**Title**: Recommendations for designing fisher habitat reserves on large landscapes: How much, how big, how far apart and how good?

**Purpose**: Test the effects of habitat amount, configuration, and quality on fisher abundance to inform the development of a habitat reserve design for fisher

**Objectives**:

* Publish the fisher agent-based model
* Calibrate/validate the fisher agent-based model
* Understand the effects of different habitat reserve configurations on fisher abundance
  + Test for differences between boreal and sub-boreal populations?

**Hypotheses**

* *H1*: Fisher abundance will increase with more habitat protected up to a point, and habitat amount will have the largest effect on fisher abundance.
  + *P1.1*: All else being equal, more habitat means more fisher on the landscape
  + *P1*.2: The first priority of fisher conservation/recovery is to protect as much forest habitat as possible
    - Habitat amount hypothesis (Fahrig 2013)
      * Spp. richness increases with total amount of habitat and is independent of habitat patch size
      * But apply concept to a population
        + Fisher abundance increase with total habitat and is independent of patch size
  + *P1*.*3*: The relationship is non-linear, sigmoidal
    - Somewhere below 10-40% of landscape must be forested to sustain population (Swift and Hannon 2010; Arroyo-Rodriquez et al. 2020)
* *H2*: Fisher abundance will increase as patch size decreases (independent of habitat loss, patch distance), and habitat patch size will have the fourth largest effect on fisher abundance.
  + *P2.1:* All else being equal, smaller patches of habitat means more fisher on the landscape
  + *P2.*2: The fourth priority of fisher conservation/recovery is to protect several small rather than a single large habitat patch
    - higher fragmentation seems to have a positive effect most of the time (independent of habitat loss), could have positive benefits of more patches as refugia from predators, disturbance, competitors, more edge to increase foraging opportunities and lower patch distances for dispersal (Fahrig 2017)
      * species with larger movement ranges show positive effects of fragmentation
        + my understanding here is that fisher would like edges, a diversity of habitat; if that’s not true, we should invert the hypothesis
* *H3*: Fisher abundance will decrease as patch distance increases (independent of habitat loss, patch size), and patch size distance have the third largest effect on fisher abundance.
  + *P3.1:* All else being equal, further patches of habitat means fewer fisher on the landscape
  + *P2.*2: The third priority of fisher conservation/recovery is to protect habitat patches closer together.
    - Some reference to dispersal distance….
    - FLEX2 max dispersal is 50km, so we might develop a hypothesis around a threshold distance?
* *H4*: Fisher abundance will increase as habitat quality increases (independent of habitat loss, patch size, etc.), and patch quality distance have the second largest effect on fisher abundance.
  + *P4.1:* All else being equal, further patches of habitat means fewer fisher on the landscape.
  + *P4.*2: The fourth priority of fisher conservation/recovery is to protect habitat patches closer together.
    - Habitat quality is linked to reproductive rate in our model
    - This hypothesis may be too banal, although understanding the relative importance of habitat quality might be useful?

Other thoughts, ideas:

* Hypotheses for non-linear effects (threshold effects, Swift and Hannon 2010; e.g., sigmoidal curves for habitat amount and distance
  + Prediction: there is minimal influence of habitat amount when there is very little, or a lot
  + Prediction: there is minimal influence of patch distance when it is too far apart or very close
* Test for interactions as well….?
* Might also want to include, consider or do as subsequent analysis test how variation in demographic effects, i.e., dispersal distances, home range sizes and the relationship between reproductive rate and habitat quality influence abundance through interactions with the habitat metrics.
  + ‘Demographic fragmentation effects’

**Methods**

* Develop a linear model test the effects of each habitat component on fisher (sub)population, e.g.,
  + Abundance = β0 + β1\*A + β2\*Q + β3\*D + β4\*S
  + Prediction:
    - Amount (A) > Quality (Q) > Distance (D) > Size (S)
    - β1 > β2 > β3 > β4
  + Sigmoidal functions:
    - Abundance = 1 / (1 + *e*A)
      * *e* = 2.71828
    - need some statistical advice on this
  + Interactions
    - need some statistical advice on this
  + model selection to determine effect size of the three habitat components
    - AIC to rank models, identify which combo of covariates is weighted highest based on trade-off between fit and parsimony
* habitat = all habitat types (e.g., denning, movement, resting) needed by fisher; won’t distinguish by type, initially
* simulation to estimate abundance
* ‘study area” = landscape of a sub-population
  + What extent?
    - Currently 100km x 100km
    - equivalent to an area of a fisher (sub)population, or area we want to manage for a self-sustaining group of fisher?
  + What resolution (grain)?
    - 1 ha

