Exploring MHW effects on fish abundance in trawl surveys

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Exploring marine heatwaves

Marine heatwave info

From Thomas Frölicher:

The SST is obtained from the NOAA/NCEI 1/4 degree daily optimum interpolation sea surface temperature (OISST) Analysis, Version 2.1 (Banzon et al. 2020, Reynolds et al. 2007).

Marine heatwaves (extreme SST anomalies) are defined with respect to a seasonally varying 95 percentile after detrending the SST dataset with a linear trend. The mean seasonal cycle has been additionally smoothed using a 30-day running mean to remove noise on a daily scale associated with the relative short SST record (similar approach as used in Le Grix et al.: https://bg.copernicus.org/preprints/bg-2020-412/). I averaged the SST over the individual survey areas. Here, in contrast to William's paper, I linearly detrended the data, whereas William used a 7-year running mean. I don't think that this heavily influences our results. Please see below in more detail the different steps applied to the SST data:

1. delete leap days
2. calculate climatological seasonal cycle
3. smooth climatological seasonal cycle with 30-day running mean
4. calculate SST anomalies relative to smoothed seasonal cycle
5. detrend SST anomalies with linear trend
6. calculate SST averages over survey area
7. calculate 95P for each survey area
8. calculate anomalies to 95P for each survey area

North America

Newer plots

Let's plot several marine heatwave indices against several CPUE indices, to see how similar patterns are across metrics. I'm also looking for whether we see effects of major known MHW events: 2012 in the Northeast, the 2014-2015 "warm blob" on the West Coast, and the 2014-2016 heatwave and partially sea ice-free period in the Eastern Bering Sea. (The other such event in the Eastern Bering Sea was 2001-2005, which also appears to show up here.)

In addition to summing all CPUE (which will be driven by common species) I've calculated proportional change first at the single-species level and then averaged across all species in a region. This gives all species equal weight while also standardizing and centering catch values. This is shown below both as an absolute value (magnitude of change only) and from averaging across true units of single-species values.

