Analysis of length weight data for Missouri River Pallid Sturgeon

Data from the Pallid Sturgeon Population Assessment Project (PSPAP) provided by C. Hubert on 4 January 2016. The objectives of this analysis are to: Estimate k and L∞ for upper and lower basin using recaptured Pallid Sturgeon. Evaluate Pallid Sturgeon condition over time. Link Pallid Sturgeon condition to fecundity. The primary function of these objectives are to parametrize the individual based growth model and links to fecundity in the population model.

## Data overview

Spatial extent of the Pallid Sturgeon Captures Pallid Sturgeon were captured and tagged as part of the Pallid Sturgeon Population Assessment Program since 2006. Fish were captured througout the upper and lower Missouri River basins (Figure 1).

# Pallid Sturgeon Length-Weight Relationship

## Overview

Initially length was modeled using a von Bertalanffy growth function predicting mean length at age. As the model has transitioned to an individual based model, growth (i.e., change in length) will occur on an individual level. This will allow the model to integrate the results of bioenergetic models. A critical aspect of this development is predicting weight from length. The relationship between length and weight also dictates fish condition which may have implications reproductive status.

## Preliminary results

Upper basin Pallid Sturgeon weigh more than similar sized fish from the lower basin (Figure 2). Fitting an allometric scaling equation (W = a ⋅ Lb) were different between the two basins, although differences among years was not evaluated here. See table 1 for preliminary estimates of a and b for the upper and lower basin for use in the population model.

# Pallid Sturgeon Condition

## Overview

Pallid Sturgeon condition was calculated as Kn = W/Ws, where Kn is the relative condition, W is the observed weight, and Ws is the standard weight. Standard weight was estimated by Shuman et al. (2011) for Pallid Sturgeon as Ws = 10 − 6.2561 ⋅ FL3.2932, where Ws is as described above and FL is fork length in mm.

## Preliminary results

Figure 3 presents Pallid Sturgeon condition since the beginning of the PSPAP. Upper basin fish appear to have higher condition than lower basin fish, although it should be recognized that the equation used to calculate relative condition might be basin specific. Overall relative condition is variable in both basins. Patterns in relative condition appear to decline since 2011, however it is unclear what is biological versus statistically significant.

# Individual growth

## Overview

Because the model has moved to a individual based framework it makes sense to model growth as individuals rather than as a population von Bertalanffy growth function (vggf). In this analysis we estimated the parameters k and L∞ given initial size at capture and size at recapture. herefore only fish with 2 or more reaptures were used for this analysis. The parameters k and L∞ can be estiamted using the Fabans methods and extensions. This approach estimates the change in length over the time at recapture. Is is reasonable because the vbgf, in ordinary differential equation form is dL/dt = k(L∞ − Lt). There are limitations to this approach resulting in bias that should be recognized. One benefit of this appraoch is that the equation governing the change in length over time is linear, which might allow the analysis to account for among individual variability.

## Preliminary results

There is substantial variation in growth trajectories among individuals. Additionally there are individuals that lose weight rapidly over a short period of time. Changes in length are lower in the upper basin varying from -100 to 400 mm over over time, which varied from 0 to almost 10 years since tagging. This is likely due to the effect of initial size on change in length, specifically larger fish tend not to change length as much as smaller fish.

### How precise are lengths of Pallid Sturgeon

The ability to precisely measure length and weight is an important component of monitoring and detecting changes in condition. Figure 5. Plot of proportional change in length for individual Pallid Sturgeon with more than 1 length recorded within 30 days. Figure 6. Plot of proportional change in weight for individual Pallid Sturgeon with more than 1 length recorded within 30 days.

