Streamlined Northern Rock Sole Analyses and Figures

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1/23/2022

Contents

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.

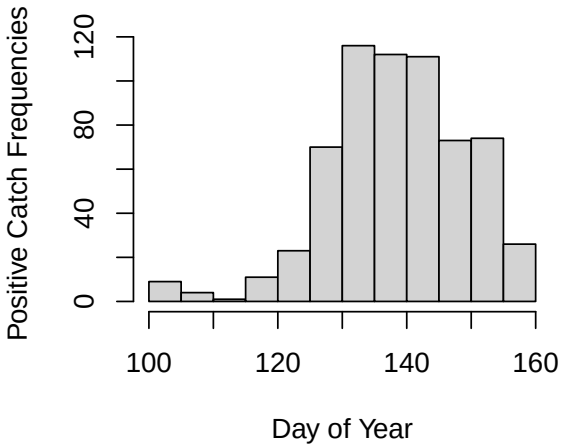
These data have been trimmed. The larval data are constrained to depths between 40 and 300 meters, to latitudes below 64.5 degrees north, and to days of year between 100 and 165. Larvae are linked to CTD-derived, *in situ* temperature and salinity measurements.

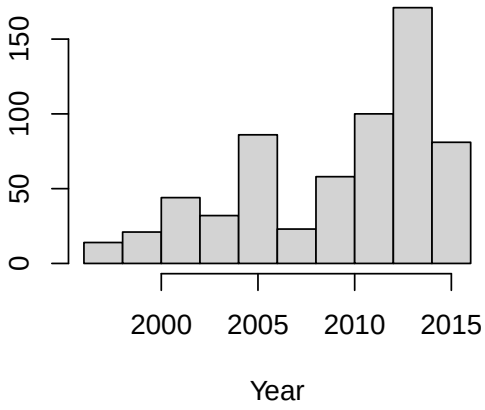
Descriptive Information:

Table 1: Descriptive Metrics for NRS Larval Data

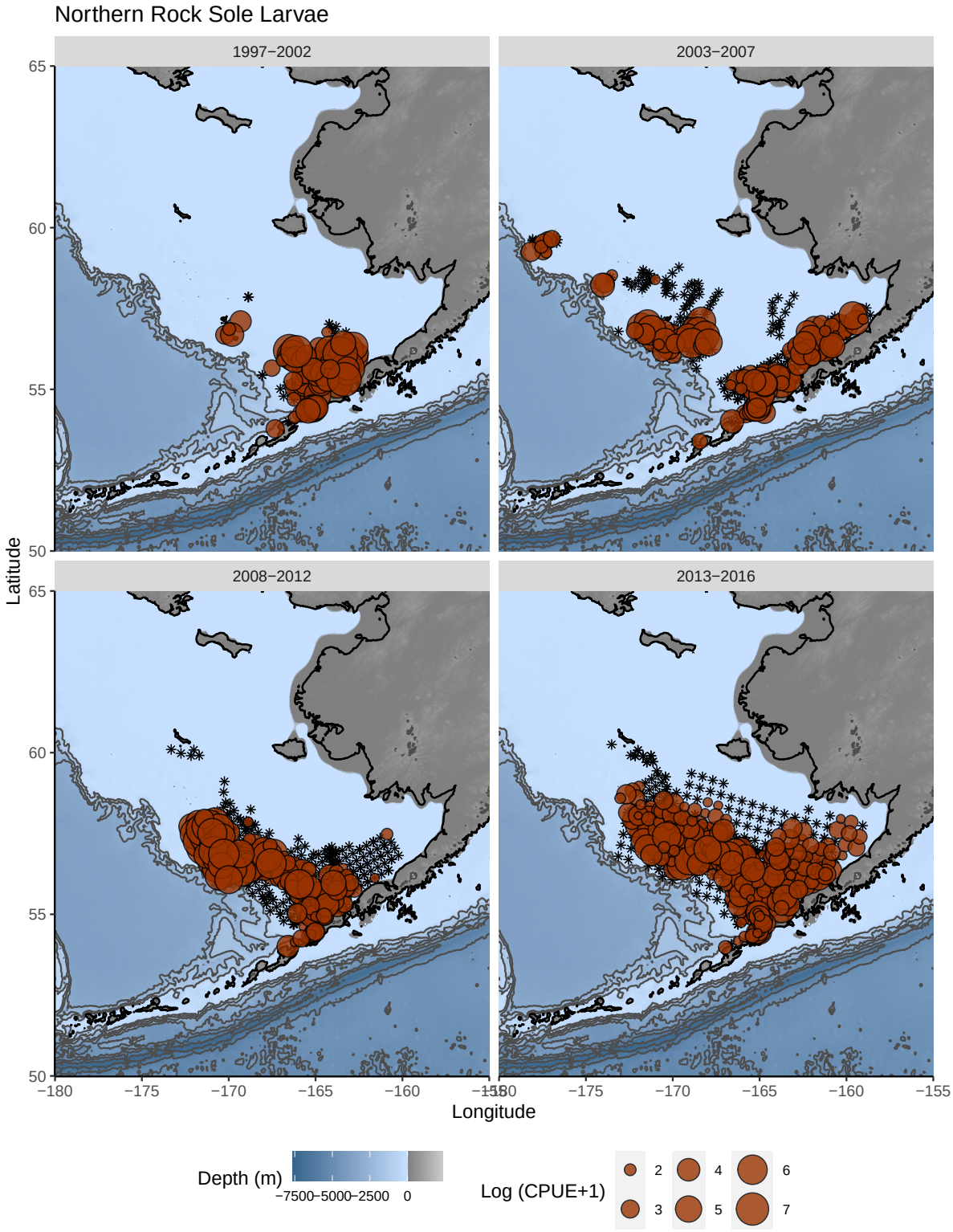
Lat Range	Lon Range	Day of Year Range	Bottom Depth Range
53.4-60.3	-178.2 to -158.6	101-159	41-298

