**Effect of condition on fecundity**

Several factors are hypothesized to influence female fecundity in fish species. One factor that has received much attention is fish condition. Condition is indexed by calculating the deviation of an observed weight from an expected or standard weight given length. Linear and log-linear regression is commonly used to estimate fecundity-weight and fecundity-length relationships. However the effect to of condition is rarely evaluated, likely because condition is a function of length and weight and is there dependent on those values. One assumption of linear regression is that covariates are independent, posing a challenge to using condition as a covariate of length or weight to explain additional variability in observed fecundities. Similarly, the use of length and weight as covariates to explain variation in observed fecundity is problematic because these covariates are nearly perfectly correlated on log scale. We used linear regression with an offset to remedy these issues and predict female fecundity from individual fish length and weight. Using offsets in linear regression assumes that the coefficient of the covariate with the dependent variable is 1. In this case, length was included as an offset in a linear model as

 (1)

where  indexes individual Pallid Sturgeon,  is expected fecundity,  is the intercept,  is the slope,  is fish weight,  is the known effect of length included as an offset, and  is a normally distributed overdispersion parameter (i.e., ). The parameters  ,, and  were estimated by maximum likelihood assuming observed fecundity was Poisson distributed as .

The length offset treats fecundity as a ratio, number of eggs per cm of length, which can then be increased or decreased depending on the estimated effect of weight. This type of regression is commonly used in exposure studies where counts of the dependent variable are a function of exposure time. This approach was used by Dick (2009) to model rockfish fecundity, however weight was used as the offset. We believe using length, rather than weight as an offset is more appropriate for this analysis because length sets the stage for how many eggs can be expected and fish that are heavier for their given length are more likely to have higher fecundity.

The model given in equation 1 was by Markov Chain Monte Carlo (MCMC). Three chains were initialized and allowed to burn in for 25K iterations and then thinned by 2 for the remaining 25K iterations to generate posterior distributions of parameters. Statistical inference was done by examining 95% credible intervals.

To evaluate the potential effect of condition on fecundity, fecundity was predicted for all possible combinations of fish lengths from 800 to 1100 by 10 mm and conditions from 0.7 to 1.1 by 0.05. Weight was then calculated by first estimating the standard weight using the length-weight relationship from Shuman and multiplying by condition. Fecundity was then estimated from the fitted model given the length and weight of the fish. Estimated fecundities were then plotted versus length and grouped by condition to visually evaluate the effect of condition on fecundity.

**Preliminary results and discussion**

Fecundity appeared to be related to length and weight (Figure 1 and 2). Model estimates suggested a positive but uncertain effect of weight on fecundity (Table 1). This was likely due to small sample size. Caveats about uncertainty in estimates of  aside, it suggests that for a 100 gram increase in weight for a given fish length there a 1.35% increase in fecundity (•100g•100) is expected (NOTE: this result is uncertain as 95% CI overlap 0, but 90%CI does not). Relating the estimated relationship to condition, results indicate that fecundity increases with increasing condition (Figure 3).

**Model plugin**

The link to the population model is that the effect of management actions may be propagated through fecundity through the equation:  where length () and weight () can be predicted from the growth module[[1]](#footnote-1). Alternatively models can be included that predict fecundity as a function of length as done for previous analyses (e.g., Wildhaber et al. , Steffensen et al. 2013).

**References**

Dick, E. J. 2009. Modeling the reproductive potential of rockfishes (*Sebastes* spp.) Doctoral Dissertation. University of California Santa Cruz.

Steffensen, K. D., M. A. Pegg, and G. Mestl. 2013. Population prediction and viability model for pallid sturgeon (Scaphirhynchus albus, Forbes and Richardson, 1905) in the lower Missouri River. Journal of Applied Ichthyology **29**:984-989.

Wildhaber, M. L., J. L. Albers, N. S. Green, and E. H. Moran. A fully-stochasticized, age-structured population model for population viability analysis of fish: Lower Missouri River endangered pallid sturgeon example. Ecological Modelling.

Table 1. Parameter estimates for the model relating Pallid Sturgeon length and weight to fecundity.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  |  | 95% Credible Interval | | 90% Credible Interval | |
| Parameter | Estimate | Lower | Upper | Lower | Upper |
|  | 2.75 | 2.23 | 3.37 | 2.29 | 3.21 |
|  | 0.0001352 | -0.00003 | 0.00028 | 0.000007 | 0.000263 |
|  | 0.33 | 0.23 | 0.49 | 0.24 | 0.46 |



Figure 1. Relationship of fecundity (*y*-axis) and fork length (*x*-axis) for lower basin Missouri River Pallid Sturgeon collected by Nebraska Game and Parks Commission.



Figure 2. Relationship of fecundity (*y*-axis) and fork length (*x*-axis) for lower basin Missouri River Pallid Sturgeon collected by Nebraska Game and Parks Commission.



Figure 1. Predicted effect of fish condition on fecundity. NOTE. Does not include uncertainty in predictions due to overdispersion.

Appendix type stuff

**Shuman equation to calculate relative condition**



**BUGS model to estimate the effect of weight on fecundity including length offset and overdispersion**

mod<- function()

{

# weight-fecundity model with offset

for(i in 1:n)

{

log(fec\_mu[i])<- a + b\_fec\*wgh[i] + log(len[i]) + disp[i]

disp[i]~dnorm(0,prec\_sigma)

fec[i]~dpois(fec\_mu[i])

}

# PRIORS

a~dnorm(0,0.001)

b\_fec~dnorm(0,0.001)

sigma~dunif(0.00001, 5)

prec\_sigma <-pow(sigma,-2)

}

Adat<- structure(list(wgh = c(2014L, 2074L, 3355L, 2084L, 3530L, 3202L,

2480L, 4575L, 3376L, 3235L, 2714L, 4778L, 3740L, 5334L, 3330L,

3060L, 5450L), len = c(829L, 788L, 944L, 816L, 948L, 939L, 860L,

1058L, 966L, 1015L, 864L, 1067L, 972L, 1060L, 938L, 895L, 1075L

), fec = c(12220L, 15484L, 16530L, 18288L, 18885L, 19570L, 19600L,

21600L, 22575L, 23370L, 24155L, 26752L, 27270L, 28950L, 36363L,

40172L, 54705L), n = 17L), .Names = c("wgh", "len", "fec", "n"))

inits<- function(t)

{

list(a=0.1,b\_fec=0.0005,sigma=.25)

list(a=0.0,b\_fec=0.0005,sigma=.25)

list(a=-0.1,b\_fec=0.0005,sigma=.25)

}

params<- c("a","b\_fec","fec\_mu","sigma")

out <- jags(data=adat,

inits=inits,

parameters=params,

model.file=mod,

n.chains = 3,

n.iter = 50000,

n.burnin = 25000,

n.thin=2,

working.directory=getwd())

# 90% BCI for estimates

lims <- quantile(out$BUGSoutput$sims.matrix[,"b\_fec"],c(0.05,0.95))

lims <- quantile(out$BUGSoutput$sims.matrix[,"a"],c(0.05,0.95))

lims <- quantile(out$BUGSoutput$sims.matrix[,"sigma"],c(0.05,0.95))

1. *Caveat emptor*. This is a bit of chicken and egg thing. Does a fish produce more eggs because it weighs more or does it weigh more because it has more eggs? [↑](#footnote-ref-1)