An Agent Based Model of the Diel Vertical Migration Patterns of Mysis diluviana

Nick Strayer[1], Jason Stockwell[2], Brian O'Malley[2], Sture Hansson[3]

[1] *College of Engineering and Mathematical Sciences, University of Vermont*

[2] *Rubenstein School for the Environment and Natural Resources, University of Vermont*

[1] *Stockholm University*

Abstract

Suspendisse potenti. Suspendisse quis sem elit, et mattis nisl. Phasellus consequat erat eu velit rhoncus non pharetra neque auctor. Phasellus eu lacus quam. Ut ipsum dolor, euismod aliquam congue sed, lobortis et orci. Mauris eget velit id arcu ultricies auctor in eget dolor. Pellentesque suscipit adipiscing sem, imperdiet laoreet dolor elementum ut. Mauris condimentum est sed velit lacinia placerat. Vestibulum ante ipsum primis in faucibus orci luctus et ultrices posuere cubilia Curae; Nullam diam metus, pharetra vitae euismod sed, placerat ultrices eros. Aliquam tincidunt dapibus venenatis. In interdum tellus nec justo accumsan aliquam. Nulla sit amet massa augue.

Keywords: Science, Publication, Complicated

---

1. Introduction

Mysis diluviana (Mysis) is a small macroinvertebrate crustacean that lives in deep glacial lakes. They occupy a critical niche in the food-web as during their diel vertical migration (or DVM) they transfer nutrients from the benthic to the pelagic environments of a lake. Previous research efforts into Mysis have been focused on particular aspects of their migrations (CITATIONS). In this paper we take a step back and access the sensitivity of migration to changes in different environmental parameters using monte-carlo style simulation of many individuals at an hourly timestep over a typical year.

More traditional methods of measuring the effects of environmental changes are costly and time consuming, requiring many hours of sampling and with the inherent noise of real world sampling.

By modeling we are able to investigate effects at a much lower cost and also escape the aforementioned pitfalls of real sampling to get a clear picture of the trends of effects.

It should be noted that the results and their specific units and/or amounts may not be exact, but what is important are the trends. We hope that the results from this modeling based exploration into DVM will help point future real-world sampling efforts in a more efficient and impactful direction.

2. Methods

2.1. Programming Language

The programming language used for the model is R (CITATION). R was chosen due to its high adoption in the ecology community. This will allow for easier expansion of the model in the future.

2.2. Agent Based

An agent based approach was used for the model as it allows the interogation of effects at a small scale of environmental changes and allows for the potential detection of multiple stable-states in migration patterns through the use of monte-carlo style running of many agents over the same environmental conditions.

2.3. Expandability

The environmental variables fed into the agent-based main model are generated using their own sub-models. This form was chosen because it allows the quick perturbation of environmental factors but also for it's ability for model data to be substituted with real data. As more sampling data is obtained it can be gradually integrated into the model to allow for more precise predictions and measurements of effects.

2.4. Variables

The following are the variables used throughout the model.

Variable	Value	Description and Units	
s	1 for winter/spring, -1 for summer/fall	Seasonality	
M	40	Max Depth	Meters
K_t	.003	Curve Steepness	
K_p	.03		
m_t	1667	Midpoint of curve	Hours
m_p	120		Energy
h	1,2,...,8750	Hour of year	Hours
min	0.15	Min value of food availability ratio	
max	0.15	Max value of food availability ratio	
s	$(min - max)/(2)$		
a	$(min + max)/(2)$		
t	$\frac{1}{365 \cdot 24}$	Sinusoidal scaler	
H	5040	Hour of peak availability	Hours
c	$27.8 \cdot 24$	Moon cycle length	Hours
h_c	h modulous c	The point in the moon cycle	Hours
k	0.3	Extinction coefficient of lake (CITATION)	UNITS
I_x	1×10^{-3}	Mysis Light threshold (CITATION)	Lux
S_l	(input)	Light level at lake surface	Lux
n	250	# of mysids	
r_h		Average hourly reward	Energy
m_c		Daily migration cost	Energy