## Individual Pallid Sturgeon Growth

Using the data for Pallid Sturgeon with 2 or more captures, I fit a Fabens type model to estimate k and L∞. Some data massaging was need to figure out fish with what I assume was data entry errors. Specifically, observations were filtered based on these criteria: 1) change in length over time was constrained to be > 0, 2) Excessively large growth rates were removed (G<0.5 and daily growth < 4). The Fabens model was recast as

L2, i = ((L∞ − L1, i) \* (1 − e − k ⋅

 Ti)) ⋅ ϵi where L2 is length at recapture, L1 is length at capture, L∞ is length at infinity, k is the how fast length approaches L∞ and T is time between capture and recapture in years. A hiearchical model was used allowing L∞ and k to vary among individuals as:

L∞, i ∼ Lognormal(μL∞, σL∞)

ki ∼ Lognormal(μk, σk)

ϵi ∼ Lognormal(1, σ)

Fitting the model in JAGS resulted in (preliminary)

Lower basin-

L∞ ∼ Lognormal(1180, 0.05)

k ∼ Lognormal(0.05, 1)

ϵ ∼ Lognormal(1, 0.003)

To do: 1. Account for L∞ and k should be nested within same fish 2. Correlation of L∞ and k?

# Pallid Sturgeon growth and weight relationships estimation

The objectives of this analysis were to: 1. Estimate $k$ and ${{L}\_{\infty }}$ for upper and lower basin using Pallid Sturgeon capture-recapture data 2. Length-weight

## Methods

### Study area

Pallid Sturgeon were captured and tagged as part of the Pallid Sturgeon Population Assessment Program since 2006. Fish were captured throughout the upper and lower Missouri River basins (Figure 1).

### Data collection

Fish captured during part of Pallid Sturgeon Population Assessment Program (PSPAP) were used for analysis. The PSPAP is a long-term monitoring program targetting Pallid Sturgeon using a variety of gear (i.e., otter trawls and trotlines). See Welker and Drobish (2012) for full details. Captured Pallid Sturgeon were evaluated measured for length and weight and examined for the presence of a passive integrated transponder (PIT) tag. Similar capture-recapture efforts occurred on the upper and lower Missouri River (Figure 1).

### Growth model

Some data massaging was need to figure out fish with what I assume was data entry errors. Specifically, observations were filtered based on these criteria: 1) change in length over time was constrained to be > 0.2). Excessively large growth rates were removed (G<0.5 and daily growth < 4. A hierarchical model was used allowing  and  to co-vary among individuals as:

 (2)

where is the length at recapture,  is the length at infinite age,  is the growth coefficient, is the time between capture and subsequent recapture, is the length at previous capture,  indexes observations within individual fish and  indexes individual fish. Estimated values of  and  were assumed to be multivariate normally distributed as

, (xx)

where

 is a vector representing the population mean

 and  on natural log scale

 is the variance of ,

 is the variance of ,

 is the covariance of the estimated means

The correlation of  and  was calculated as . The model was fit to the data assuming observations were normally distributed as:

 (xx)

where  was the observed length at recapture, was the predicted length of the the ith observation in the jth individual fish, and  was observation error.

Priors and model fitting.—We specified non-informative priors for estimated parameters. , , , , ,  to fit the model to the data. Overall average values,  and , were specified as a normal distribution with mean 0 and variance of 1000. The prior for was specified as an inverted Wishart distribution with mean values along the diagonal of the 2 x 2 matrix equal 0.1 and precision of 10 for off diagonal covariance elements of the matrix (Helser and Lai 2004). Observation error, , was specified as gamma distributed with scale and shape parameters equal to 0.001. The model was fit to data using JAGS (Plummer 2003) using the R2jags package in R (R Development Core Team 2010, Su and Yajima 2013). The model was fit by initializing 3 chains and simulating 500k iterations, with the first 200k were discarded as burn-in samples. The Gelman-Rubin convergence statistic and visual inspection of the 3 MCMC chains were used to ensure adequate chain mixing was achieved (Gelman and Rubin 1992).

### Weight model

A length-weight model was estimated for upper and lower basin Pallid Sturgeon. The standard allometric scaling equation was used and linearize by taking the log of both sides as:

 (1)

Where



is fish weight,



is the intercept,



is the allometric scaling coefficient,



is the length of the fish, and

 is normally distributed with mean 0 and standard deviation .

