

Streamlined Northern Rock Sole Analyses and Figures

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1/23/2022

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Northern Rock Sole (NRS):

Loading Data:

Northern Rock Sole: larval data only are included for this species. NRS spawn from December to March, live roughly 19 years, and transform to juveniles at standard lengths between 15 and 18 mm.

These data have been trimmed. The larval data are constrained to depths between 40 and 300 meters. The data are also restricted to latitudes below 64.5 degrees north. Larvae are linked to CTD-derived, *in situ* temperature and salinity measurements.

Descriptive Information:

Table 1: Descriptive Metrics for NRS Larval Data

Lat Range	Lon Range	Day of Year Range	Bottom Depth Range
53.4-60.3	-178.2 to -158.6	101-174	41-298

The following two plots show *the day of year distribution for positive NRS larval catch* (left) and *the year distribution for positive NRS larval catch* (right).

Larval Generalized Additive Models:

Now we'll move into the GAMs. The following code *is only necessary if the data were re-trimmed and new GAMs need to be run*. In this case, modify markdown document such that “{eval = TRUE}”. The other model figures are marked as “eval = FALSE” if they, as of the last model run, do not produce the best model results. **Make sure to save the new models as RDS objects.**

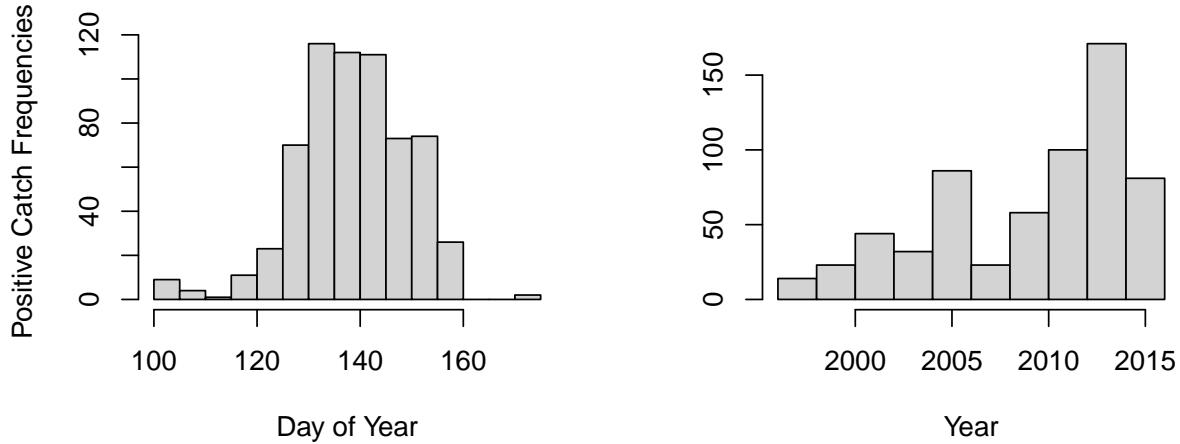


Figure 1: Northern Rock Sole Larvae

Northern rock sole larvae were best explained by the bivariate salinity-temperature model, in which the spatial and temporal distribution of larvae were modeled in association with a smooth containing *in situ* salinity-temperature data.

