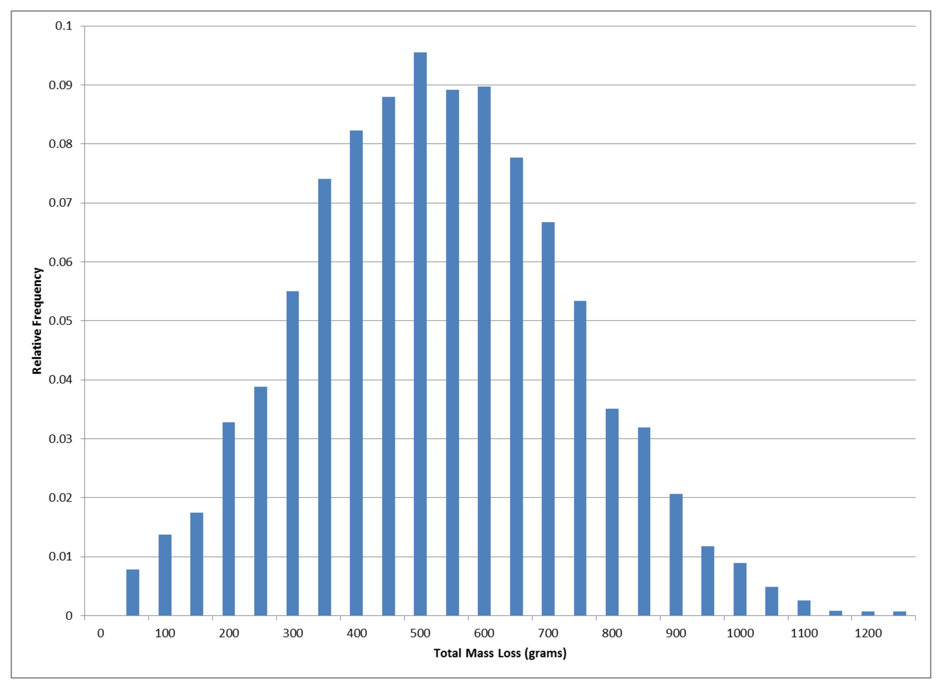


Figure: Historgram of total mass loss per marmot over the hibernation period. Data was generated from the Hibernation Submodel using a sample of 100 marmots per hibernation period, and 100 hibernation periods.

- Our model is adequately representing the mean total mass loss of juveniles per hibernations period (as compared to [1]), where the number of days per hibernation period varies.

Female Dispersal Submodel

- All male yearlings disperse; about 50% of adult females disperse.
- Let d be the shortest distance along the matriline network from female A to female B. Then the relatedness of A to B is defined to be $r_{AB} = 0.5^d$ provide a path exists between A and B. If no such path exists, then we set $r_{AB} = 0$.
- The dispersal submodel is executed directly after hibernation and right before reproduction.