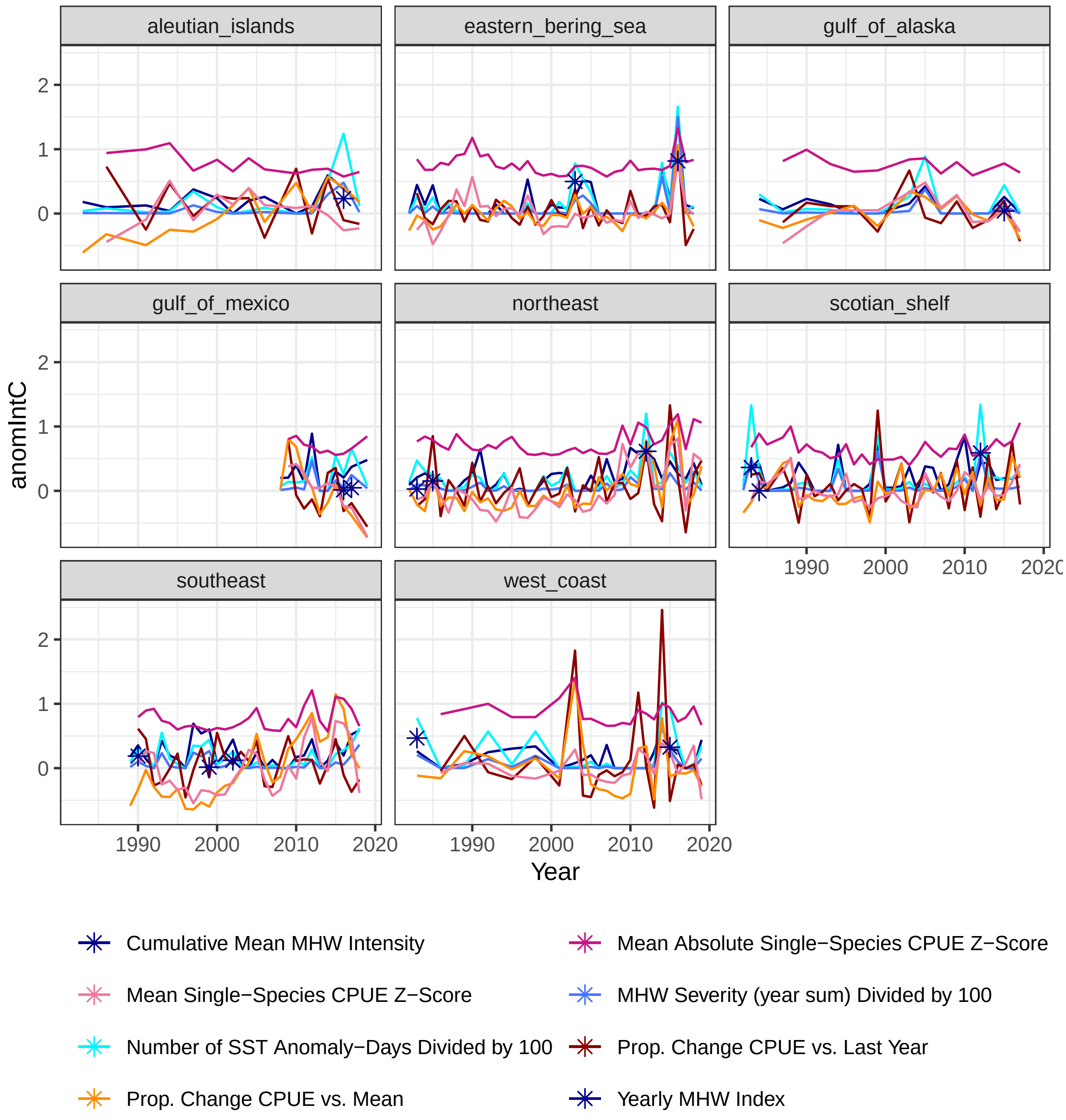


Figure 1: MHW Metrics vs. Sum CPUE Change

Older plots / models

Characterizing MHWs in North America

How frequent and severe have heatwaves been in North America since 1982 (the start of the MHW data)?

