

Streamlined Pacific Cod Analyses & Figures

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Pacific Cod (Pac cod):

Loading Data:

Pacific cod: larval data only are included for this species. Pac cod spawn in March and April under the sea ice, live roughly 13 years, and transform to juveniles at standard lengths between 25 and 35 mm.

These data have been trimmed. The larval data are constrained to depths between 40 and 250 meters and to latitudes south of 62 degrees north. Larvae are linked to CTD-derived, *in situ* temperature and salinity measurements.

Descriptive Information:

Table 1: Descriptive Metrics for Pac Cod Larval Data

| Lat Range | Lon Range | Day of Year Range | Bottom Depth Range |
|-----------|------------------|-------------------|--------------------|
| 53.4-60 | -178.2 to -158.6 | 100-174 | 41-232 |

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

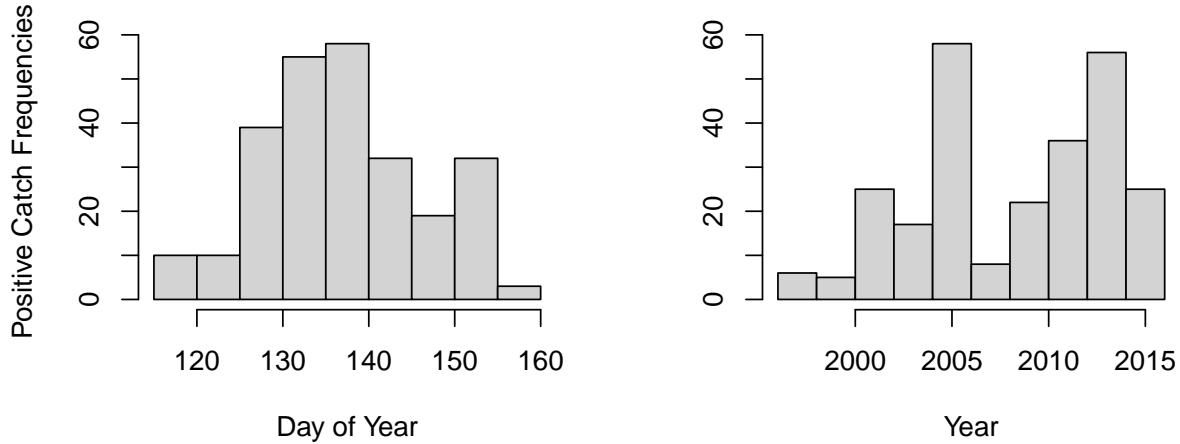


Figure 1: Pac Cod Larvae

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

We begin with the base larval model:

```
lv.base<-readRDS("./GAM Models/pc_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)            2.05672   0.24163   8.512 < 2e-16 ***
## factor(year)1998 -3.43778   0.75648  -4.544 6.02e-06 ***
## factor(year)1999 -1.50230   0.44964  -3.341 0.000858 ***
## factor(year)2000 -0.22217   0.36341  -0.611 0.541076
## factor(year)2002 -0.42655   0.28272  -1.509 0.131610
## factor(year)2003 -0.05085   0.29715  -0.171 0.864140
## factor(year)2005  0.80654   0.27079   2.978 0.002951 **
## factor(year)2006 -0.85148   0.26599  -3.201 0.001402 **
## factor(year)2007 -0.87192   0.29166  -2.990 0.002847 **
## factor(year)2008 -1.47733   0.37797  -3.909 9.76e-05 ***
## factor(year)2009 -1.17791   0.26914  -4.377 1.30e-05 ***
## factor(year)2010 -1.70329   0.26201  -6.501 1.14e-10 ***
## factor(year)2011 -1.26775   0.36078  -3.514 0.000457 ***
```

```

## factor(year)2012 -1.10151    0.25653  -4.294 1.89e-05 ***
## factor(year)2013 -1.42204    0.31319  -4.540 6.14e-06 ***
## factor(year)2014 -1.12982    0.25821  -4.376 1.31e-05 ***
## factor(year)2015 -0.91340    0.31424  -2.907 0.003715 **
## factor(year)2016 -1.14773    0.25792  -4.450 9.33e-06 ***
## ---
## 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)      5.604 5.926 8.945 < 2e-16 ***
## s(lon,lat) 25.954 28.402 37.362 < 2e-16 ***
## s(bottom_depth) 3.418 3.794 9.799 4.26e-07 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## R-sq.(adj) =  0.412 Deviance explained = 66.6%
## -REML = 2916.9 Scale est. = 0.98365 n = 1345