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).


Positive Catch Frequencies
0
40
80
120
100
120
140
160
Day of Year


0
50
100
150
2000
2005
2010
2015
Year

The following plots show northern rock sole larval catch distributions (Catch per unit effort, or per $10m^2$) across five year increments from 1997 to 2016.



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.**

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)         3.9782     0.3107  12.805  < 2e-16 ***
## factor(year)1998   -0.5003     0.9961  -0.502 0.615591
## factor(year)1999   -1.4077     0.5851  -2.406 0.016266 *
## factor(year)2000   -1.4310     0.4798  -2.983 0.002909 **
## factor(year)2002    1.4793     0.3634   4.070 4.98e-05 ***
## factor(year)2003   -0.9398     0.3861  -2.434 0.015074 *
## factor(year)2005   -0.7234     0.3496  -2.069 0.038720 *
## factor(year)2006   -1.7510     0.3417  -5.125 3.43e-07 ***
## factor(year)2007   -1.2025     0.3790  -3.173 0.001546 **
## factor(year)2008   -3.1462     0.4977  -6.321 3.55e-10 ***
## factor(year)2009   -2.4943     0.3476  -7.177 1.20e-12 ***
## factor(year)2010   -1.9833     0.3382  -5.864 5.73e-09 ***
## factor(year)2011   -2.5878     0.4684  -5.524 3.99e-08 ***
## factor(year)2012   -0.9289     0.3313  -2.804 0.005125 **
## factor(year)2013   -2.6212     0.4066  -6.446 1.61e-10 ***
## factor(year)2014   -1.1036     0.3328  -3.316 0.000939 ***
## factor(year)2015   -2.1946     0.4189  -5.239 1.88e-07 ***
## factor(year)2016   -1.8722     0.3339  -5.607 2.52e-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)           5.166  5.696  7.129 3.98e-06 ***
## s(lon,lat)      27.485 28.844 22.573  < 2e-16 ***
## s(bottom_depth)  3.663  3.925 11.699  < 2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
```

```
## R-sq.(adj) =  0.223   Deviance explained = 55.1%
## -REML = 4894.2  Scale est. = 1.743     n = 1358
```

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