We begin with the base larval model:

```
lv.base<-readRDS("./GAM Models/nrs_larvae_base.rds")
summary(lv.base)
```

```
##
## Family: Tweedie(p=1.99)
## Link function: log
##
## Formula:
## (Cper10m2 + 1) ~ factor(year) + s(doy, k = 7) + s(lon, lat) +
##   s(bottom_depth, k = 5)
##
## Parametric coefficients:
##                               Estimate Std. Error t value Pr(>|t|)
## (Intercept)            3.9937    0.3104 12.868 < 2e-16 ***
## factor(year)1998     -0.5290    0.9693 -0.546  0.58533
## factor(year)1999     -1.3982    0.5833 -2.397  0.01666 *
## factor(year)2000     -1.3596    0.4745 -2.865  0.00423 **
## factor(year)2002      1.4567    0.3633  4.009 6.43e-05 ***
## factor(year)2003     -0.9764    0.3842 -2.542  0.01115 *
## factor(year)2005     -0.7290    0.3493 -2.087  0.03708 *
## factor(year)2006     -1.7628    0.3413 -5.165 2.78e-07 ***
## factor(year)2007     -1.2204    0.3786 -3.224  0.00130 **
## factor(year)2008     -3.1622    0.4976 -6.355 2.87e-10 ***
## factor(year)2009     -2.5040    0.3468 -7.221 8.73e-13 ***
## factor(year)2010     -1.9941    0.3377 -5.905 4.49e-09 ***
## factor(year)2011     -2.6145    0.4656 -5.616 2.39e-08 ***
```

```

## factor(year)2012 -0.9411    0.3302   -2.850  0.00444 ***
## factor(year)2013 -2.6647    0.4051   -6.578 6.89e-11 ***
## factor(year)2014 -1.1190    0.3326   -3.364  0.00079 ***
## factor(year)2015 -2.2767    0.4107   -5.544 3.57e-08 ***
## factor(year)2016 -1.9097    0.3328   -5.739 1.18e-08 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Approximate significance of smooth terms:
##          edf Ref.df      F p-value
## s(doy)      5.387 5.847 6.775 2.23e-05 ***
## s(lon,lat)  27.464 28.840 22.588 < 2e-16 ***
## s(bottom_depth) 3.652 3.920 11.583 < 2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## R-sq.(adj) =  0.224 Deviance explained = 55.1%
## -REML = 4905.2 Scale est. = 1.7426 n = 1362

```

```
AIC(lv.base)
```

```

## [1] 9776.941

##
## Family: Tweedie(p=1.99)
## Link function: log
##
## Formula:
## (Cper10m2 + 1) ~ factor(year) + s(doy, k = 7) + s(lon, lat) +
##   s(bottom_depth, k = 5) + s(temperature)
##
## Parametric coefficients:
##             Estimate Std. Error t value Pr(>|t|)
## (Intercept) 4.1297    0.2977 13.873 < 2e-16 ***
## factor(year)1998 -1.1500    0.5926 -1.941 0.052533 .
## factor(year)1999 -2.2628    0.3860 -5.863 5.75e-09 ***
## factor(year)2000 -1.6992    0.4289 -3.962 7.84e-05 ***
## factor(year)2002  0.7285    0.3604  2.021 0.043454 *
## factor(year)2003 -1.6253    0.3799 -4.278 2.02e-05 ***
## factor(year)2005 -1.3777    0.3593 -3.835 0.000132 ***
## factor(year)2006 -1.8986    0.3155 -6.018 2.29e-09 ***
## factor(year)2007 -1.4975    0.3633 -4.122 3.99e-05 ***
## factor(year)2008 -1.8747    0.5010 -3.742 0.000191 ***
## factor(year)2009 -2.5557    0.3324 -7.688 2.92e-14 ***
## factor(year)2010 -1.6643    0.3308 -5.032 5.54e-07 ***
## factor(year)2011 -1.9878    0.4374 -4.545 6.01e-06 ***
## factor(year)2012 -0.5904    0.3312 -1.782 0.074920 .
## factor(year)2013 -1.6383    0.4066 -4.030 5.91e-05 ***
## factor(year)2014 -1.7254    0.3396 -5.080 4.32e-07 ***
## factor(year)2015 -2.8590    0.3942 -7.252 6.99e-13 ***
## factor(year)2016 -2.3132    0.3861 -5.991 2.69e-09 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

```

```

##
## Approximate significance of smooth terms:
##          edf Ref.df      F p-value
## s(doy)      1.000 1.001 0.006 0.942
## s(lon,lat) 27.504 28.848 25.296 <2e-16 ***
## s(bottom_depth) 3.699 3.939 15.185 <2e-16 ***
## s(temperature) 7.012 8.123 24.862 <2e-16 ***
## ---
## Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## R-sq.(adj) = 0.256 Deviance explained = 58.8%
## -REML = 4836.9 Scale est. = 1.6179 n = 1362