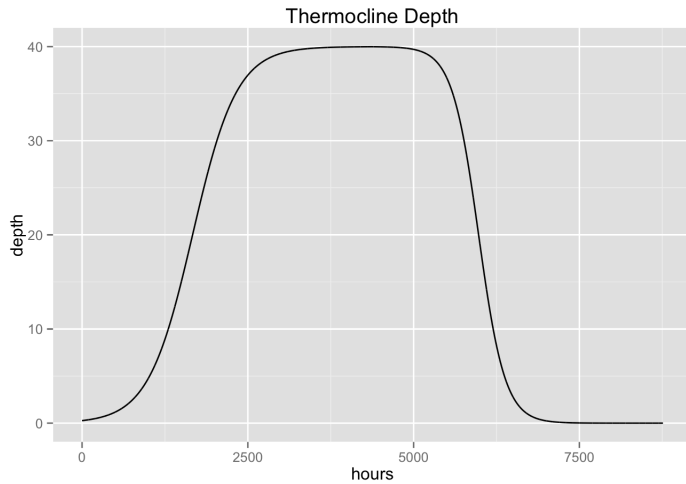
2.5. Sub Models

Four sub-models were developed to generate environmental variables for the main model. R Markdown scripts of all data generate are available in the appendix at rpubs.com/nstrayer.

2.5.1. Thermocline Model:

The first is a model of the depth in the water column at which 10 degrees celcius is attained. This temperature was chosen as a Mysis threshold based upon the work of (CITATION). To model this two sigmoidal curves were joined together to form the pattern observed in all large bodies of water over a year.

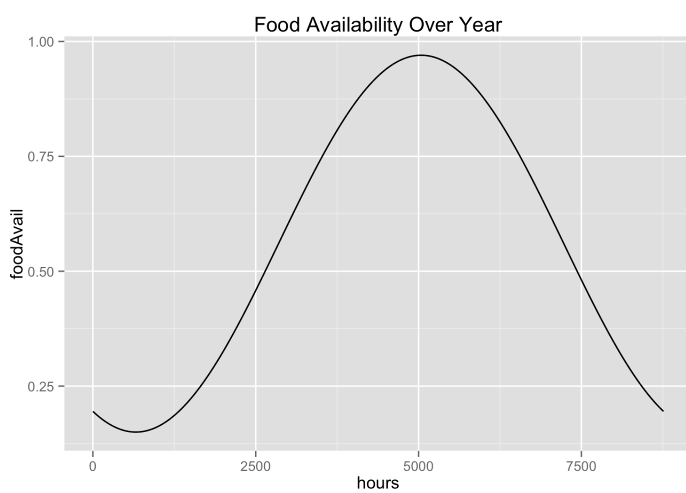
$$Th(h) = \frac{s \cdot M}{1 + e^{-k_t(h - m_t)}}$$



2.5.2. Food Availability

The food availability ratio is bounded between 0 and 1 and is a normalized measure of food quality in the pelagic waters to the whole water column. E.g. food availability = 0.8 implies 80% of the food is available in the pelagic waters.

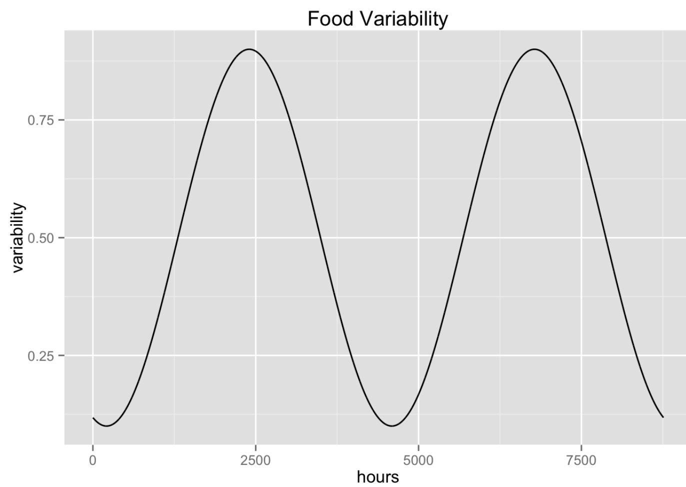
$$FA(h) = s \cdot \cos\left[(1/8750) \cdot 2\pi \cdot (h - H) + a\right]$$



2.5.3. *Food Variablity*

To generate the food variability curve for food availability we simply doubled the frequencies of the curve in section 2.5.2 to capture high variability in food availability during spring and fall. This value is used in the model to control the deviation of the distribution of the individual's feeding reward.

$$FV(h) = s \cdot \cos\left[(1/8750) \cdot 4\pi \cdot (h - H) + a\right]$$



2.5.4. *Isocline Depth*

Mysis are photophobic. (CITATION) looked at this sensitivity and found a threshold of light in lux (mention at what wavelength). The depth at which this light level is reached the water column was modeled over the course of the entire year. To do this data of light intensity levels in Burlington were obtained from the National Renewable Energy Laboratory (NREL CITATION). Due to the sensitivity of the sensors in low light levels the data needed to be filled in with a simple moon cycle model.

