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An Agent-Based Model of Diel Vertical Migration in *Mysis diluviana*

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Structure

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- Methods
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Introduction

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Mysis diluviana

- “*Mysis*” are a macro-invertebrate crustacean in Lake Champlain.
- Transfer nutrients from bottom to surface waters.
- Exhibit a behavior known as diel vertical migration.

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The Model

- Modeling helps deal with the cost and man-hours needed to sample *Mysis*.
- Agent-based and Monte Carlo style.
- Works on an hourly time-step over an entire year.

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Sub-Models

- Main model is fed by data-generating sub-models.
- Input comes in the form of *Mysis* migration extent (or Mysocline) and ...
- Food availability and variability for the pelagic (surface) waters.

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Methods

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Language

- The entire model was coded in R.
- This makes it easier to share the code with peers for future investigation and expansion.
- Shiny Servers and RMarkdown furthered the accessibility.

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Agent-Based Modeling

- Simulates an individual *Mysis* throughout the entire year.
- At every hour draws are taken from probability distributions for decision making.
- Many individuals are simulated to get an idea of population-wide trends.

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Model Structure

```

graph TD
    M[Migrate] --> HD[Hourly Decision]
    M --> TD[Time Daily Decision]
    M --> MD[Migrate Once]
    M --> SD[Second Migration Decision]
    
    HD --> M
    HD --> TD
    HD --> MD
    HD --> SD
    
    TD --> IAS[1 hour after arrival]
    TD --> IS[no return]
    
    MD --> Y[Yes]
    MD --> N[No]
    
    Y --> RPD[Reevaluate Return Decision]
    RPD --> AC[Add result to Condition]
    AC --> CC[New Condition]
    CC --> MD
    
    N --> RPD
    
    SD --> F1[1st arrival]
    F1 --> NM1[Not Migrating]
    NM1 --> SD
    
    SD --> F2[2nd arrival]
    F2 --> SD2[Second Migration Decision]
    SD2 --> C1[1st arrival]
    C1 --> NM2[Not Migrating]
    NM2 --> SD2
    
    SD2 --> C2[2nd arrival]
    C2 --> NM3[Migrating again in next time]
    NM3 --> SD2
  
```

The flowchart illustrates the decision-making process for migration, starting from a central 'Migrate' node. It branches into four main paths: 'Hourly Decision', 'Time Daily Decision', 'Migrate Once', and 'Second Migration Decision'. The 'Hourly Decision' path leads to a 'Migrate' node, which then leads to a 'Time Daily Decision' node. The 'Time Daily Decision' node branches into '1 hour after arrival' and 'no return'. The 'Migrate Once' path leads to a 'Yes' or 'No' decision. If 'Yes', it leads to 'Reevaluate Return Decision', which then leads to 'Add result to Condition', which leads to 'New Condition', which leads back to 'Migrate Once'. If 'No', it leads to 'Reevaluate Return Decision'. The 'Second Migration Decision' path leads to a '1st arrival' or '2nd arrival' decision. If '1st arrival', it leads to 'Not Migrating', which leads back to 'Second Migration Decision'. If '2nd arrival', it leads to 'Second Migration Decision', which then leads to a '1st arrival' or '2nd arrival' decision. If '1st arrival', it leads to 'Not Migrating', which leads back to 'Second Migration Decision'. If '2nd arrival', it leads to 'Migrating again in next time', which leads back to 'Second Migration Decision'.

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Mysocline

- Light intensity levels
- +
- Temperature profile
- =
- Mysocline

The figure consists of three vertically stacked graphs sharing a common x-axis representing time in hours from 0 to 7200.

- Top Graph: Depth of Mysis Light Threshold**
The y-axis is 'Depth from surface' (0 to 4000). It shows a series of white, bell-shaped pulses representing light intensity. The pulses are periodic, with peaks occurring roughly every 1200 hours. The depth of the pulses varies, with some reaching down to 4000 and others being shallower.
- Middle Graph: Thermocline Depth**
The y-axis is 'depth' (0 to 40). The curve shows a thermocline that starts at a depth of about 5, rises to a plateau of about 35 between 2000 and 4000 hours, and then falls back to about 5 by 6000 hours.
- Bottom Graph: Depth of Mysocline**
The y-axis is 'depth from surface (m)' (0 to 1200). It shows a series of white, bell-shaped pulses representing the mysocline depth. The pulses are periodic, with peaks occurring roughly every 1200 hours. The depth of the pulses varies, with some reaching down to 1200 and others being shallower.

The bottom graph is the result of the light intensity levels (top) and temperature profile (middle) being combined.

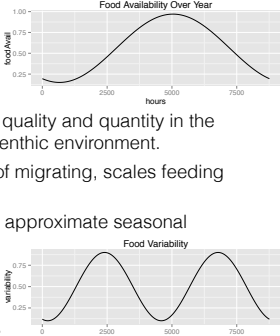
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- $+$

- $$=$$

Food Availability

- Normalized measure of food quality and quantity in the pelagic environment to the benthic environment.
- Directly maps to probability of migrating, scales feeding reward.
- Paired with food variability to approximate seasonal variability.