```

Then additive temperature and salinity, in individual additive terms. This is the second-best performing model.

```

lv.temp.sal<-readRDS("./GAM Models/nrs_larvae_addtempsal.rds")
summary(lv.temp.sal)

```

```

##
## Family: Tweedie(p=1.99)
## Link function: log
##
## Formula:
## (Cper10m2 + 1) ~ factor(year) + s(doy, k = 7) + s(lon, lat) +
##   s(bottom_depth, k = 5) + s(temperature) + s(salinity)
##
## Parametric coefficients:
##             Estimate Std. Error t value Pr(>|t|)
## (Intercept) 4.2070    0.3010 13.976 < 2e-16 ***
## factor(year)1998 -1.1194    0.6278 -1.783 0.0748 .
## factor(year)1999 -2.3380    0.4216 -5.546 3.54e-08 ***
## factor(year)2000 -1.7549    0.4363 -4.022 6.09e-05 ***
## factor(year)2002  0.5770    0.3669  1.572 0.1161
## factor(year)2003 -1.6959    0.3819 -4.441 9.72e-06 ***
## factor(year)2005 -1.4470    0.3635 -3.980 7.26e-05 ***
## factor(year)2006 -2.0331    0.3236 -6.282 4.54e-10 ***
## factor(year)2007 -1.6760    0.3676 -4.559 5.61e-06 ***
## factor(year)2008 -2.0795    0.5072 -4.100 4.39e-05 ***
## factor(year)2009 -2.7384    0.3378 -8.105 1.20e-15 ***
## factor(year)2010 -1.7972    0.3320 -5.414 7.35e-08 ***
## factor(year)2011 -2.0779    0.4385 -4.739 2.39e-06 ***
## factor(year)2012 -0.7785    0.3347 -2.326 0.0202 *
## factor(year)2013 -1.7091    0.4105 -4.164 3.33e-05 ***
## factor(year)2014 -1.7015    0.3425 -4.967 7.70e-07 ***
## factor(year)2015 -2.9642    0.3972 -7.462 1.55e-13 ***
## factor(year)2016 -2.3528    0.3903 -6.028 2.15e-09 ***
## ---
## Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Approximate significance of smooth terms:
##          edf Ref.df      F p-value
## s(doy)      1.423 1.742 0.129 0.82915

```

```

## s(lon,lat)      27.468 28.830 25.556 < 2e-16 ***
## s(bottom_depth) 3.639  3.914 14.324 < 2e-16 ***
## s(temperature)  6.908  8.037 18.095 < 2e-16 ***
## s(salinity)     4.939  6.169  3.845 0.00077 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## R-sq.(adj) =  0.282  Deviance explained = 59.4%
## -REML =    4833  Scale est. = 1.6026   n = 1362