```
## [1] 9755.342
```

```
##
## 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)         4.1517     0.2977  13.944  < 2e-16 ***
## factor(year)1998   -1.0782     0.5963  -1.808  0.07084 .
## factor(year)1999   -2.2057     0.3889  -5.671 1.75e-08 ***
## factor(year)2000   -1.5017     0.4649  -3.230  0.00127 **
## factor(year)2002    0.7160     0.3606   1.986  0.04729 *
## factor(year)2003   -1.6747     0.3807  -4.399 1.18e-05 ***
## factor(year)2005   -1.4158     0.3595  -3.939 8.63e-05 ***
## factor(year)2006   -1.8882     0.3157  -5.981 2.87e-09 ***
## factor(year)2007   -1.4764     0.3638  -4.059 5.23e-05 ***
## factor(year)2008   -1.8754     0.5010  -3.743  0.00019 ***
## factor(year)2009   -2.5539     0.3323  -7.684 3.01e-14 ***
## factor(year)2010   -1.6456     0.3309  -4.973 7.47e-07 ***
## factor(year)2011   -2.0361     0.4386  -4.642 3.79e-06 ***
## factor(year)2012   -0.6017     0.3315  -1.815  0.06970 .
## factor(year)2013   -1.6337     0.4065  -4.019 6.17e-05 ***
## factor(year)2014   -1.7847     0.3412  -5.230 1.97e-07 ***
## factor(year)2015   -2.8523     0.3943  -7.233 8.03e-13 ***
## factor(year)2016   -2.3765     0.3876  -6.131 1.15e-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)            1.000  1.001  0.035   0.852
## s(lon,lat)       27.506 28.848 24.626  <2e-16 ***
## s(bottom_depth)   3.700  3.939 15.342  <2e-16 ***
## s(temperature)    7.055  8.157 24.826  <2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## R-sq.(adj) =  0.253   Deviance explained = 58.9%
## -REML = 4825.6  Scale est. = 1.6164    n = 1358
```

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)         4.2268     0.3008  14.053  < 2e-16 ***
## factor(year)1998   -1.1341     0.5968  -1.900 0.057617 .
## factor(year)1999   -2.3507     0.3929  -5.983 2.83e-09 ***
## factor(year)2000   -1.5567     0.4687  -3.321 0.000921 ***
## factor(year)2002    0.5806     0.3664   1.585 0.113278
## factor(year)2003   -1.7345     0.3820  -4.540 6.13e-06 ***
## factor(year)2005   -1.4710     0.3629  -4.053 5.35e-05 ***
## factor(year)2006   -2.0232     0.3226  -6.271 4.86e-10 ***
## factor(year)2007   -1.6443     0.3677  -4.472 8.42e-06 ***
## factor(year)2008   -2.0644     0.5073  -4.069 5.00e-05 ***
## factor(year)2009   -2.7307     0.3376  -8.090 1.36e-15 ***
## factor(year)2010   -1.7789     0.3320  -5.358 9.97e-08 ***
## factor(year)2011   -2.1098     0.4381  -4.816 1.64e-06 ***
## factor(year)2012   -0.7948     0.3334  -2.384 0.017284 *
## factor(year)2013   -1.7046     0.4103  -4.155 3.47e-05 ***
## factor(year)2014   -1.7582     0.3440  -5.111 3.68e-07 ***
## factor(year)2015   -2.9554     0.3970  -7.444 1.77e-13 ***
## factor(year)2016   -2.3977     0.3908  -6.136 1.12e-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  1.000  0.208 0.64864
## s(lon,lat)       27.469 28.832 24.905 < 2e-16 ***
## s(bottom_depth)   3.641  3.916 14.505 < 2e-16 ***
## s(temperature)    6.956  8.079 18.627 < 2e-16 ***
## s(salinity)       4.855  6.078  3.748 0.00102 **
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## R-sq.(adj) =  0.278   Deviance explained = 59.4%
## -REML =   4822  Scale est. = 1.6021    n = 1358
```