```

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

```
## [1] 5777.961
```

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

```
lv.temp.sal<-readRDS("./GAM Models/pc_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) 2.13419   0.24551   8.693 < 2e-16 ***
## factor(year)1998 -3.23292   0.72395  -4.466 8.68e-06 ***
## factor(year)1999 -1.59851   0.44902  -3.560 0.000384 ***
## factor(year)2000 -0.23401   0.36495  -0.641 0.521507  
## factor(year)2002 -0.16992   0.30314  -0.561 0.575220  
## factor(year)2003  0.05437   0.31137  0.175 0.861408  
## factor(year)2005  0.86191   0.29845  2.888 0.003943 ** 
## factor(year)2006 -1.10716   0.27164  -4.076 4.87e-05 ***
## factor(year)2007 -1.21284   0.29814  -4.068 5.03e-05 ***
## factor(year)2008 -1.66426   0.39735  -4.188 3.00e-05 ***
## factor(year)2009 -1.51093   0.27476  -5.499 4.60e-08 ***
## factor(year)2010 -2.05193   0.26680  -7.691 2.90e-14 ***
## factor(year)2011 -1.17524   0.36817  -3.192 0.001447 ** 
## factor(year)2012 -1.37134   0.28140  -4.873 1.24e-06 ***

```

```

## factor(year)2013 -1.61433    0.32763  -4.927 9.43e-07 ***
## factor(year)2014 -1.04489    0.27607  -3.785 0.000161 ***
## factor(year)2015 -1.15348    0.31976  -3.607 0.000321 ***
## factor(year)2016 -1.16152    0.31571  -3.679 0.000244 ***
## ---
## 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)      5.244 5.763 6.356 0.000803 ***
## s(lon,lat)  25.551 28.232 32.577 < 2e-16 ***
## s(bottom_depth) 2.978 3.468 9.439 3.57e-06 ***
## s(temperature) 7.117 8.201 3.321 0.000821 ***
## s(salinity)   4.501 5.650 6.192 7.77e-06 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## R-sq.(adj) =  0.409  Deviance explained = 67.8%
## -REML = 2904.9  Scale est. = 0.95801 n = 1345

```

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

```
## [1] 5748.12
```

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

```
lv.2d<-readRDS("./GAM Models/pc_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) 2.02154   0.24638   8.205 5.61e-16 ***
## factor(year)1998 -2.69360   0.72425  -3.719 0.000209 ***
## factor(year)1999 -1.46400   0.44531  -3.288 0.001038 **
## factor(year)2000 -0.04201   0.36066  -0.116 0.907297
## factor(year)2002 -0.08282   0.30917  -0.268 0.788822
## factor(year)2003  0.22089   0.32011   0.690 0.490307
## factor(year)2005  1.06912   0.30016   3.562 0.000382 ***
## factor(year)2006 -0.86149   0.27219  -3.165 0.001587 **
## factor(year)2007 -1.02520   0.30245  -3.390 0.000721 ***
## factor(year)2008 -1.58446   0.39929  -3.968 7.65e-05 ***
## factor(year)2009 -1.24422   0.27430  -4.536 6.28e-06 ***
## factor(year)2010 -1.79863   0.26243  -6.854 1.12e-11 ***
## factor(year)2011 -1.29588   0.36948  -3.507 0.000468 ***