```

```
AIC(lv.temp.sal)
```

```
## [1] 9621.861
```

And finally, the best performing model: the bivariate salinity-temperature additive term:

```
lv.2d<-readRDS("./GAM Models/nrs_larvae_2d.rds")
summary(lv.2d)
```

```

##
## Family: Tweedie(p=1.99)
## Link function: log
##
## Formula:
## (Cper10m2 + 1) ~ factor(year) + s(lon, lat) + s(doy, k = 7) +
##   s(bottom_depth) + s(salinity, temperature)
##
## Parametric coefficients:
##             Estimate Std. Error t value Pr(>|t|)
## (Intercept) 4.3974    0.3037 14.478 < 2e-16 ***
## factor(year)1998 -0.9822    0.5922 -1.658 0.09747 .
## factor(year)1999 -2.6559    0.3959 -6.709 2.93e-11 ***
## factor(year)2000 -1.9047    0.4343 -4.386 1.25e-05 ***
## factor(year)2002  0.3364    0.3760  0.895  0.37121
## factor(year)2003 -2.0850    0.3942 -5.289 1.44e-07 ***
## factor(year)2005 -1.6011    0.3675 -4.357 1.43e-05 ***
## factor(year)2006 -2.0342    0.3269 -6.222 6.63e-10 ***
## factor(year)2007 -2.0667    0.3756 -5.503 4.51e-08 ***
## factor(year)2008 -2.1584    0.5128 -4.209 2.74e-05 ***
## factor(year)2009 -2.7402    0.3390 -8.084 1.43e-15 ***
## factor(year)2010 -1.5800    0.3284 -4.811 1.68e-06 ***
## factor(year)2011 -2.4760    0.4381 -5.652 1.95e-08 ***
## factor(year)2012 -1.0671    0.3381 -3.156 0.00164 **
## factor(year)2013 -1.9231    0.4132 -4.655 3.58e-06 ***
## factor(year)2014 -2.1617    0.3485 -6.204 7.42e-10 ***
## factor(year)2015 -3.3262    0.3992 -8.332 < 2e-16 ***
## factor(year)2016 -2.7337    0.3906 -7.000 4.12e-12 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Approximate significance of smooth terms:
##          edf Ref.df      F p-value

```

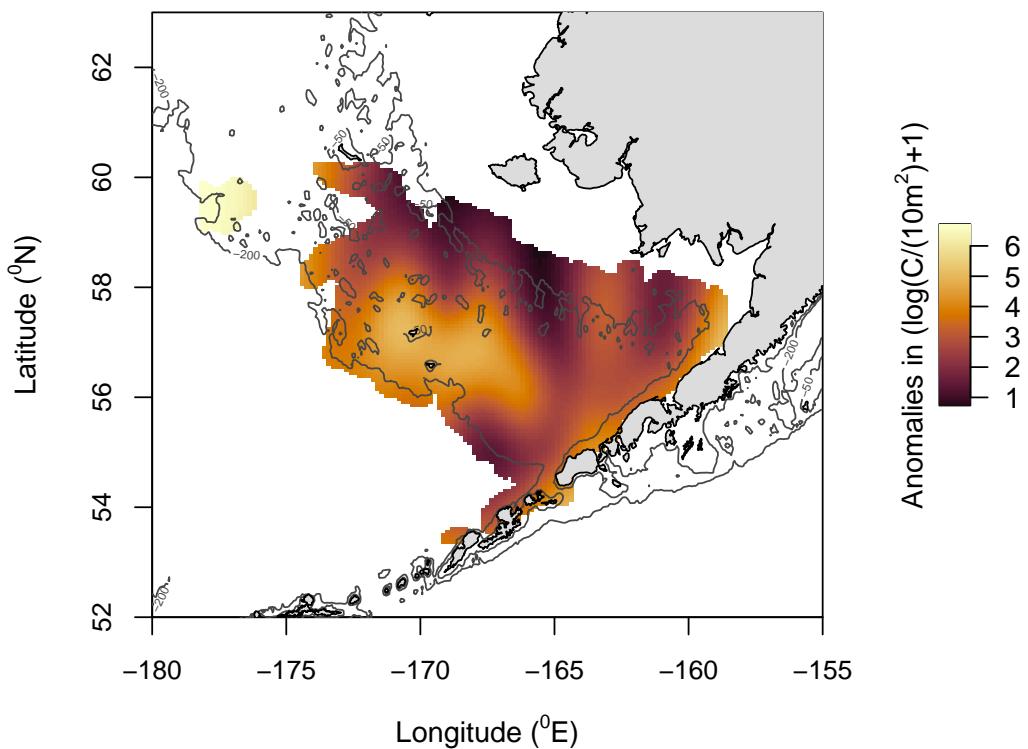
```
## s(lon,lat)           27.286 28.777 19.860 <2e-16 ***
## s(doy)                1.006  1.011  1.076   0.298
## s(bottom_depth)       6.913  7.925  9.944 <2e-16 ***
## s(salinity,temperature) 24.156 27.616 12.057 <2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## R-sq.(adj) =  0.281  Deviance explained =  62%
## -REML = 4808.5  Scale est. = 1.5257    n = 1362
```

```
AIC(lv.2d)
```