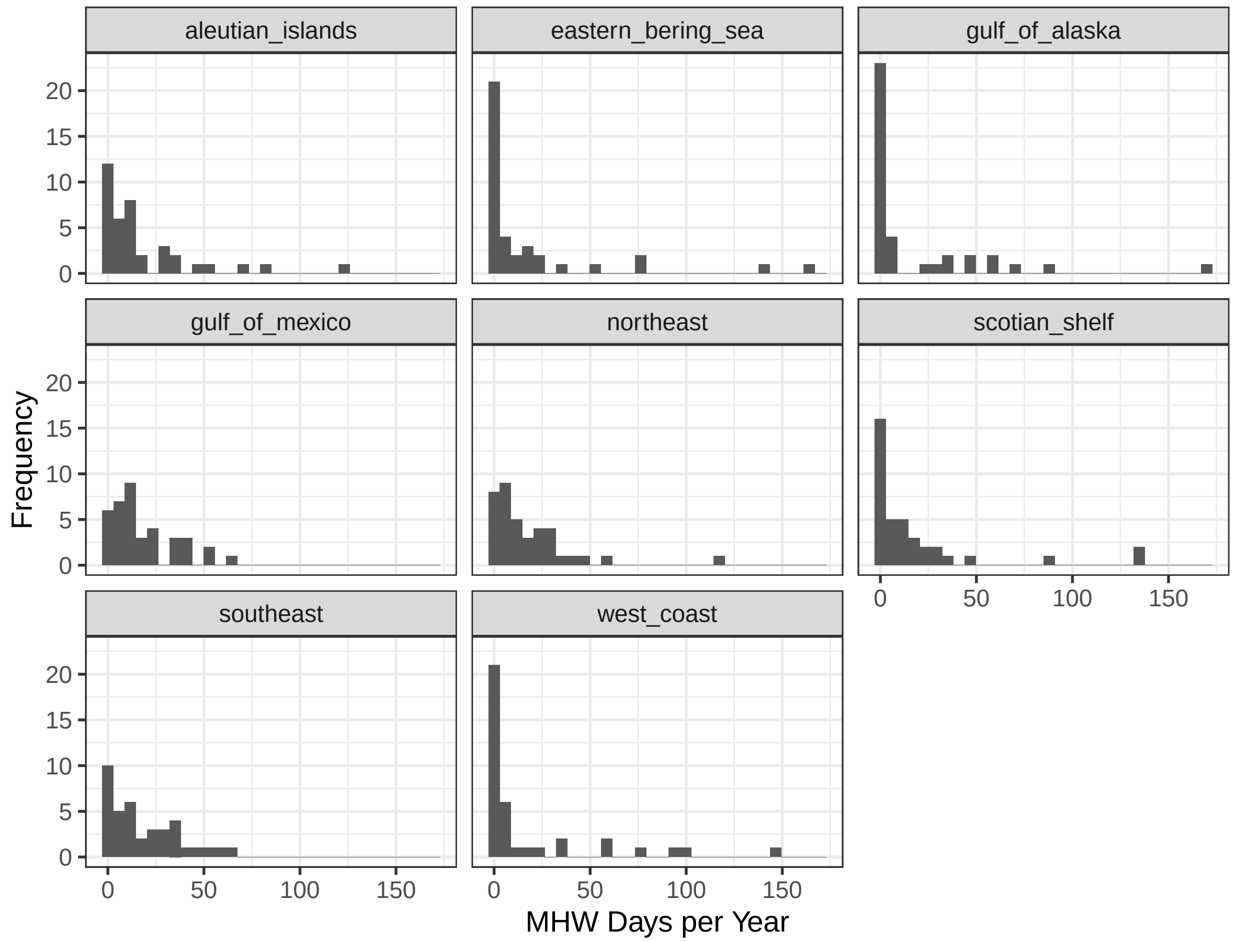


Figure 2: Frequency of MHW Events in North America

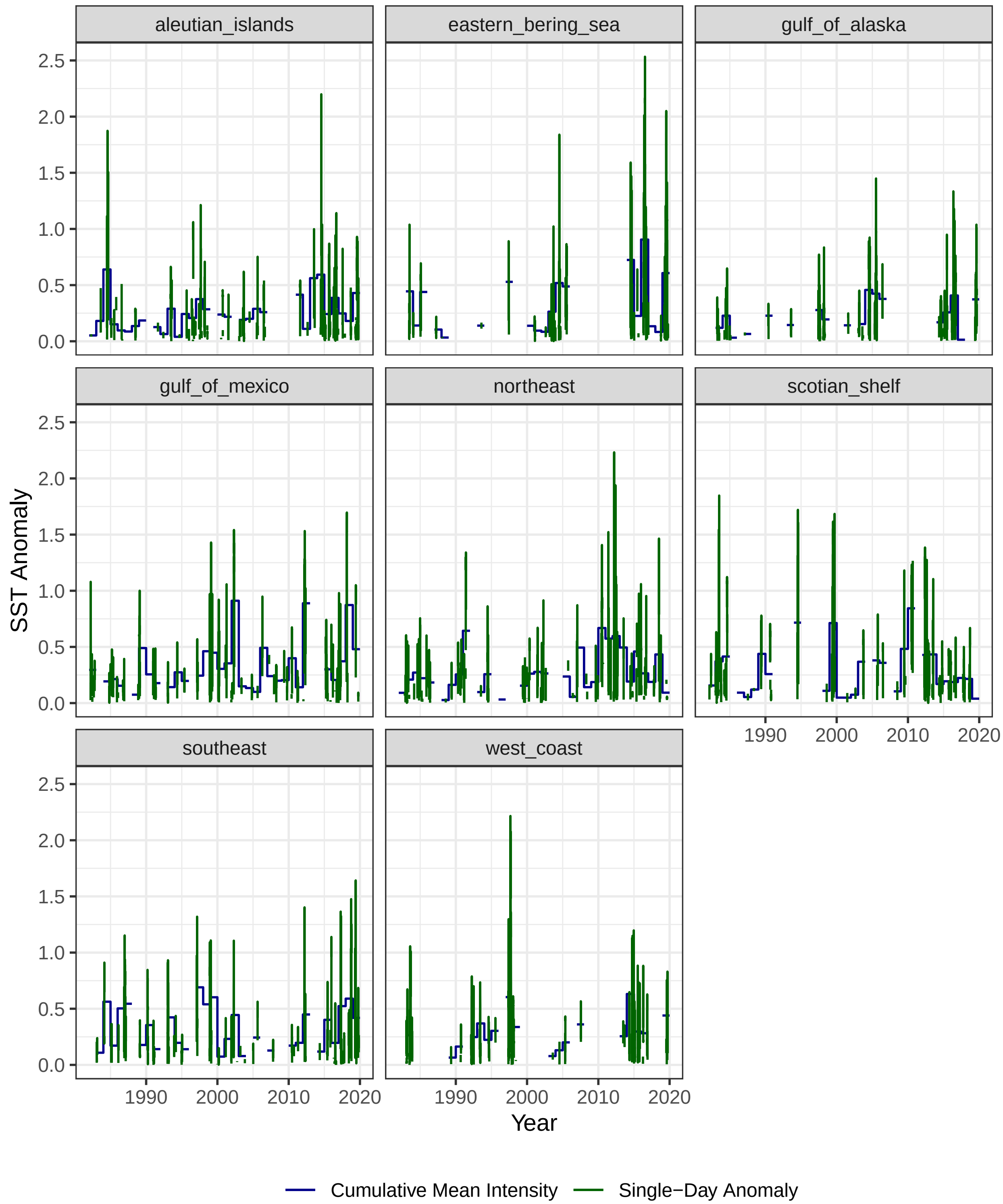


Figure 3: Anomaly of MHW Events in North America

MHWs vs. CPUE

Let's look at annual cumulative mean intensity (sum of SST anomalies in the calendar year / number of MHW-days in the calendar year) vs. trends in aggregate abundance (total CPUE across all species) for the whole region. The two metrics of CPUE change used are proportion change CPUE vs. last year ((cpueThisYear - cpueLastYear)/cpueLastYear), and proportion change CPUE relative to the long-term mean ((cpueThisYear - cpueSeriesMean)/cpueSeriesMean).