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

```
## [1] 9595.43
```

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

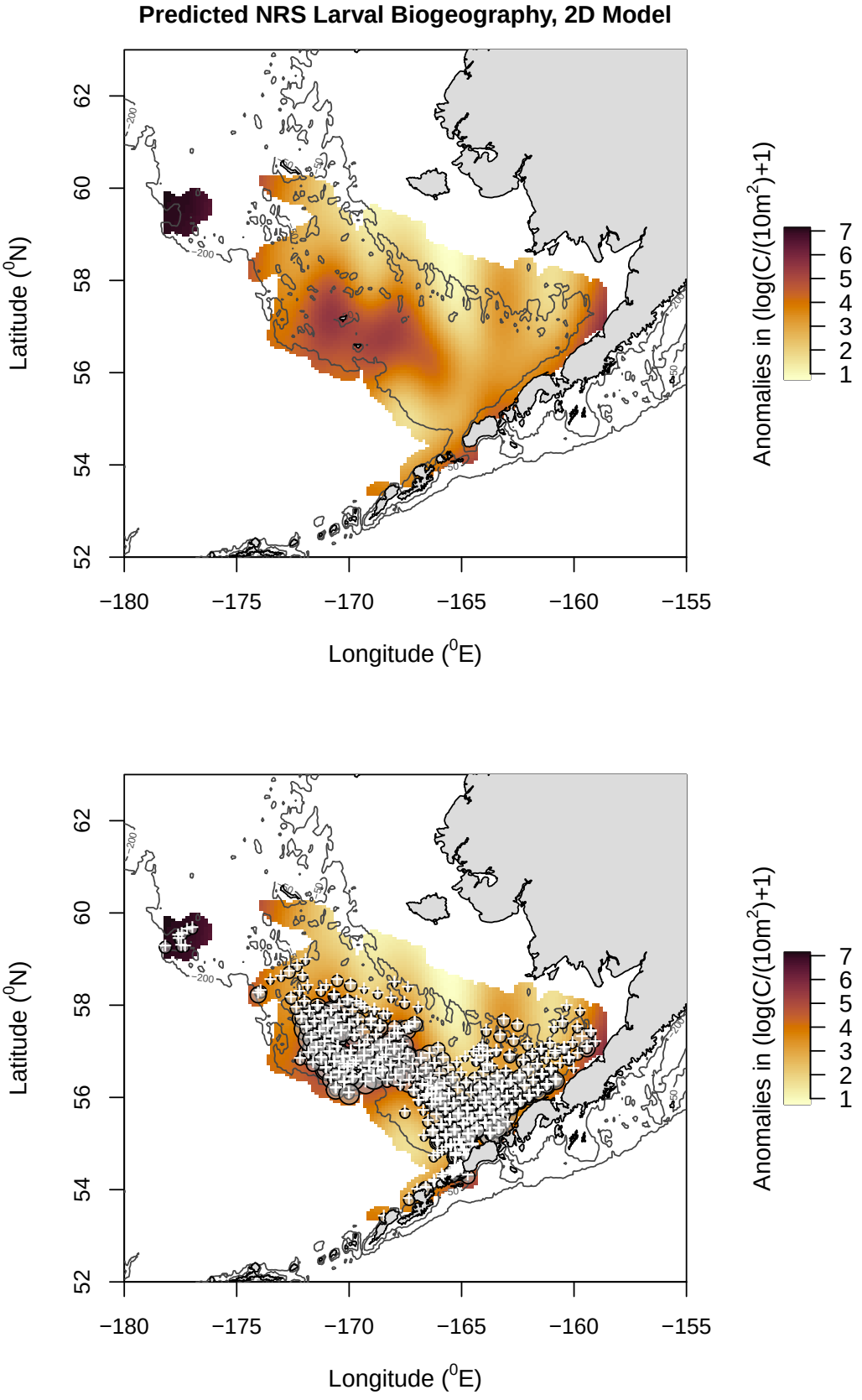
```
lv.2d<-readRDS("./GAM Models/nrs_larvae_2d.rds")
summary(lv.2d)
```