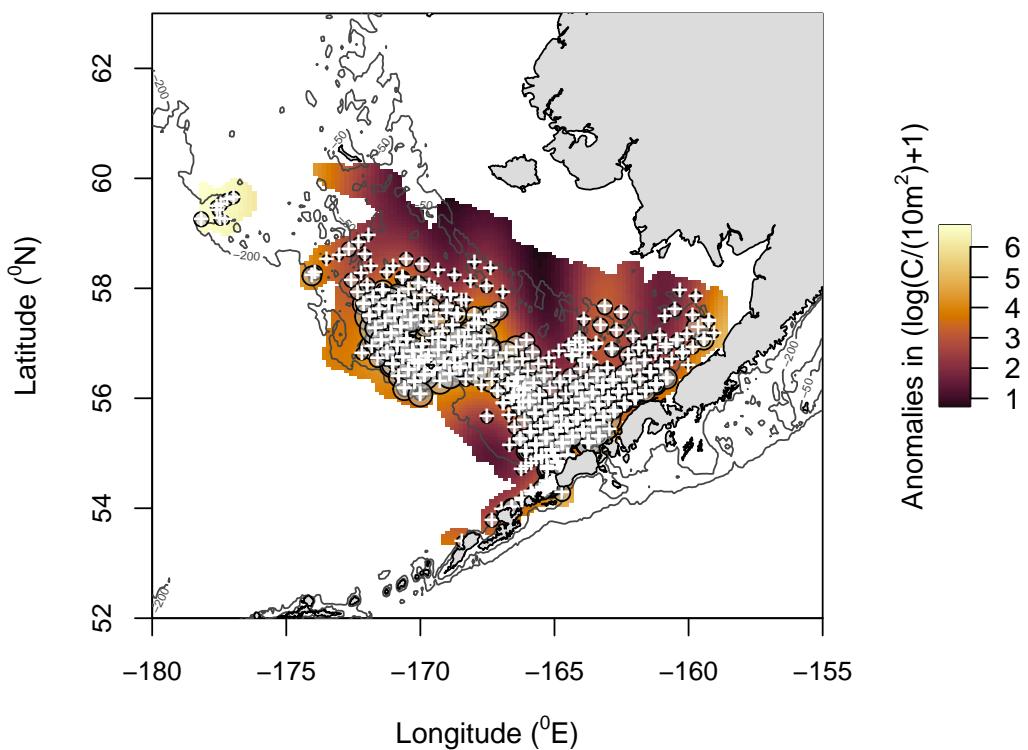
```
## [1] 9536.362
```

The following plot is the predicted NRS larval biogeography based on the best performing model, the bivariate salinity-temperature GAM. Observations (log transformed, n+1) are shown as well.