```

```

## factor(year)2012 -1.34833    0.28233  -4.776 2.00e-06 ***
## factor(year)2013 -1.58407    0.32713  -4.842 1.44e-06 ***
## factor(year)2014 -1.22014    0.27867  -4.378 1.29e-05 ***
## factor(year)2015 -0.98099    0.32297  -3.037 0.002435 **
## factor(year)2016 -1.12411    0.31469  -3.572 0.000367 ***
## ---
## 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)              25.182 28.048 29.896 < 2e-16 ***
## s(doy)                  5.312  5.790  7.285 3.51e-05 ***
## s(bottom_depth)         6.467  7.576  6.826 < 2e-16 ***
## s(salinity,temperature) 22.655 26.689  5.516 < 2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## R-sq.(adj) =  0.424  Deviance explained = 70.3%
## -REML = 2871.6  Scale est. = 0.90096  n = 1345

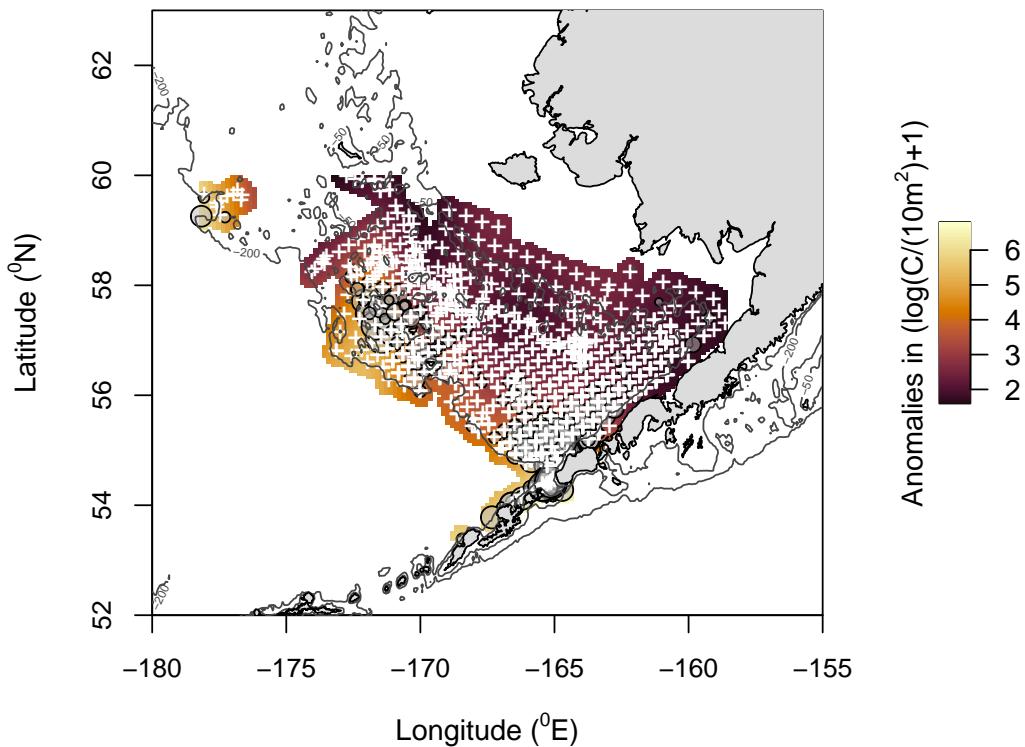
```

AIC(lv.2d)