The top graph, titled "Food Availability Over Year", plots "food/avail" on the y-axis (ranging from 0 to 1.00) against "hours" on the x-axis (ranging from 0 to 7500). The curve shows a single peak of 1.00 at approximately 5000 hours, with values decreasing to near 0 at the start and end of the period.

The bottom graph, titled "Food Variability", plots "variability" on the y-axis (ranging from 0 to 0.75) against "hours" on the x-axis (ranging from 0 to 7500). The curve shows two peaks of approximately 0.75, one at approximately 2500 hours and another at approximately 6500 hours, with a trough of 0 at approximately 5000 hours.

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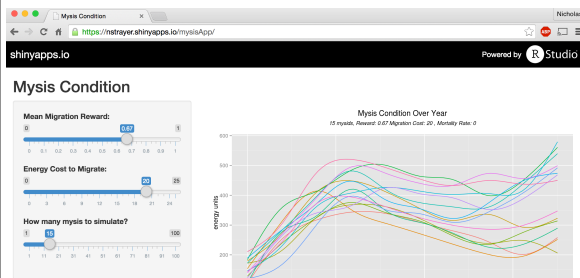
Interactive App

- Model was put into a shiny server.
- Allows the model to be utilized by those who might be new to or intimidated by code.
- Reproducible results.

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<https://nstrayer.shinyapps.io/mysisApp/>



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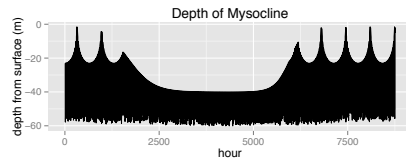
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Results

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The Mysocline



- Highlights seasonal fluctuations in migration extent
- Early spring and late fall are light bounded.
- Late spring, summer and early fall are thermocline bound

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A Single Run

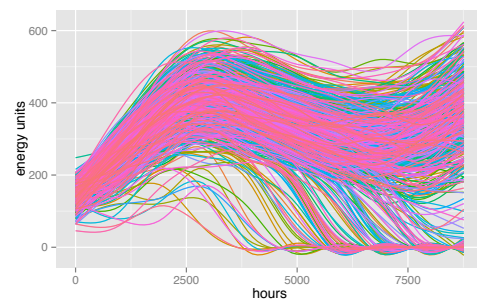
- Each line represents a single Mysis.
- We can see seasonal trends in condition values.
- Indicates that the cost of migration weighed with the variability of reward is dangerous.

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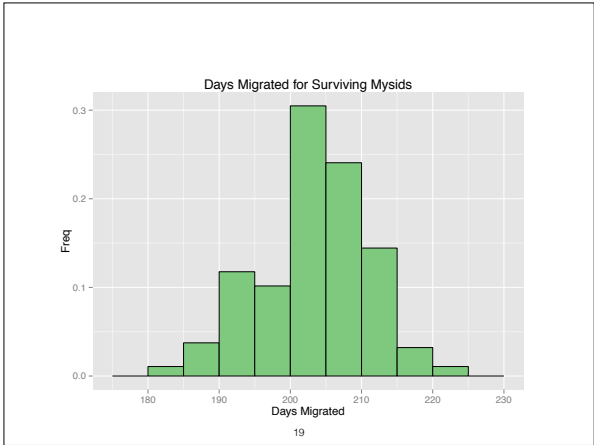
Condition Over Year

500 mysids, Reward: 0.68, Migration Cost: 20, Mortality Rate: 0.182



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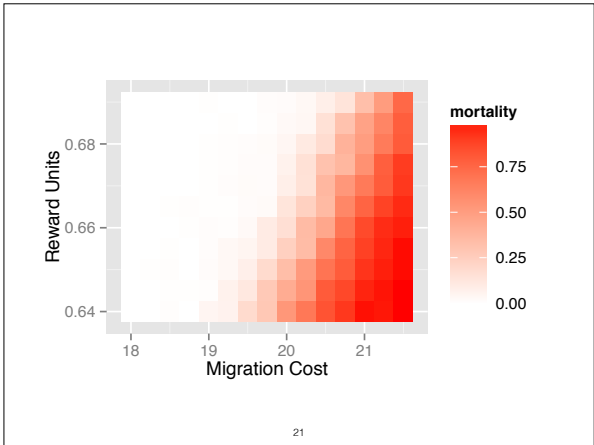


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Sensitivity Analysis

- The model was run over a range of average feeding reward values and migration costs.
- Follows expected trends based upon ecological theory ($y = x$ line).
- Greater sensitivity to migration cost changes than feeding reward.

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Future Directions

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Where To Go Now?

- Probe the possibility of multiple stable migration patterns.
- Dig in to specific aspects of the model. E.g. predation risk, benthic food availability
- Utilize real data in model inputs such as thermocline depth and food availability. (Oh, and to validate.)

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- Office of Undergraduate Research.
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