Calibration:

Due to limited availability of stock assessment data for paddlefish, I was unable to create a fully descriptive individual based population dynamics model. (Such a model would rely on empirically estimated spawner-recruit relationships and fishing mortality.) However, I was able to come up with a relatively simple model that simulates individuals moving between reservoirs and spawning. The population model has four demographic processes that drive the overall dynamics: birth (recruitment), death (mortality), aging, and movement (passage between reservoirs). Individuals age one year per time step of the model, and are then subjected to a series of processes defined by their age:

New recruits (Age 0) disperse downstream to the next reservoir or not depending on *PDOWN* (binomial prob of downstream movement), and then either die or not depending on *MJ* (proportional juvenile mortality).

Immature adult fish age 1-7 do not move, but can die or survive depending on *MA* (proportional adult mortality).

Mature adult fish age 8+ pass upstream to the next reservoir or not depending on *PUP* (binomial probability of upstream passage), and then either die or survive depending on *MA*.

At the end of each timestep, the number of fish in each reservoir is counted, and new recruits are added to each reservoir proportionally. The population in each reservoir is multiplied by a random draw from a normal distribution with mean *R* (recruitment) and variance *RVAR* to allow for stochastic changes in recruitment from year to year. I simulated 50-year time series of population dynamics.

I selected *MA* from Rider 2011 which estimated the annual natural mortality of Alabama River paddlefish to be 0.29. Given that juvenile mortality is extremely high for most fish species, I set this parameter at 0.6. At first, I fixed the passage rates at 0 so that each reservoir was independent of the others. Then, I calibrated the model by testing values of *R* until the time series of reservoir abundance stabilized for longer than 50 years. Once I found a set of parameters that created a stable population, I began the experiments: to see what combinations of parameters disrupt that stability.

The metric I designed to assess stability was the proportion of 10 simulations that result in a population crash at some point during the 50 year time series. (I originally designed the model to last 300 years, but this exacerbated problems with computation power, so I had to limit the length of each simulation.) I defined a “crash” as a population size of less than 10 fish at the end of the time series. Remember: the main driver of stochasticity is the annual variance in recruitment which represents wet and dry years. I decided not to set a random seed so that each simulated time series has independent variation in recruitment.

The first experiment was to see how changing natural mortality and the probability of upstream passage by adults interacts to affect the probability of population crashes. I ran 10 simulated time series for each combination of parameters: (MA = 0.10, 0.14, 0.18, 0.22, 0.26, 0.30, 0.34, 0.38) and (PUP = 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1.0). The result was an 8 by 10 data matrix of the proportion of 10 simulations that resulted in population crash.

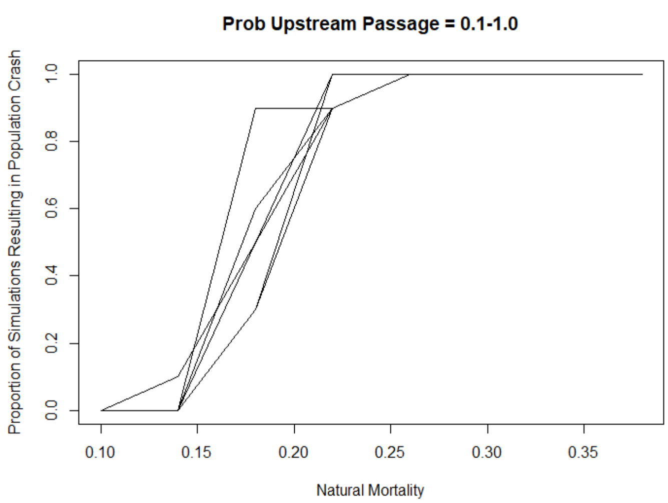
The second experiment was to see how average annual recruitment and upstream passage of adults interact to affect the probability of population crash. I ran 10 simulated time series for each combination of parameters: (R = 1.5, 1.6, 1.7, 1.8, 1.9, 2.0, 2.1, 2.2, 2.3, 2.4, 2.5, 2.6, 2.7, 2.8, 2.9, 3.0, 3.1, 3.2, 3.3, 3.4, 3.5) and (PUP = 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1.0). I fixed the variance RVAR at 0.02 to limit interannual stochasticity and not mask the interaction.

Finally, I tested the interaction of juvenile mortality and the downstream dispersal of juveniles. I ran 10 simulated time series for each combination of parameters: (MJ = 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1.0) and (PDOWN = 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1.0). I fixed upstream passage probability of adults at 0.5 for these simulations.