Predicted NRS Larval Biogeography, 2D Model

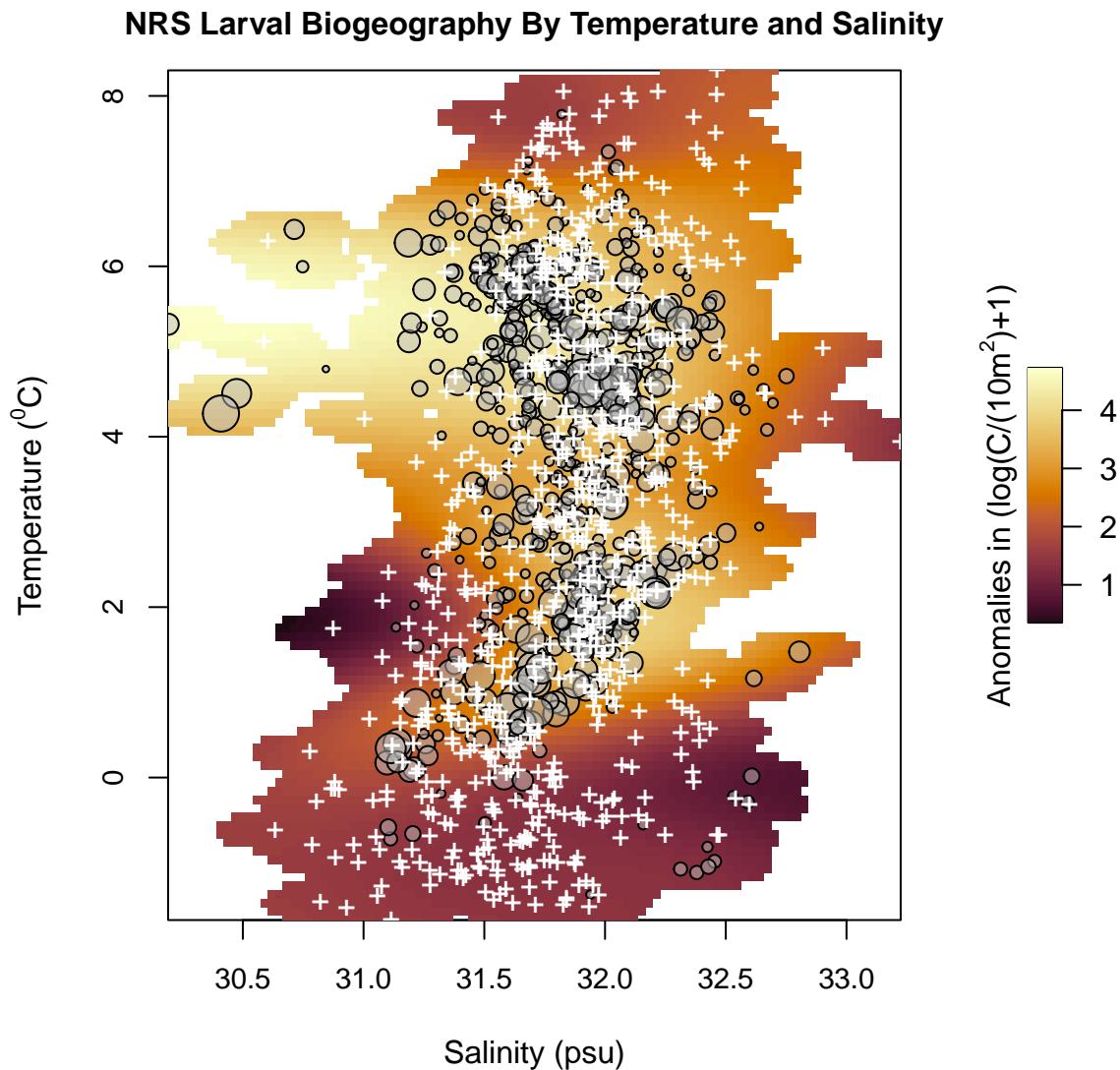


Predicted NRS Larval Biogeography, 2D Model



With this bivariate model, we can also calculate the predicted anomalous larval catch (more or less than expected) on a salinity-temperature plot. This figure shows that prediction, with observed larval catch ($\log(n=1)$) overlaid.

```
## Warning in symbols(nrslarv.ctd$salinity[nrslarv.ctd$Cper10m2 > 0],  
## nrslarv.ctd$temperature[nrslarv.ctd$Cper10m2 > : "alpha" is not a graphical  
## parameter
```



To again share the improvements of the best performing models from the base models, we can look at the AIC division produces.

Table 2: Model Power through AIC Comparisons, Northern Rock Sole

	Best Divided By Base	Best Divided By Second Best
Larvae	0.9753932	0.9911141