The model was fit to natural log transformed length and weights using the lm() function in R (R Development Core Team 2010). Analyses were run separately for upper and lower basin Pallid Sturgeon populations.

## Results

### Data

Data available for analysis varied between basins. Pallid Sturgeon with length and corresponding weights spanned 2003-2016 and 2005-2015 for the lower and upper Missouri River basins respectively. Collectively, there were 12,312 fish used to fit the length-weight relationship, 7088 and 5224 for the lower and upper basin respectively. Growth was estimated for 2859 lower and 1619 upper basin individual fish after filtering Pallid Sturgeon that did not meet criteria for analysis inclusion. The actual number of observations used to estimate growth of theses XXXX individual fish was 3664 and 1838 for the lower and upper basin respectively.

The amount of time at large (i.e., time between subsequent capture events) varied among individual fish and basin. Time at large varied from 1-4955 and 1-5472 days for lower and upper basin Pallid Sturgeon respectively. Average time at large was 1427 (lower basin) and 1018 (upper basin) days. The majority of individual Pallid Sturgeon were recaptured once, representing 80% and 88% of the fish used to estimate growth in the lower and upper basin respectively (Table 1). The maximum number of recaptures of an individual fish was 6 and 4 for the lower and upper basins.

### Growth

Change in length and growth trajectories varied among individuals and basins. A linear relationship of change in length with time between captures was observed for the upper and lower basin (Figure 2). Absolute growth was similar between basins… Smaller fish , those tagged that were less than 500 mm exhibited faster, albeit variable growth, relative to larger fish as in indicated by the slope of the growth line (Figure 3). Larger fish had smaller change in length than smaller fish (Figure 3). Estimates of  and  varied between basins with upper basin (Table 2). Estimated was higher for upper basin fish while  was lower for lower basin fish. A negative correlation between  and  was estimated for both basins that exceeded 0.75.

### Length-weight relationship

Length and weight varied between upper and lower basin Pallid Sturgeon. The maximum length was higher for the upper basin fish as well as upper basin fish weighed more than similar sized fish from the lower basin (Figure 2; Table 3). Parameter estimates for the allometric scaling equation varied between the two basins (Table 3).

## Discussion

Change in length was modeled using a von Bertalanffy growth function predicting mean length at age. As the model has transitioned to an individual based model, growth (i.e., change in length) will occur on an individual level. This will allow the model to integrate the results of bioenergetic models. A critical aspect of this development is predicting weight from length. The relationship between length and weight also dictates fish condition which may have implications reproductive status.

Shuman…., Wildhaber, ect relationships

No aging error….

Plugin for bioenergetics model…

## Plugin codes

# Hatchery operations

Notes.

\* Collection started May 5th 2014 for USFWS and MTFWP, May 18th in 2015

Table 1. Months when are fish are spawned? 1992-2014 data.

| RPMA | Month | Females spawned |

|:----: |:-----: |:---------------: |

| 2 | 5 | 1 |

| | 6 | 40 |

| | 7 | 15 |

| 4 | 4 | 13 |

| | 5 | 6 |

| | 6 | 21 |

| | 7 | 14 |

Table 2. What hatchery sources are fish from that are stocked into RPMA 2 and 4? 1992-2014 data.

| Hatchery | RPMA 2 | RPMA 4 |

|-------------- |-------- |-------- |

| Blind Pony | | x |

| Bozeman | x | |

| Fort Peck | x | |

| Garrison | x | x |

| Gavins Point | x | x |

| Miles City | x | |

| Neosho | | x |

Table 3. Summary of the number of fish stocked into RPMA 2 and 4 by age

at stocking and year outplanted into the river. 1992-2014 data.