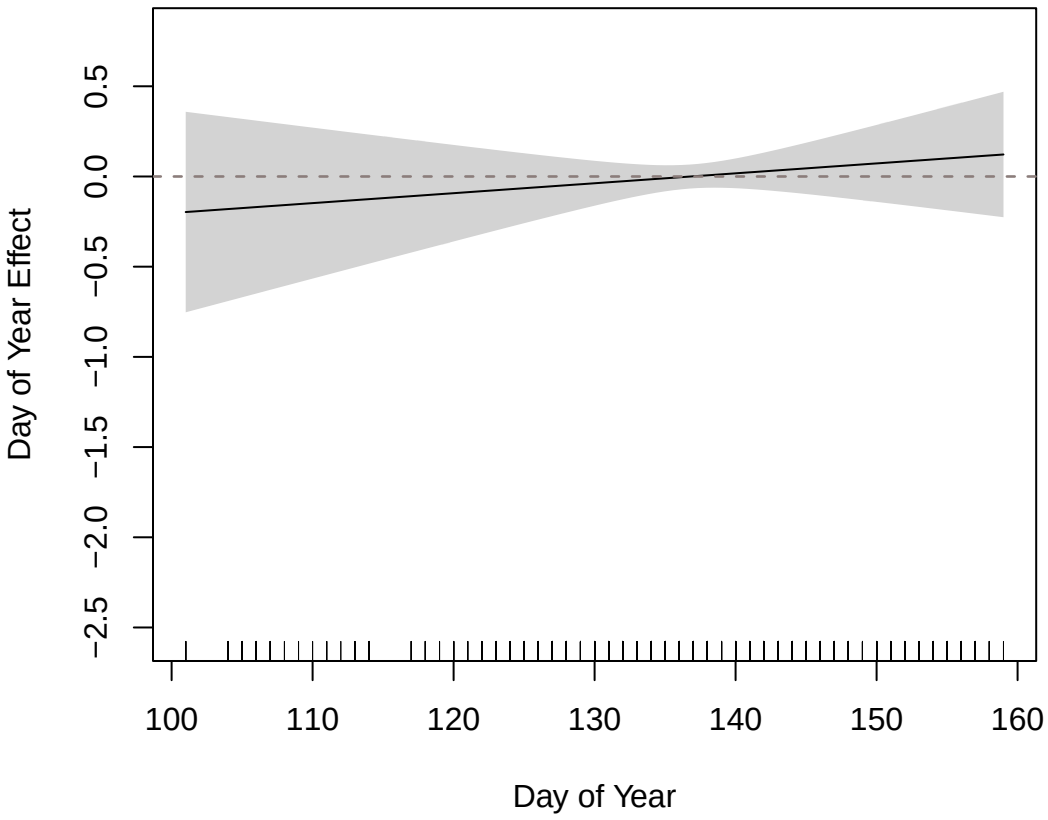
```
##
## Family: Tweedie(p=1.99)
## Link function: log
##
## Formula:
## (Cper10m2 + 1) ~ factor(year) + s(lon, lat) + s(doy, k = 7) +
##     s(bottom_depth) + te(salinity, temperature)
##
## Parametric coefficients:
##                   Estimate Std. Error t value Pr(>|t|)
## (Intercept)         4.1709     0.3023  13.798  < 2e-16 ***
## factor(year)1998   -0.9917     0.5915  -1.677  0.09387 .
## factor(year)1999   -2.0265     0.3975  -5.098 3.95e-07 ***
## factor(year)2000   -1.2592     0.4648  -2.709  0.00684 **
## factor(year)2002    0.5333     0.3559   1.498  0.13432
## factor(year)2003   -1.8264     0.3896  -4.688 3.05e-06 ***
## factor(year)2005   -1.4144     0.3606  -3.923 9.21e-05 ***
## factor(year)2006   -1.7473     0.3285  -5.319 1.23e-07 ***
## factor(year)2007   -1.5674     0.3726  -4.206 2.77e-05 ***
## factor(year)2008   -1.6774     0.5110  -3.282  0.00106 **
## factor(year)2009   -2.5647     0.3372  -7.605 5.47e-14 ***
## factor(year)2010   -1.4174     0.3292  -4.306 1.79e-05 ***
## factor(year)2011   -2.2140     0.4410  -5.020 5.88e-07 ***
## factor(year)2012   -0.7220     0.3346  -2.158  0.03113 *
## factor(year)2013   -1.6500     0.4170  -3.957 8.01e-05 ***
## factor(year)2014   -2.0273     0.3482  -5.822 7.35e-09 ***
## factor(year)2015   -3.1045     0.3967  -7.825 1.05e-14 ***
## factor(year)2016   -2.5580     0.3915  -6.534 9.18e-11 ***
## ---
## 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)                 27.358 28.798 21.289  <2e-16 ***
## s(doy)                      1.001  1.001  0.511   0.475
## s(bottom_depth)             6.969  7.969 10.291  <2e-16 ***
## te(salinity,temperature)   17.488 19.773 15.317  <2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## R-sq.(adj) =  0.282   Deviance explained = 61.5%
## -REML =   4792  Scale est. = 1.5376    n = 1358
```