2.5.5. *Moon Cycle*

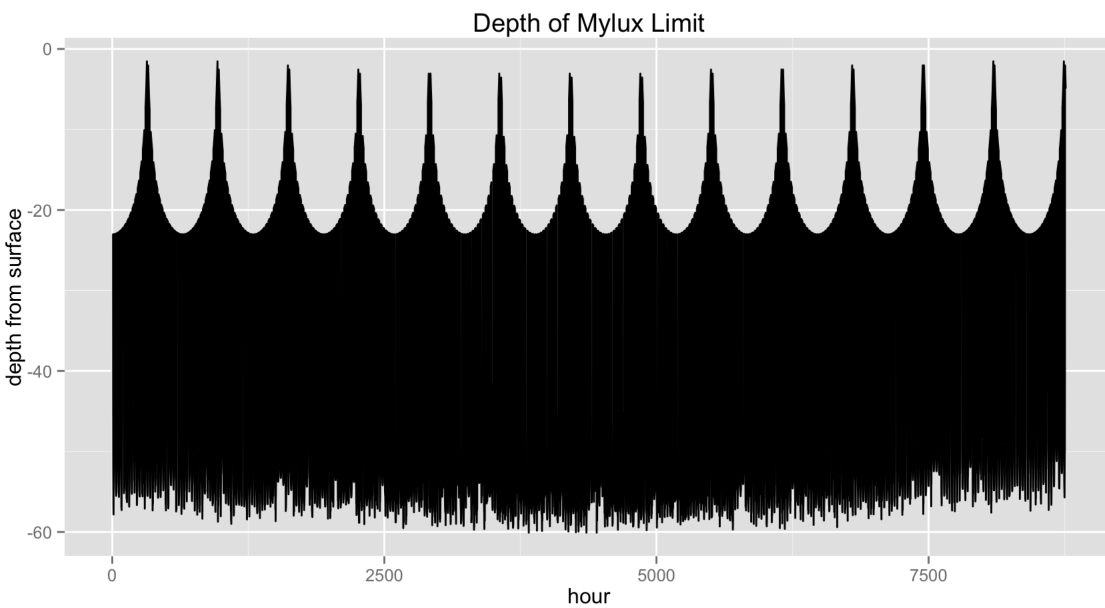
Raw data was read in from the National Renewable Energy Laboratories data explorer (Citation), however the sensitivity was not high enough to pick up the lunar cycles. Due to this nighttime light intensity levels were substituted with the model. The greatest light intensity between the moon cycle model and real data was chosen for the final dataset.

$$MC(h_c) = 0.5\left[\cos\left(\frac{1}{c} \cdot 2\pi \cdot h_c\right)\right] + 0.5$$

2.5.6. Beer's Law

Once a complete dataset was had for the year the light intensity was run through an equation derived from Beer's Law (CITATION). This equation takes in light intensity levels and returns the depth at which the mysis light threshold is reached.

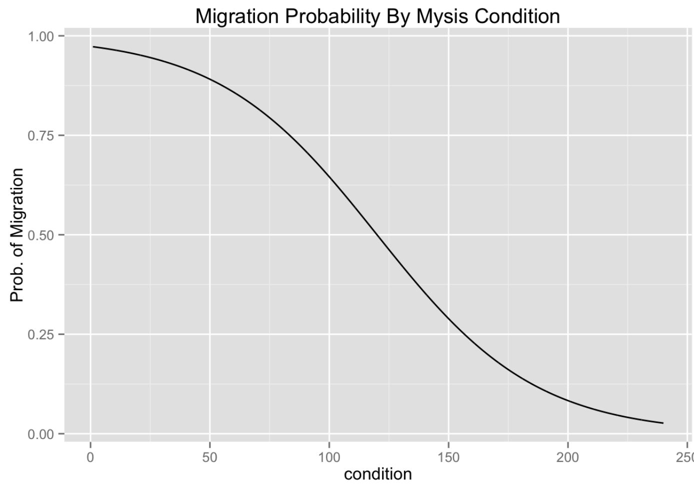
$$B(S_l) = \frac{1}{k} \cdot \log\left(\frac{S_l}{I_x}\right)$$