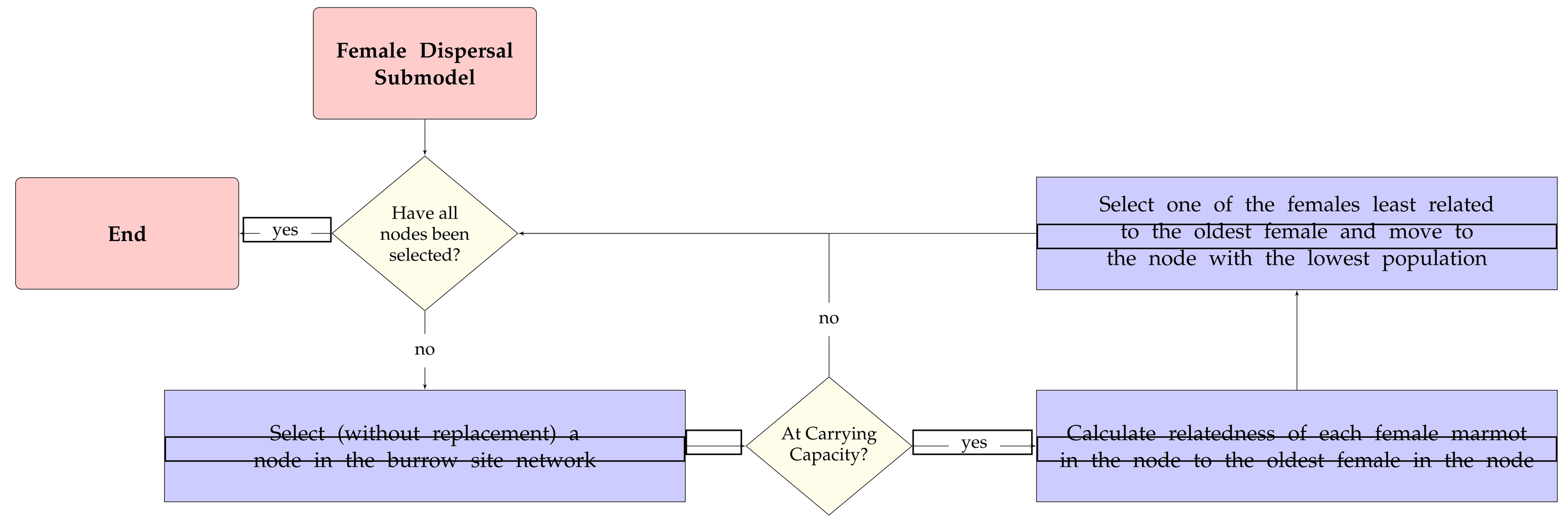


Figure: Flow diagram of modeling dispersal

Reproduction Submodel

- Typically only the oldest female of each harem reproduces. As a result, an average of 48% of females reproduce each year.
- In our model we use networks to represent relatedness within a matriline. Links (edges) are established between mother-daughter pairs and sister pairs.
- The reproduction submodel simulates the entire 30 day gestation period in one time step.
- The reproduction submodel is executed directly after the female dispersal submodel and before the active season will be simulated.

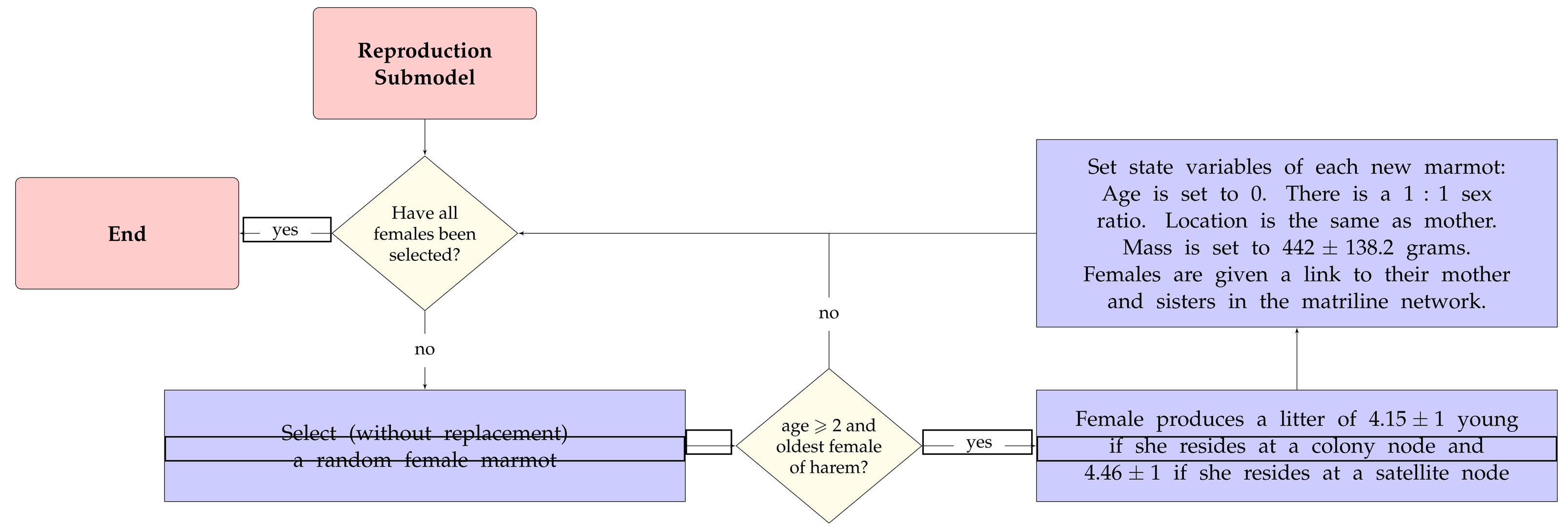


Figure: Flow diagram of modeling reproduction

Future Work

- Construct a mechanism to track the harem to which each female belongs (if any). Currently, the granularity by which we track group structure is at the node level, but there may be multiple harems within one node. The number of harems a node can support will be a function of the following node variables: locality type, site type, size, and carrying capacity.
- Run simulations to determine the average relatedness within a node and within a harem. We expect the later to be ~ 0.375, and the average relatedness within a node to be lower.
- Add a mechanism to the model which accounts for the difference in length of hibernation days based on slope facing direction of each node. Including the effect of slope facing direction will add noise to simulation results.
- Design a submodel that simulates the mass gain of each marmot during the active season that takes place over the summer, while the male marmots are gathering food for hibernation.
- Build a submodel that simulates mortality during the active season. Death is largely due to predation during the summer, in which male marmots are the primary targets.
- Run simulations with a decreasing numbers of hibernation days over many years. Compare the increase in population size to those found in the literature in order to test the validity of the model.

Bibliography

[1] C. Lenihan and D. van Vuren. *Canadian Journal of Zoology*, 1996; 74: 297–302.
[2] A. Ozgul, et al. *Nature*, 2010; 466: 482–485.
[3] K. B. Armitage and J.F. Downhower. *Ecology*, 1974; 55: 1233-1245.

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