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

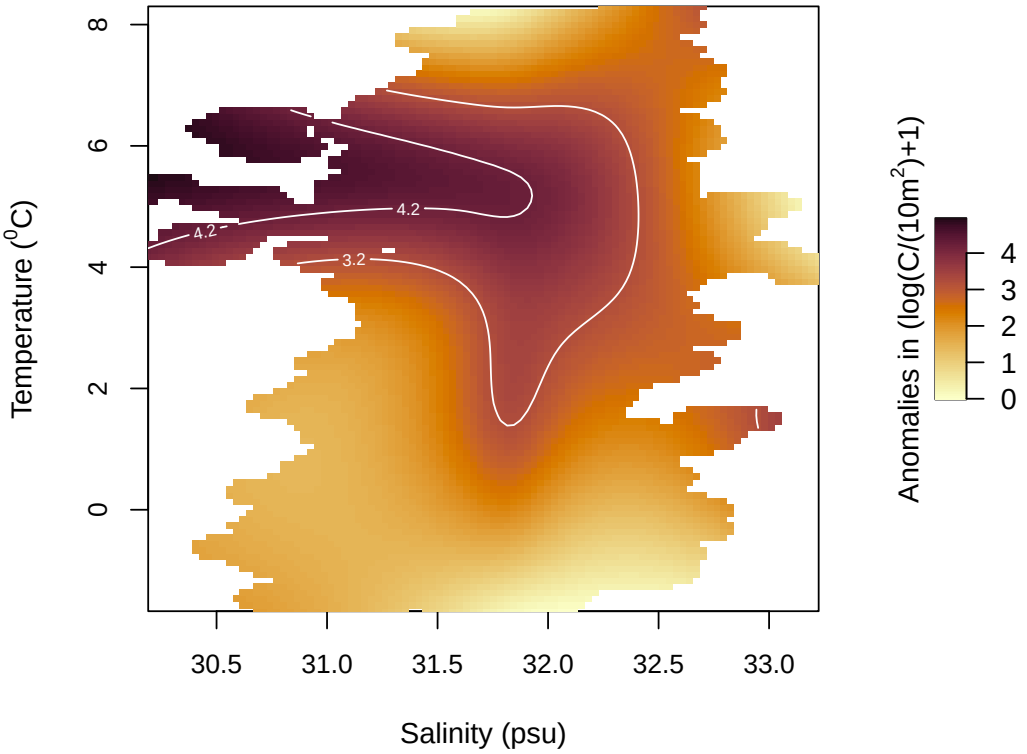
```
## [1] 9524.234
```

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.

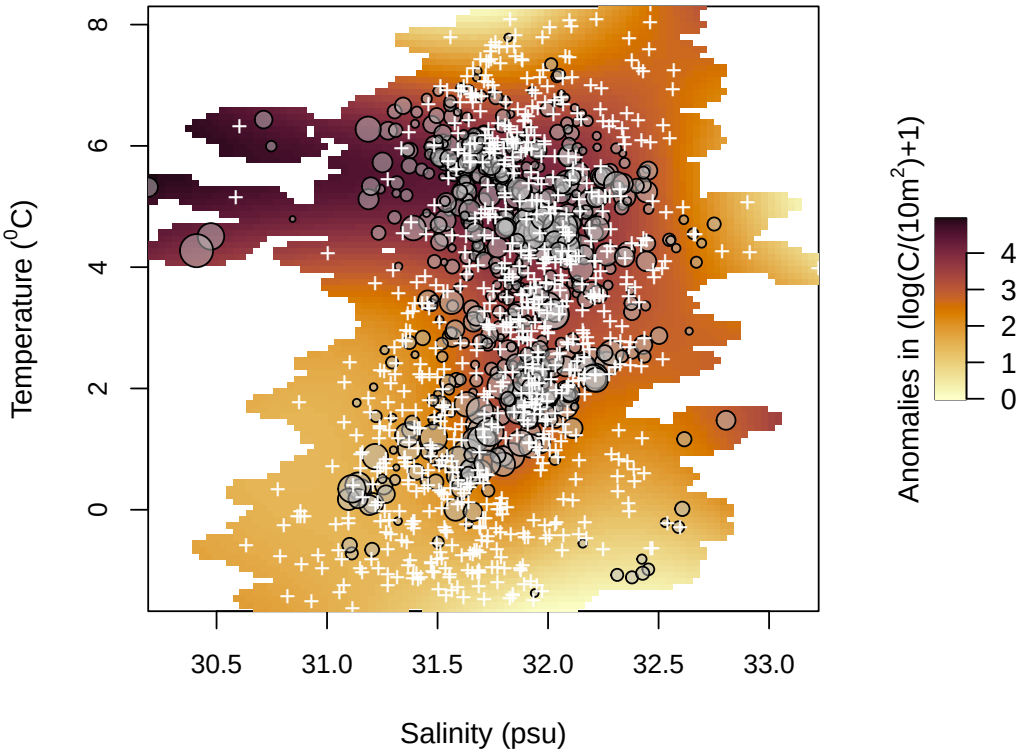

Predicted NRS Larval Biogeography, 2D Model
Latitude (0N)
52
54
56
58
60
62
−180
−175
−170
−165
−160
−155
Longitude (0E)
Anomalies in (log(C/(10m2)+1)
7
6
5
4
3
2
1



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.