2.5.7. Probability to Migrate

In order to simulate responses to body condition we generated a curve to influence a mysis' desire to migrate to their body condition. With this curve a mysis with a high body condition is less likely to migrate than a mysis with a low body condition with the midpoint of the sigmoid sitting at what we decided was a 'normal' mysis body condition.

$$PM(x) = \frac{1}{1 + e^{-k_p(x - m_p)}}$$



2.5.8. Migration Reward

If the individual is in the state of migrated then at every hour h_i it draws its energy reward from a normal distribution with mean scaled with food availability and a standard deviation of $FV(h_i)$. Note that this value can be negative.

$$MR(h) = N\Big(r_h \cdot [1 + FA(h)], FV(h)\Big)$$

2.5.9. Stay Reward

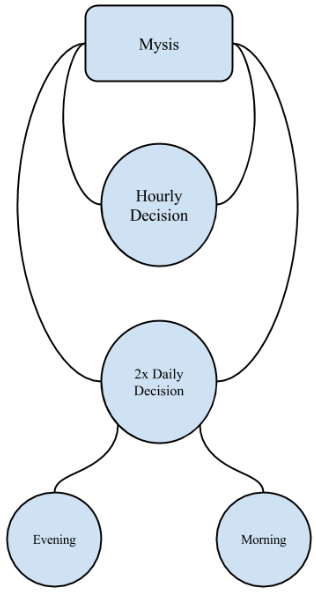
If the individual is not migrating their reward is the the largest value between twenty percent of the migration reward or 0.2 energy units.

$$SR(h) = \max\Big[0.2 \cdot MR(h), 0.2\Big]$$

2.6. Agent Based Model

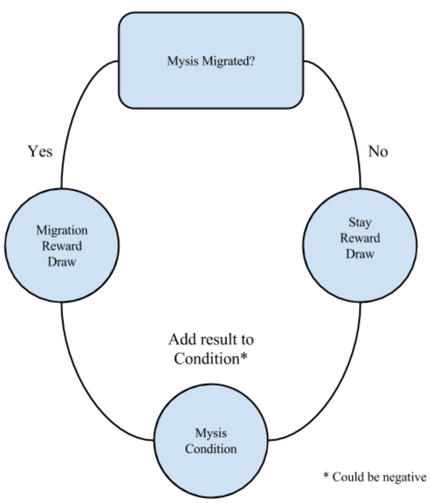
Our agent based model runs an individual through a year on an hourly time step. At every hour the mysis attempts to feed based upon its current habitat (Benthic or Pelagic). Twice a day, once one hour after sunset and then again one hour before sunrise the mysis decides to migrate based upon its condition and environmental food availability.

2.6.1. *Main Model*

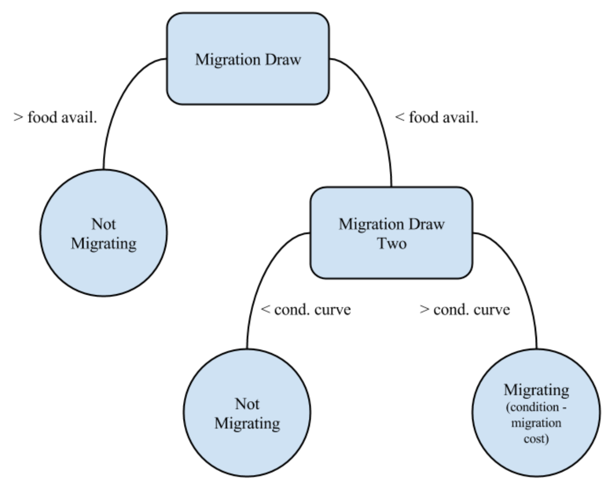


2.6.2. *Sub-Models*

Hourly Decision



Twice Daily Decision:

