**Abstract**

**Introduction**

**Methods**

*Study Sites*

Study sites were located on 1st and 2nd order streams in the Loyalsock Creek watershed in Pennsylvania (Fig. 1); 100 m study reaches were established on each of 30 tributaries. SITE DESCRIPTION. SUBSTRATES, GRADIENT, FOREST COVER. Brook trout were the dominant fish species at most sites, but brown trout were also present in 16 of 30 study reaches.

Tropical Storm Lee dropped large quantities of rain on the study region from Sep 5, 2011 to Sep 8, 2011 (Fig 1), following closely after Hurricane Irene struck much of the northeastern U.S. The study sites received ~250mm of rain from Tropical Storm Lee, which raised discharge on Loyalsock Creek to its highest observed level on record (Fig. 2, Fig. 1, period of record: 1925-2015, U.S. Geological Survey 2015).

*Sampling*

Brook trout were sampled by backpack electrofishing during June and July 2011-2015. On most sampling occasions, three pass depletion surveys were conducted to allow for estimation of individual detection probability. On occasions when zero fish were caught on a pass, subsequent passes were not completed (97% of 2nd passes and 79% of 3rd passes were completed). WHAT OTHER DETAILS?. Wetted stream width was measured every XXX m on each sampling occasion. Total length and wet mass were measured for each individual. Within each year, there were obvious breaks between young-of-year (YOY) and adult brook trout in the length distributions (Appendix XXX, Fig AXXX); thus, individuals were classified as either YOY or adult based on length.

*Analysis*

Brook trout abundance was estimated using an N-mixture model, which corrects counts for detection probability to estimate latent abundance parameters (Royle 2004, see Appendix XXX for JAGS code). Importantly, this approach is robust to missing data because fewer than three passes were conducted in some sites/years. The model included two stages, YOY and adult, for which detection probability and abundance were considered independent. Abundance was modeled as poisson distribution:

where the parameter is the expected abundance at site 𝑖, in year 𝑡, for stage 𝑎. Expeceted abundance was modeled as linear on the log scale:

where the intercept, was modeled separately for each year and stage. Average site width across all sampling occasions was included as a covariate with slope 1, as a correction for site area. The parameter is a random site effect which was assumed to follow a normal distribution with mean zero.

Detection probability was assumed to be constant across passes, such that counts in pass 𝑝 () were modeled as:

where 𝑃 is the detection probability. Detection probability was modeled as a linear function of site width during sampling on the log scale:

where is the stage-specific intercept and is the stage-specific effect of site width at site 𝑖 in year 𝑡.

Biomass was estimated using abundance from the N-mixture model combined with mass measurements from each captured fish (N = 7908, range for site/year 1-212, mean = 54). We tested for differences in biomass (logarithm transformed), total length, and condition factor by modeling each as a function of a fixed year effect and a random site effect and comparing the 95% credible intervals among years. Fulton’s condition factor was calculated as , where 𝐾 is condition factor, 𝑊 is weight, and 𝐿 is total length (Ricker 1975). We also evaluated the relationship between length and logarithm transformed densities using a linear model with a random site effect on the intercept and a shared slope.

All statistical analyses were conducted using R 3.2.1 (R Core Team 2015) and JAGS (Plummer 2003). Vague priors were used for all parameters (Appendix XXX). Bayesian models were evaluated with three chains for a total of 10,000 iterations with a burn-in of 8,000. Every third iteration was saved after burn-in as a sample of the posterior distribution. Convergence was checked by visually examining posterior chains and using the R-hat statistic, which indicates convergence when R-hat values for all parameters are <1.1 (Gelman & Hill 2007). Posterior predictive checks were used to evaluate whether the model was appropriate for the data (Gelman et al. 2004).

**Results**

*Detection probability*

Average detection probability was estimated to be 0.74 (95% credible interval = 0.72-0.75) for YOY and 0.81 (CI: 0.79-0.82) for adults. Detection probability was negatively related to site width (slope on the logit scale: YOY mean = -0.13, 95% CI = -0.20 to -0.05; adult mean = -0.38, CI = -0.48 to -0.28); Appendix XXX, Fig AppendixXXX).

*Density*

Brook trout density varied significantly and substantially across years. The largest difference occurred after Tropical Storm Lee, with YOY increasing 23-fold on average and adult density decreasing by half (Fig 3). There was substantial variation in the size of these responses across sites. The increase in YOY density after the storm outweighed decreases in adult density such that overall density increased significantly, and elevated density was maintained for the duration of the study period.