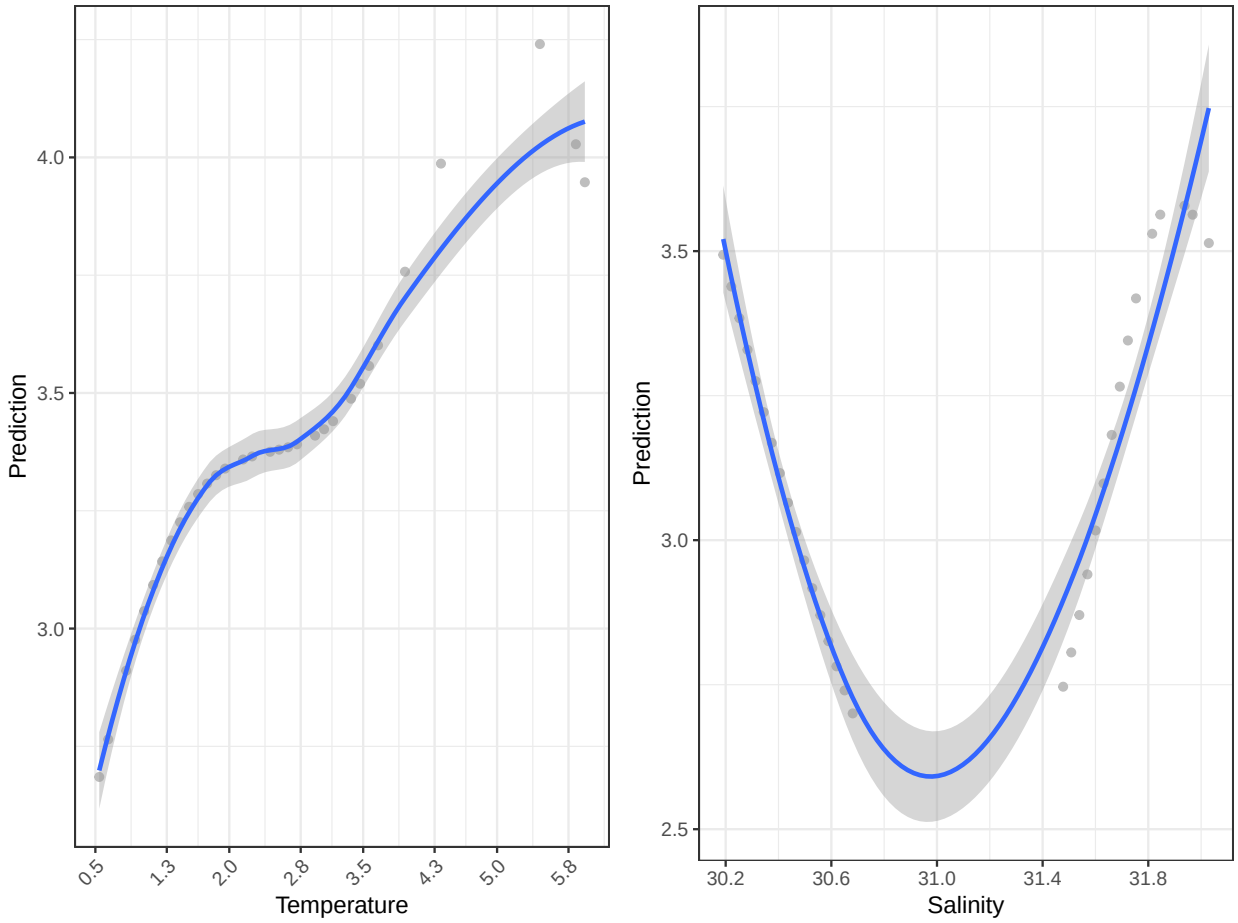
NRS Larval Biogeography By Temperature and Salinity



Now I'll calculate a specific range of temperature, salinity, and both temperature and salinity to evaluate breadth of environmental tolerances.

For the univariate predictions, make a grid that holds either temperature or salinity constant depending on the variable of interest.