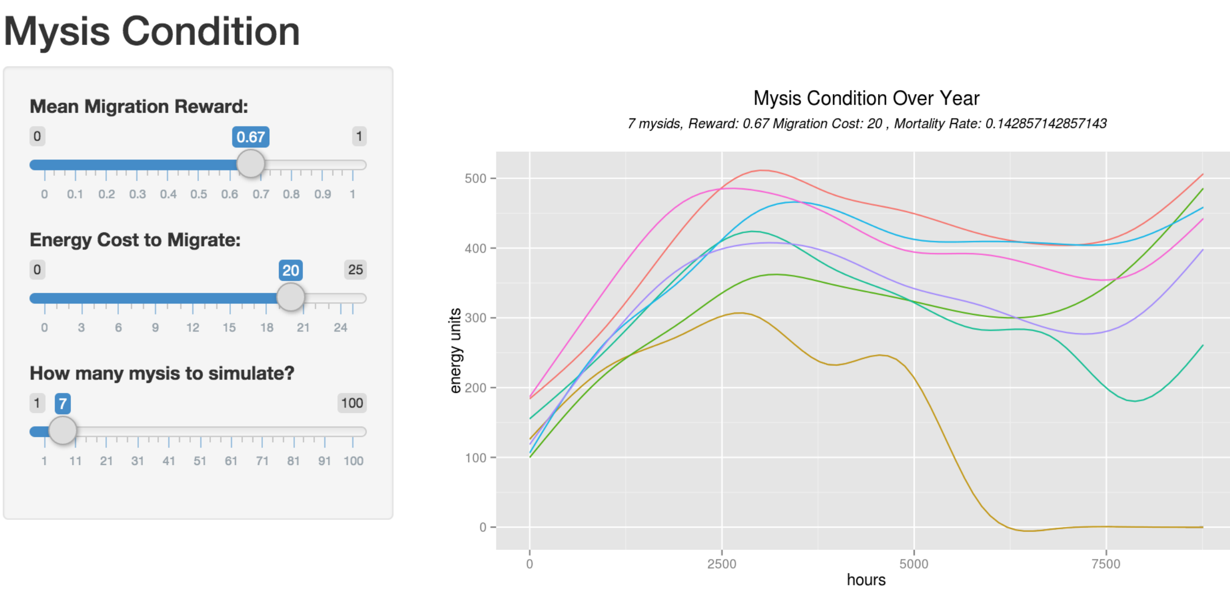


2.6.3. Testing of Agent Based Model

To test the agent based model's sensitivity to changes in variables we ran the model through an entire year, simulating n mysids while perturbing the mysids average hourly energy reward and cost of migration. At each simulation we recorded the proportion of surviving individuals with predation risk set to zero as to isolate the effects of the perturbing the variables.

2.7. Interactive Model Server

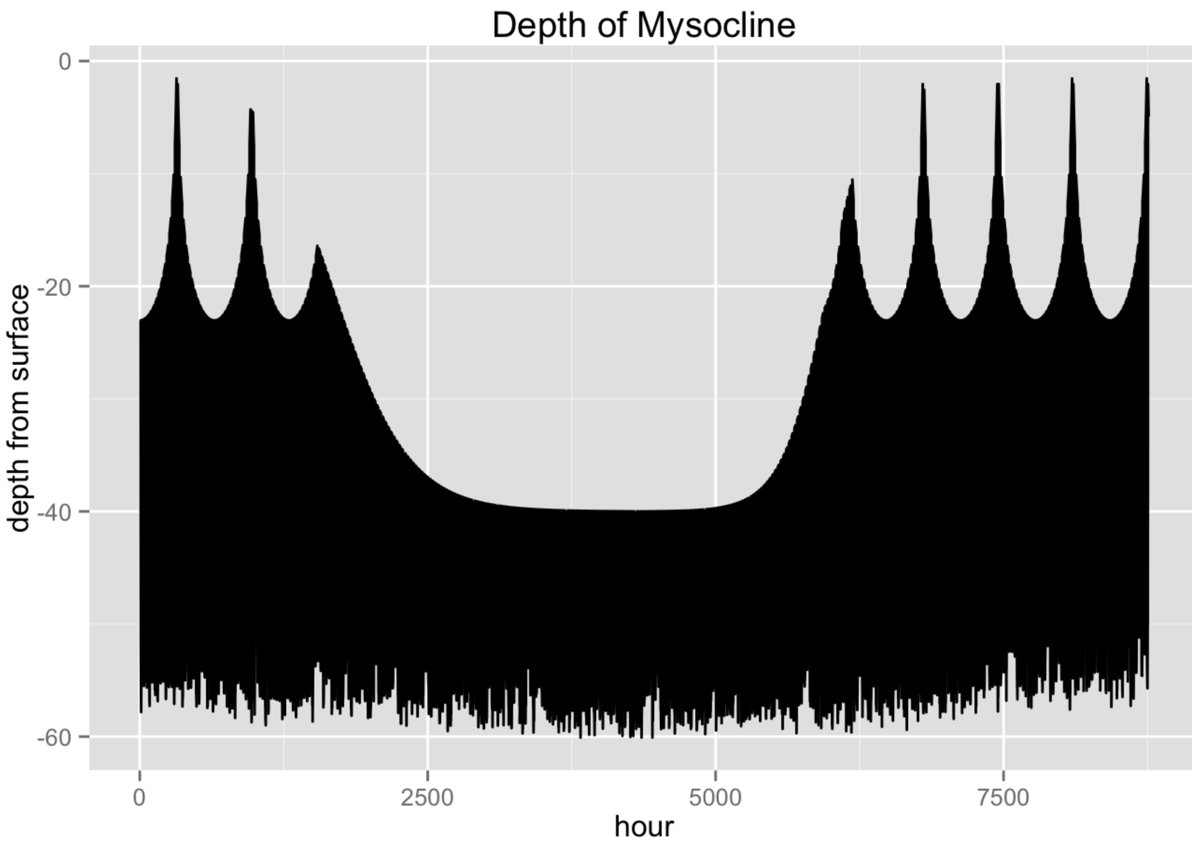
In order to help speed up analysis of variable perturbation an interactive R shiny server (CITATION) was developed. This server allowed the user through a graphical user interface to manipulate parameters of the model and in real time watch the effects of those manipulations over the course of a year on the simulated individuals.