**Background Stuff**

* Big picture:
  + Global loss of forest cover and thus loss of forest spp.
  + But forest harvest is important economic driver in many areas; need to ‘balance’ multiple forest values
    - Need to identify efficient ways to conserve and allow for forest development
* Effective conservation planning requires understanding effects of different reserve configurations on forest spp. (Arroyo-Rodriquez et al. 2020)
  + forest-dependent spp. require 40% of area to be forested (Arroyo-Rodriquez et al. 2020)
  + population/community response to habitat threshold less than 10-30% (Swift and Hannon 2010)
  + more spp. do better with more smaller patches than fewer large patches, but depends on spp. (Arroyo-Rodriquez et al. 2020)
  + at least ~25% of forest or ~10% of landscape should be protected in a single patch (Arroyo-Rodriquez et al. 2020)
  + Negative benefits are insufficient habitat to form a home range (but depends on the scale of the model) and edge effects, degrading habitat quality
* simulation experiment; explore spp. or landscape characteristics associated with thresholds; relative effects; thresholds unlikely to be the same as in real landscape though (Swift and Hannon 2010)
* a similar approach developed for America Badger (Jager et al. 2004)
  + habitat loss had a negative influence on abundance, but also fragmentation
  + negative effects due to Allee effects (isolation of habitat, individuals) and greater exposure to ‘high-risk’ habitat

**Model Validation**

ABM must capture the most essential elements of the system. We don’t want to miss some key features of the system. Assess the representativeness of the model. WE are modelling individual behaviour and observed interactions at population level. Two levels – individual (micro-validation) and population level (macro-validation).

Micro – Have we included all key agents? Have we included key behaviours, proportion of agents representative of real world, is the environment representative? Is the network representative?

Macro – output represent the pattern observed in the real world?

Exploring model behaviour – number of inputs to see if model is reasonable

Compare the model with another analytics model – PVA?

Event validity – compare the occurrence of events ot real world

Extreme-condition test – outputs are plausible for extreme and unlikely parameters.

Historical data validation – can the model replicate the data?

Rationalism – are the underlying assumptions true?

Empiricism – every assumption is empirically validated

Internal stochasticity – to determine the amount of internal stochastic variability in the model

Parameter variability – sensitivity analysis – changing the values of parameters to determine effect on model behaviour

Traces – following a entitie in the model (trace) to determine if the models logic is correct

Appendix A – Note: This is incomplete; conceptual only; see ‘landscape\_simulator.Rmd” for raster landscape outputs and table of scenarios

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| Scenario | Total Area | Patch Size | Patch Distance | Quality |
| 1 | 100 | 100 | 0 | H |
| 2 | 100 | 100 | 0 | L |
| 3 | 50 | 25, 25 | 0 | H |
| 4 | 50 | 25, 25 | 0 | L |
| 5 | 50 | 25, 25 | 1 | H |
| 6 | 50 | 25, 25 | 1 | L |
| 7 | 50 | 25, 25 | 2 | H |
| 8 | 50 | 25, 25 | 2 | L |
| 9 | 50 | 12.5, 12.5, 12.5, 12.5 | 1 | H |
| 10 | 50 | 12.5, 12.5, 12.5, 12.5 | 1 | L |
| 11 | 25 | 12.5, 12.5 | 0 | H |
| 12 | 25 | 12.5, 12.5 | 0 | L |
| 13 | 25 | 12.5, 12.5 | 2 | H |
| 14 | 25 | 12.5, 12.5 | 2 | L |
| 15 | 25 | 6.25, 6.25, 6.25, 6.25 | 1 | H |
| 16 | 25 | 6.25, 6.25, 6.25, 6.25 | 1 | L |
| 17 | 25 | 6.25, 6.25, 6.25, 6.25 | 2 | H |
| 18 | 25 | 6.25, 6.25, 6.25, 6.25 | 2 | L |
| 19 | 25 | 3.13, 3.13, 3.13, 3.13, 3.13, 3.13, 3.13, 3.13 | 0 | H |
| 20 | 25 | 3.13, 3.13, 3.13, 3.13, 3.13, 3.13, 3.13, 3.13 | 0 | L |

Scenario 1

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| High quality |  |  |  |
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Scenario 2

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| Low quality |  |  |  |
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Scenario 3

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Scenario 10

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Scenario 11

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Scenario 16

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Scenario 17

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Scenario 19

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Scenario 20

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