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Pull and kable from dbase

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Table 4. Numbers of days post hatch for age at stocking classification.

| RPMA | Age at stocking | DPH Mean | DPH min | DPH max | Size (mm) |

|------ |----------------- |---------- |--------- |--------- |----------- |

| 2 | fry | 28 | 4 | 69 | |

| | fingerling | 88 | 52 | 113 | |

| | adv. fing. | 119 | 77 | 150 | |

| | yearling | 316 | 264 | 490 | |

| | 2 yr old | 853 | 853 | 853 | |

| | 6 yr old | 2266 | 2266 | 2266 | |

| 4 | fingerling | 148 | 64 | 202 | |

| | yearling | 392 | 281 | 545 | |

| | 2 yr old | 671 | 626 | 706 | |

| | 3 yr old | 1109 | 1044 | 1236 | |

| | 5 yr old | 1774 | 1774 | 1774 | |

| | 6 yr old | 2126 | 2126 | 2126 | |

| | 7 yr old | 2521 | 2521 | 2521 | |

# Appendix-XX Model plugins

## Overview

Types of plugins:

initialization,

transition- survival, maturity, so on Boxes

dynamics- growth, so on

Initialization

Length, weight, age initialization

\* Basin specific

\* PSPAP data

\* Reduce to below of L > L\_inf

\* Assign weight

\* Assign age given 7mm at hatch

\* Assign location given PSPAP densities at segment level, randomized within segment

\* Assign

\* Draw L\_inf and k from MVN distribution for upper and lower basin

$$\[\left( \begin{matrix}

\ln {{L}\_{\infty ,i}} \\

\ln {{k}\_{i}} \\

\end{matrix} \right)\tilde{\ }MVN\left( \left( \begin{matrix}

{{\mu }\_{\ln ({{L}\_{\infty }}),basin}} \\

{{\mu }\_{\ln (k),basin}} \\

\end{matrix} \right),\left( \begin{matrix}

\sigma \_{^{\_{\ln ({{L}\_{\infty }}),basin}}}^{2} & {{\sigma }\_{\ln ({{L}\_{\infty }}),basin}}\cdot {{\sigma }\_{\ln (k),basin}} \\

{{\sigma }\_{\ln (k),basin}}\cdot {{\sigma }\_{\ln ({{L}\_{\infty }}),basin}} & \sigma \_{\_{\ln (k),basin}}^{2} \\

\end{matrix} \right) \right)\] (xx)$$

\* $L\_{\infty ,i,t=0}\tilde$

\* $k\_{i,t=0}\tilde$

\* $F{{L}\_{i,t=0}}\tildegeneratedfromdata$

\* $Origi{{n}\_{i,t=0}}=$

\* 

# Figures

Figure 1. Spatial extent of Pallid Sturgeon captures and recaptures in the upper and lower Missouri River basins.

Figure 2. Relationship of length with weight for upper and lower Missouri River Basin Pallid Sturgeon.

Figure 3. Estimated relative condition over time for Pallid Sturgeon captured in the upper and lower Missouri River basins.

Figure 4. Plot of change in length (y-axis) and change in length (x-axis) for Pallid Sturgeon that were captured and recaptured in the upper and lower Missouri River basins.

figures(1) # study area

savePlot("./figures/figure-01.png",type="png")

figures(2) # length weight plot for upper and lower basin

savePlot("./figures/figure-02.png",type="png")

figures(3) # Change in length (y-axis) versus time at large (x-axis) plot for upper and lower basin

savePlot("./figures/figure-03.png",type="png")

figures(5)# PLOT TIME AND GROWTH

savePlot("./figures/figure-05.png",type="png")

# Tables

Table 1. Estimated a and b parameters for upper and lower Missouri River Pallid Sturgeon. Values in parentheses are 95% confidence intervals.

tbl1<- tables("tbl1") # length weight relationship by basin

write.csv(tbl1, "./tables/table-01.csv")

tbl2<- tables("tbl2") # growth model selection

write.csv(tbl2, "./tables/table-02.csv")

tbl3<- tables("tbl3") # growth model parm estimates

write.csv(tbl3, "./tables/table-03.csv")

tbl5<- tables("tbl5")# growth model parm estimates-correlated linf and k

write.csv(tbl5, "./tables/table-05.csv")