3. Results

3.1. Mysocline

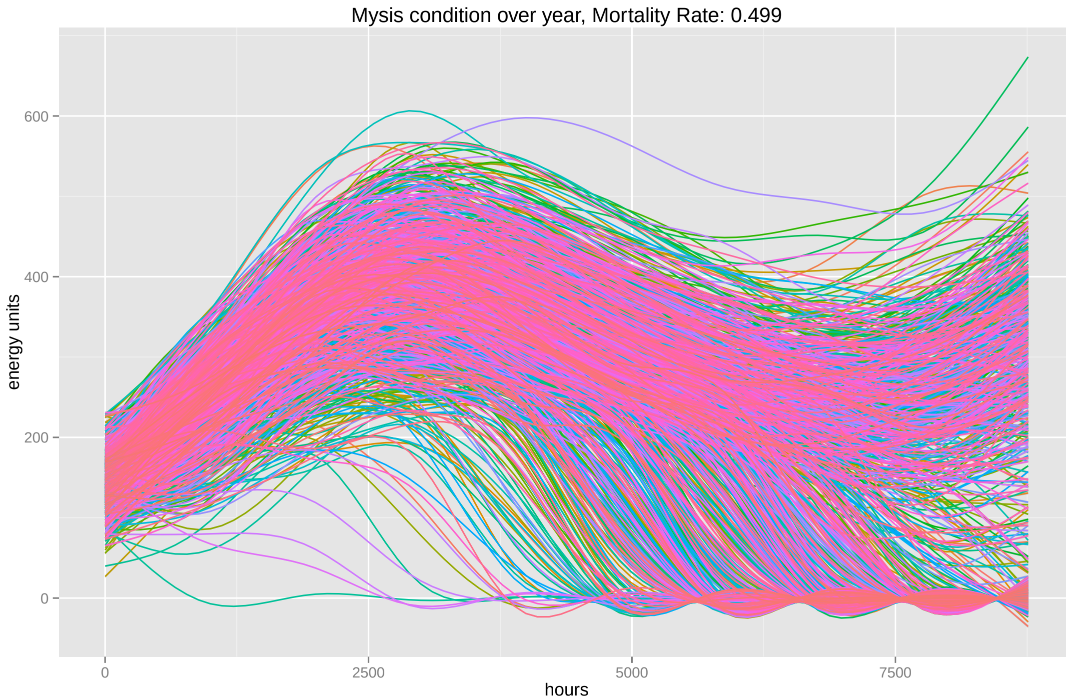
By merging the theoretical migration limit provided by where ten degrees celsius is in the water column with the location of the Mylux limit I_x we are able to get a macro-view of migration extent for mysids in Lake Champlain over the course of the year.