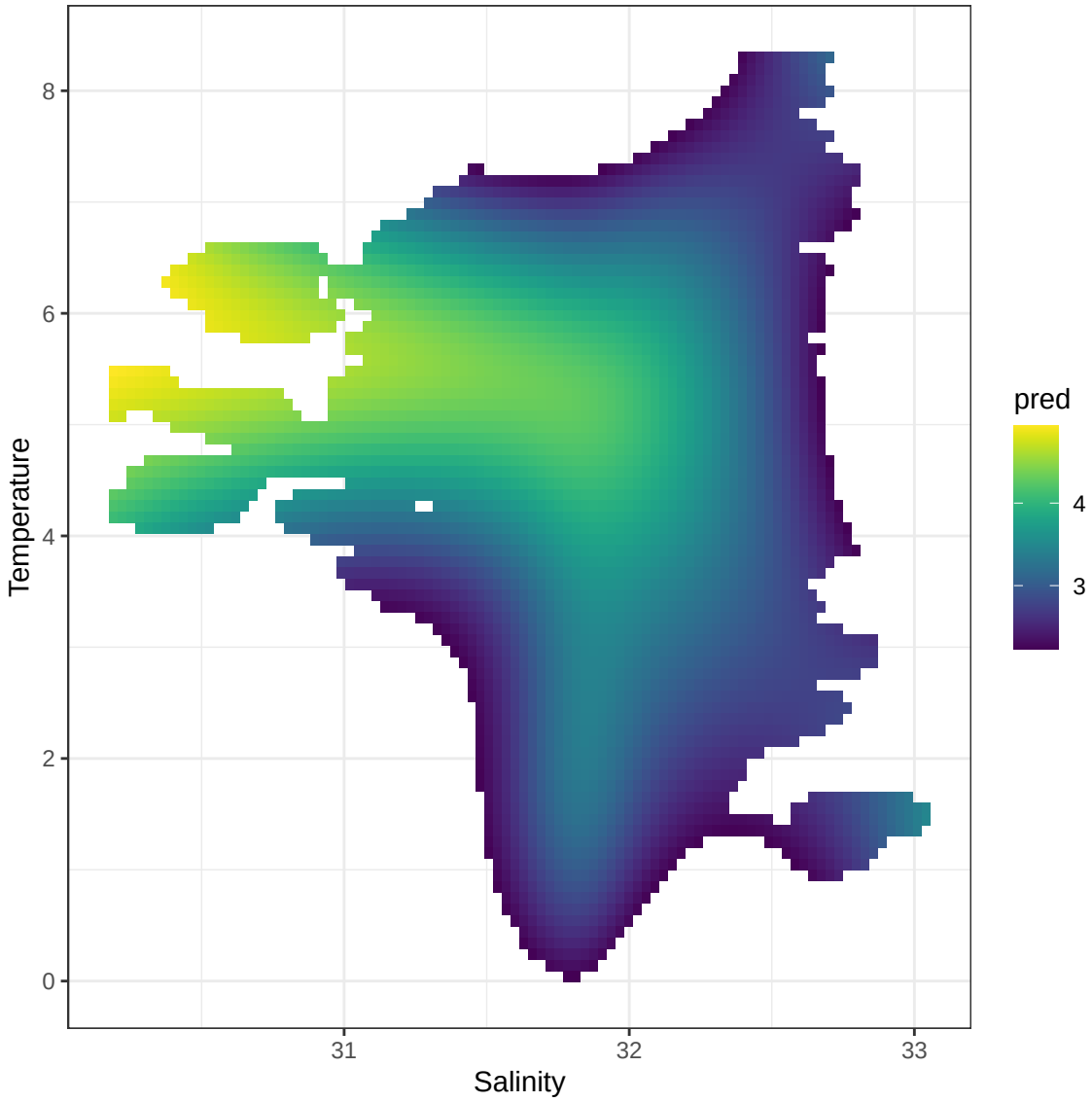
```
## `geom_smooth()` using formula 'y ~ x'
## `geom_smooth()` using formula 'y ~ x'
```



For the bivariate analysis:

```
##   salinity temperature       dist year       lon      lat doy bottom_depth
## 1 30.19073    5.479385 0.15928494 2005 -165.7674 56.52625 137           84
## 2 30.22138    5.479385 0.16220557 2005 -165.7674 56.52625 137           84
## 3 30.25202    5.479385 0.17066785 2005 -165.7674 56.52625 137           84
## 4 30.19073    5.378647 0.05854674 2005 -165.7674 56.52625 137           84
## 5 30.28266    5.479385 0.18390839 2005 -165.7674 56.52625 137           84
## 6 30.37459    6.285291 0.23001422 2005 -165.7674 56.52625 137           84
##       pred
## 1 4.936183
## 2 4.922947
## 3 4.909711
## 4 4.897286
```

```
## 5 4.896477
## 6 4.888897
```



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	0.9763096	0.9925803

Reduction in MSE (%):

```
## [1] 11.78358
```