*Biomass*

Changes in stage-specific biomass density mirrored those of density, with YOY biomass density increasing 46-fold after the storm and adult biomass density decreasing to 40% of pre-storm levels (Fig 3c-d). However, the increases in YOY biomass were offset by declines in adult biomass, such that overall biomass density did not differ significantly among any of the study years (Fig 3e).

*Length and condition factor*

Average total length changed significantly for both YOY and adult brook trout across the study period, but age classes responded differently. Average YOY length did not change the year after Tropical Storm Lee, but subsequently YOY became smaller with a slight rebound at the end of the study (Fig 4). In contrast, adult total length became larger by 20% the year after Tropical Storm Lee but then dropped sharply as the abundant 2012 year-class matured. Adult length then remained lower than its starting point for the remainder of the study period (Fig 4).

There were significant relationships between brook trout density and length for both YOY and adults. Higher adult densities were associated with smaller lengths of both YOY and adults. In contrast, higher YOY densities were positively associated YOY and adult length, though the magnitude of these slopes was much lower (Table 1).

Average condition factor also changed significantly over time, with a stronger response in YOY than in adults. YOY condition decreased from 2011 to 2014 and then rebounded some in 2015. Adult condition decreased as the large 2012 year-class matured, and neither adult nor YOY condition had returned to pre-flood levels by the end of the study.

**Discussion**

**Tables and Figures**

**Table 1.** Parameter estimates for the slope between total length and logarithm transformed density.

|  |  |  |
| --- | --- | --- |
| Response | Predictor | Slope (95% CI) |
| YOY length | YOY density | 1.53 (1.14, 1.92) |
| YOY length | Adult density | -3.58 (-3.84, -3.30) |
| Adult length | YOY density | 0.80 (0.10, 1.46) |
| Adult length | Adult density | -23.51 (-25.12, -21.88) |

**Figure 1.**



**Figure 1. a)** Cumulative precipitation from Tropical Storm Lee (September 5, 2011 to September 8, 2011) with the study area delimited in the rectangle CITE DAYMET FOR THE DATA. **b)** The Loyalsock Creek watershed showing study site locations (filled circles) and the USGS gauging station (asterix) and precipitation from Tropical Storm Lee (background color).

**Figure 2.**

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**Figure 2.** Discharge from the USGS gauging station on Loyalsock Creek (U.S. Geological Survey 2015).

**Figure 3.**

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**Figure 3.** Density (a-c) and biomass (d-e) for young-of-year, adult, and all brook trout. Gray lines are values for each site, and the black lines show the modeled means with 95% credible intervals. Within a panel, different symbols show years that have non-overlapping credible intervals (RIGHT NOW THERER ARE A FEW THAT HAVE MUTIPLE OVERLAPPING SYMBOLS BUT YOU CAN’T SEE THEM, NEED TO COME UP WITH A BETTER WAY TO DISPLAY SITES THAT ARE NOT DIFFERENT FROM MULTIPLE OTHER SITES).

**Figure 5.**

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**Figure 5.** Total length (a,b) and condition factor (c,d) for young-of-year (a,c) and adults (b,d). Gray lines show site means, and black lines show model results for overall means with 95% credible intervals. Within each panel, different symbols show years non-overlapping credible intervals.

**References**

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**Appendix XXXX.**

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**Figure XXX.** Length-frequency histograms for each year illustrating the breaks in the distribution between YOY and adults.

JAGS code used for N-mixture model for abundance:

#Priors

#detection parameters (betaP[1,]=intercept,betaP[2,]=slope for site width)

for(a in 1:nAges){

for(b in 1:2){

betaP[b,a]~dnorm(0,0.01)

}

#random site effect

for(i in 1:nSites){

muSite[i,a]~dnorm(0,tauSite[a])

}

sdSite[a]~dunif(0,15)

tauSite[a]<-1/pow(sdSite[a],2)

#fixed year effect

for(t in 1:nYears){

muYear[t,a]~dnorm(0,0.01)

}

#Likelihood

for(i in 1:nSites){

for(t in 1:nYears){

for(a in 1:nAges){

#abundance

N[i,t,a]~dpois(lambda[i,t,a])

log(lambda[i,t,a])<-muSite[i,a]+muYear[t,a]+

meanSiteWidth[i]

#Observation for depletion sampling

y[i,t,a,1]~dbin(p[i,t,a],N[i,t,a])

y[i,t,a,2]~dbin(p[i,t,a],N[i,t,a]-y[i,t,a,1])

y[i,t,a,3]~dbin(p[i,t,a],N[i,t,a]-y[i,t,a,1]-y[i,t,a,2])

logitP[i,t,a]<-betaP[1,a]+siteWidth[i,t]\*betaP[2,a]

p[i,t,a]<-1/(1+exp(-logitP[i,t,a]))

}

}

}