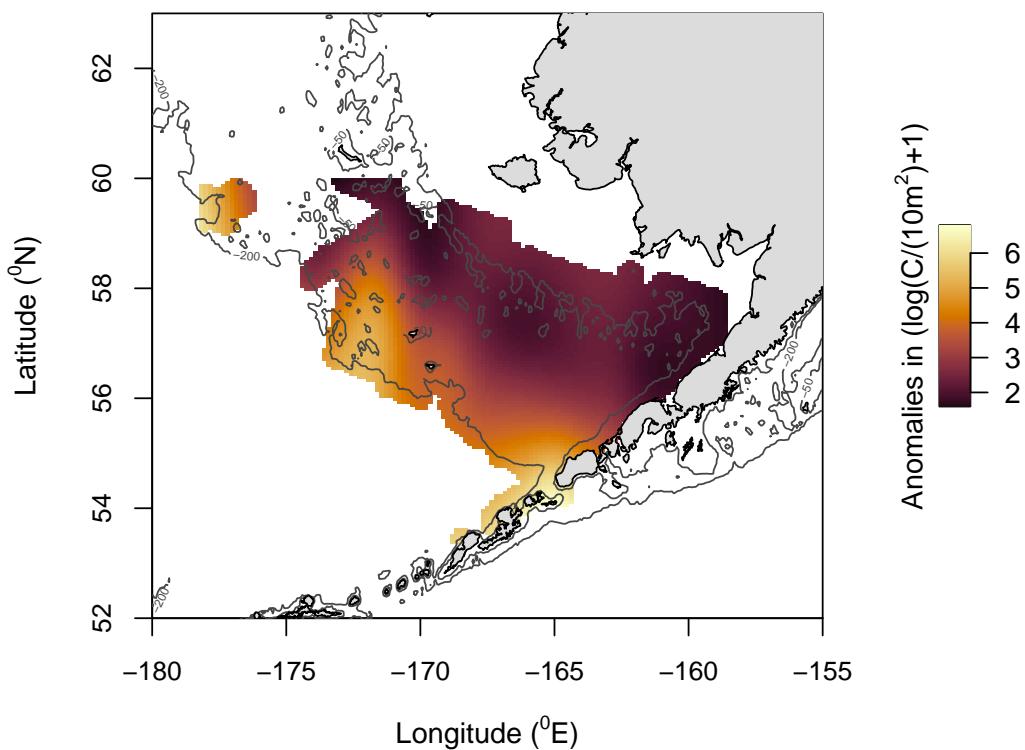
```
## [1] 5651.313
```

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

Predicted Pac cod Larval Biogeography, 2D Model

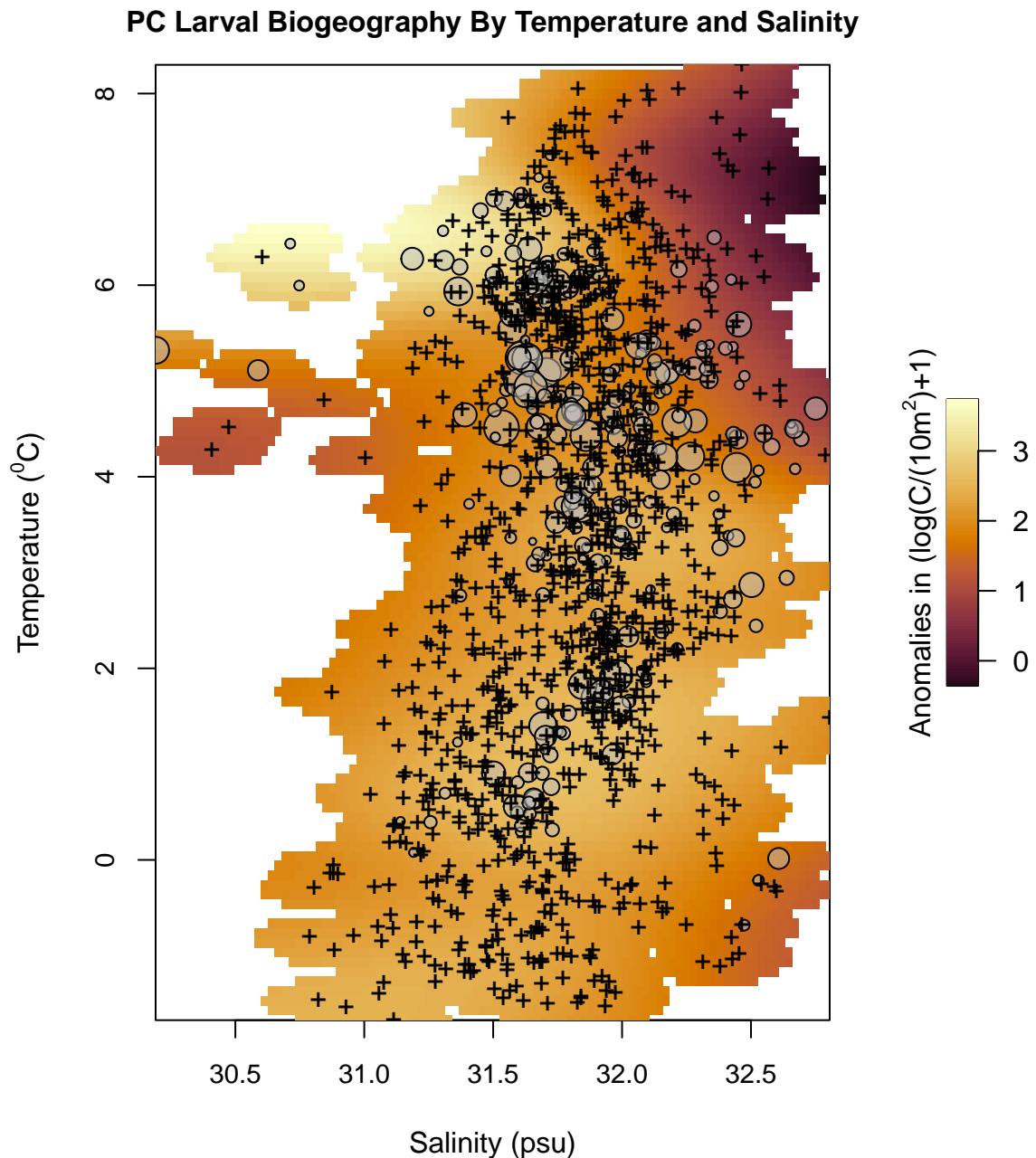


Predicted Pac cod Larval Biogeography, 2D Model



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 plot.xy(xy.coords(x, y), type = type, ...): "color" 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, Pacific Cod

| | Best Divided By Base | Best Divided By Second Best |
|--------|----------------------|-----------------------------|
| Larvae | 0.978081 | 0.9831586 |