From this figure we can see that during the winter the factor limiting mysid migration is the light intensity levels, and in the summer it is the thermocline.

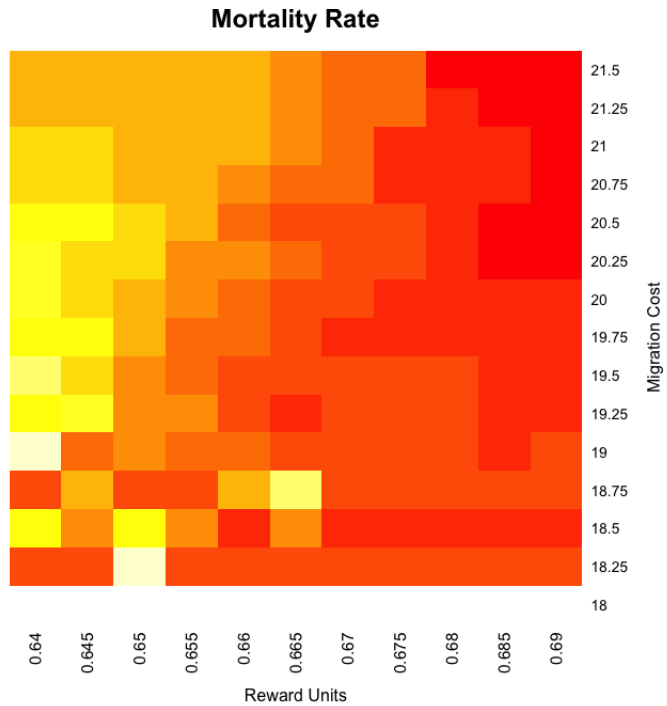
3.2. Sensitivity to Rewards and Cost

Using the shiny app we located a range of expected behavior for the parameters of average energy reward (r_h) and daily migration cost (m_c). We then set the model to run on a range of these values of 0.64 to 0.69 for r_h and 18 to 21.5 for m_c. At each combination of the variables we recorded mortality rates.



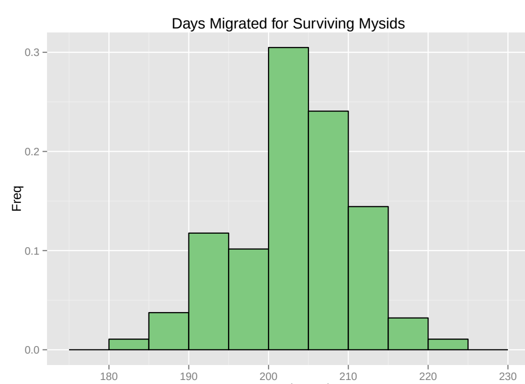
From this run of a year and one thousand mysids we can see that most individuals fair very well in the first few months of the year, and then the whole population's condition starts to decline around late spring, continuing to decline until early winter and then resuming a climb in the last couple months of the year. This particular run with r_h of 0.68, and m_c of 20 has a mortality rate of around 50%.

By repeating this simulation over the aforementioned ranges of r_h and m_c we can see the model's sensitivity to their changes.



3.3. Multiple Migration Strategies

For each run the number of days that a given surviving individual chose to migrate was recorded and plotted. We found that most of the time the distribution of days was normal, however some days, such as the shown example there is slight bi-modal tendencies. None enough to make any definitive statements about the presence of multiple stable strategies for migration behavior.



4. Conclusions and Future Directions

4.1. Environmental Roll

The models response to variable perturbations implies high sensitivity to environmental changes. For example population level conditions were highly tied to the seasons with a large portion of the population getting close to starvation in the mid-summer months, if the pull out of that fall didn't occur until later in the year there is a strong potential for a high impact on the survival rate of individuals.

4.2. Roll in the Lab

Sampling enough to get a confident image of mysis behavior is simply too expensive and time consuming. That being said, modeling, especially with so many assumptions is not an exact science. Nothing will replace physical sampling of mysids. The model developed fits into the workflow of mysis research well by the potential to guide future sampling and field research.

4.3. Future Directions

We have seen that survival over the course of the year is highly affected by small perturbations in the cost of migrating and feeding rewards, future projects could look at where mysis populations sit in the water column, potentially sitting higher as to lower migration costs, or potentially staying at the bottom because the food availability outweighs the migration costs associated with a longer migration.