Results:

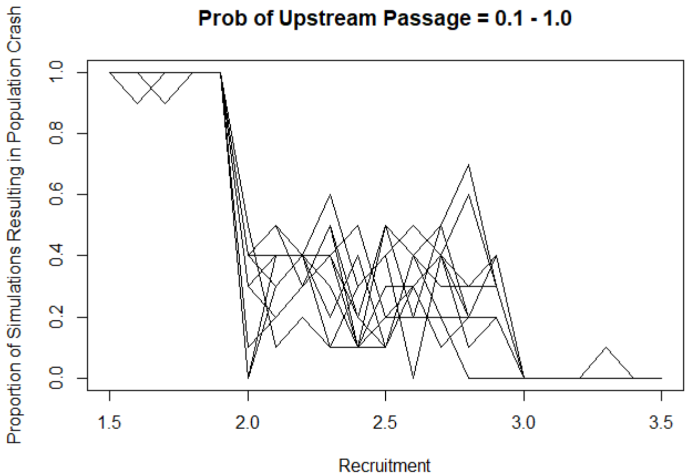
Experiment 1

Altering the probability of upstream passage had little effect on the steepness of the relationship between natural adult mortality and the probability of population crash. As expected, at low levels of natural mortality, the population is stable through time. Unexpectedly, at the currently estimated value of natural mortality (0.29), 100% of simulated time series resulted in population crash, regardless of the levels of upstream passage. Each line corresponds to a crash-mortality relationship at a different level of upstream passage probability.



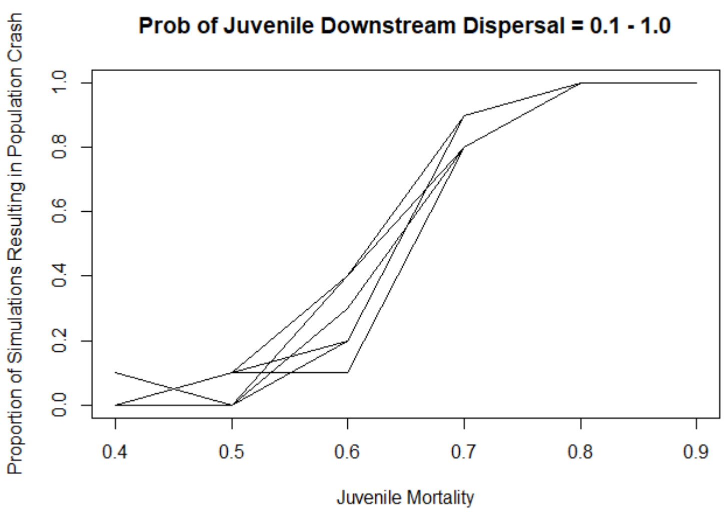
Experiment 2

The relationship between the probability of upstream passage and recruitment was more complex. Regardless of the level of upstream passage, the probability of population crash was relatively constant (around 100%) until recruitment was 2 or greater. At values between 2 and 3, the probability of population crash was variable, but low (between 0 and 60%) and at values higher than 3, the probability was nearly 0%. Each line corresponds to a crash-recruitment relationship at a different level of upstream passage probability.The wide variance between the different levels of upstream passage is most likely due to the stochasticity in recruitment, given that the lines intersect randomly between recruitment levels of 2 and 3.



Experiment 3

Similar to the relationship between adult mortality and upstream passage, the interaction between juvenile mortality and downstream passage was not particularly strong. Each line in figure 3 corresponds to a crash-mortality relationship at a different level of downstream passage probability.The probability of population crash was logistically related to juvenile mortality, with very little variation accounted for by downstream dispersal probability. Interestingly, the probability of population crash did not maximize until juvenile mortality was very high: >0.8. As expected, at low levels of juvenile mortality, simulated populations were relatively stable.



Discussion:

Overall, it is impossible to tell if this simulation represents true population dynamics in the Alabama River because we lack empirical information for comparison. However, it does reveal interesting relationships between demographic processes that could have important implications for the management of movement between the metapopulations. The steepness of the relationship between natural mortality and crash probability indicates that this parameter is the strongest driver of population dynamics in the system. Increasing passage rates between the dams may not actually be important for overall population stability if natural mortality is truly 0.29 as estimated by Rider 2011.

Future iterations of this model will develop more complexity in the stock-recruit relationship. The simplistic approach I took with a random proportional multiplier (R, RVAR) does not reflect the true relationship, which is log-linear. Recruitment, as hypothesized by the Beverton-Holt model, increases rapidly with the number of spawners at low population sizes, but slowly at large population sizes. This reflects the effects of density dependence. Once a maximum number of spawners in the population is reached, the number of additional recruits reaches an asymptote. This model assumes a linear relationship between spawners and recruits. Without empirically estimated parameters of the Beverton-Holt model for this population, I will have to do further testing and calibration.

An important thing to note is that the probability of passage (up or downstream) was applied to all three dams. Future iterations of the model will have a separate passage probability at each structure to see how this influences reservoir-specific demographics. For the purposes of this study, I elected to simplify the model and examine the impacts on the overall demography of the population.