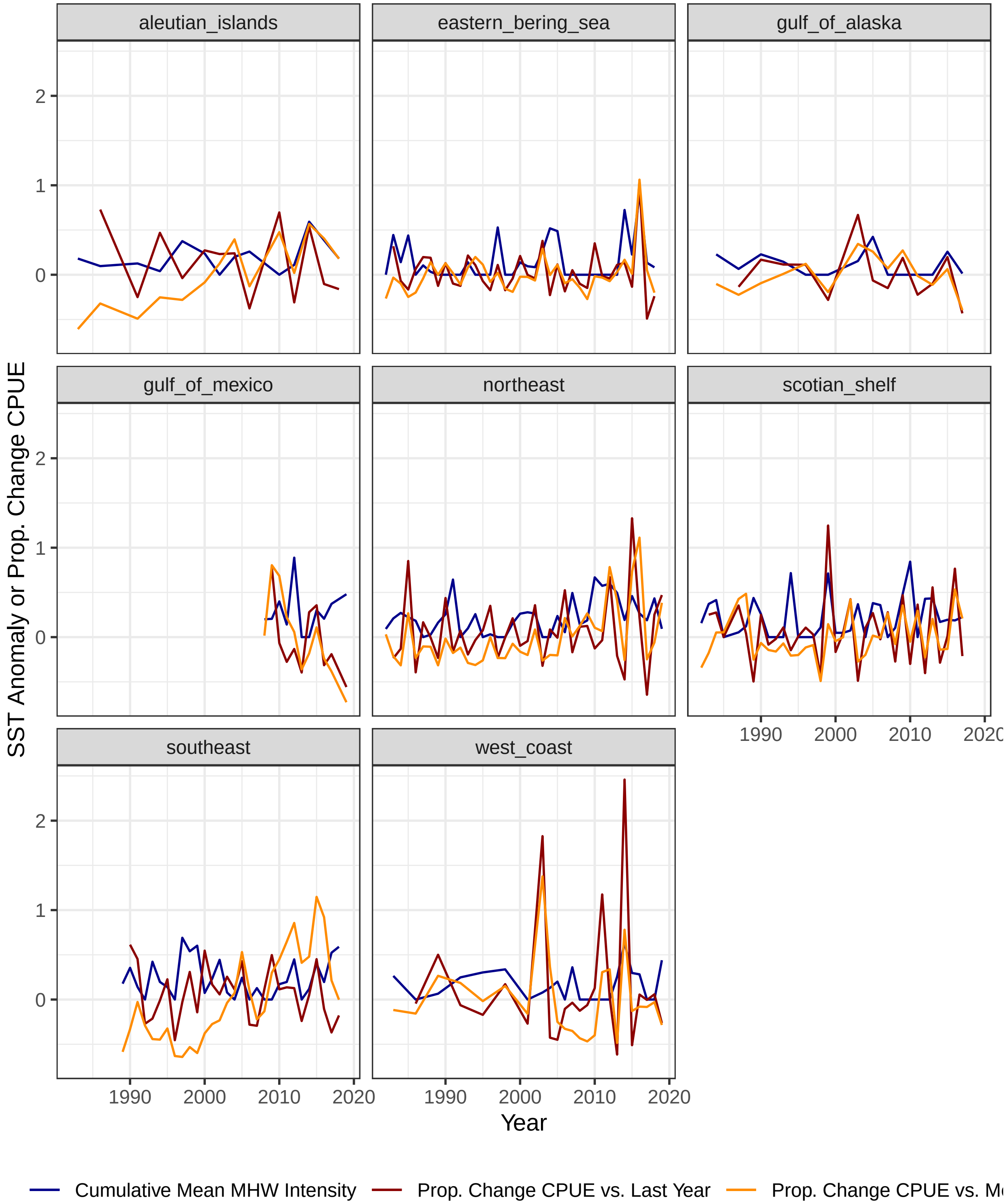


Figure 4: MHW Cumulative Mean Intensity and Change in Total CPUE Over Time

Rather than comparing both MHW intensity and CPUE trends over time, we can just plot cumulative mean intensity against the CPUE trend in that year:

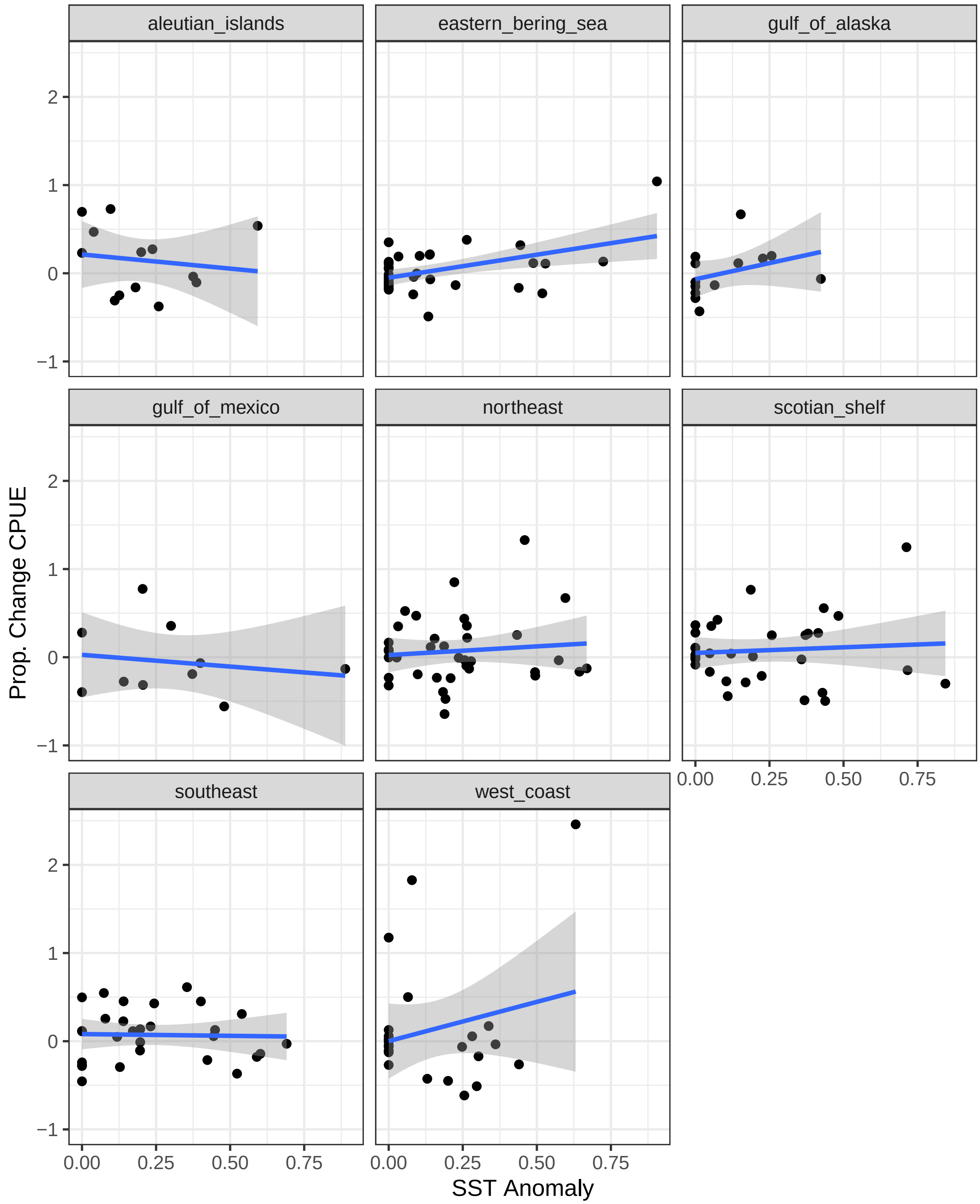


Figure 5: MHW Cumulative Mean Intensity vs. Change in Total CPUE

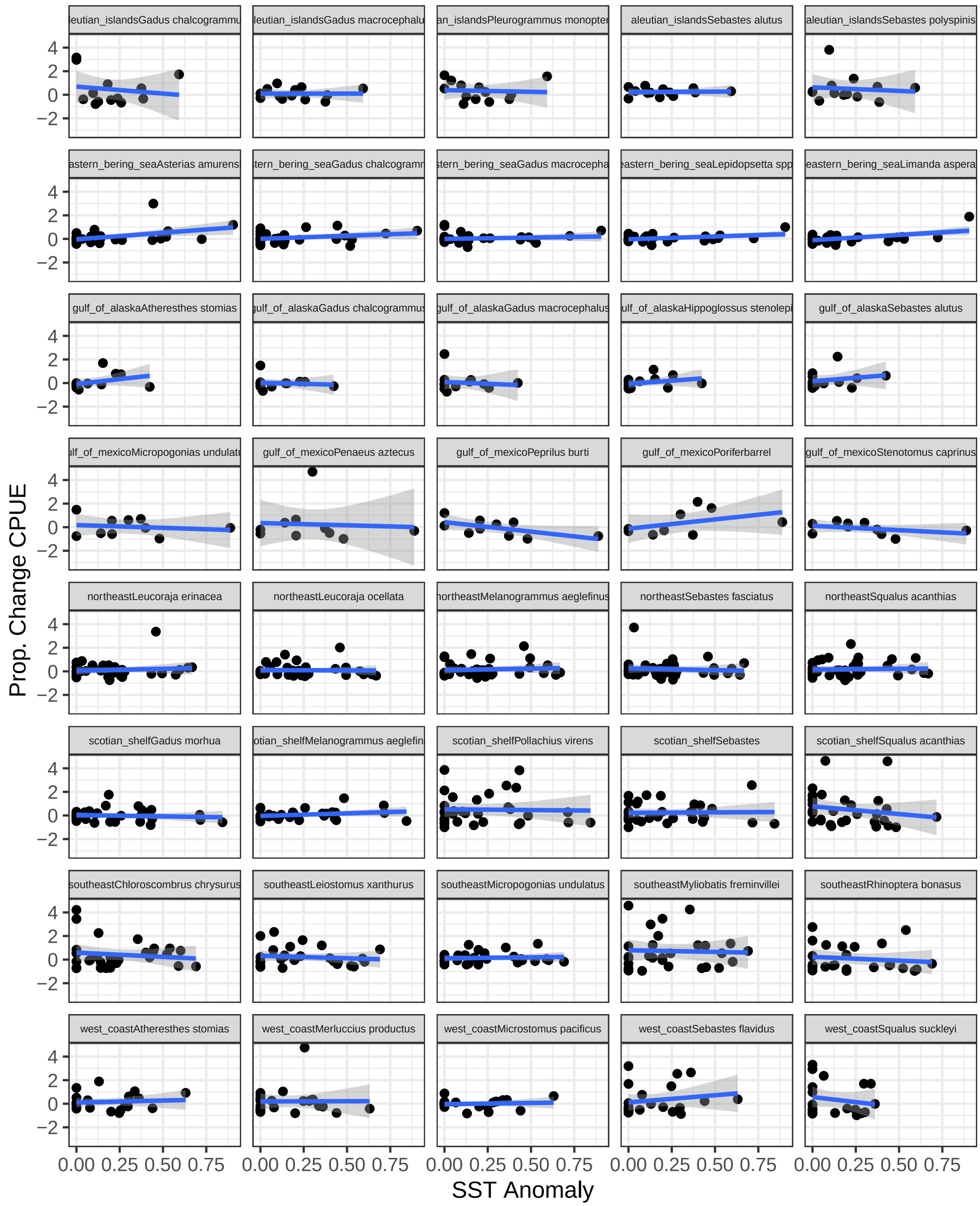


Figure 6: MHW Cumulative Mean Intensity vs. Single-Species Change in Total CPUE

Evaluating a yearly MHW index

At Thomas's suggestion, let's try using a yearly definition of MHWs rather than a daily one, to match the time scale of the trawl data. In the histograms below I've imputed zeros for NA values (no MHW) just to see the data distribution.

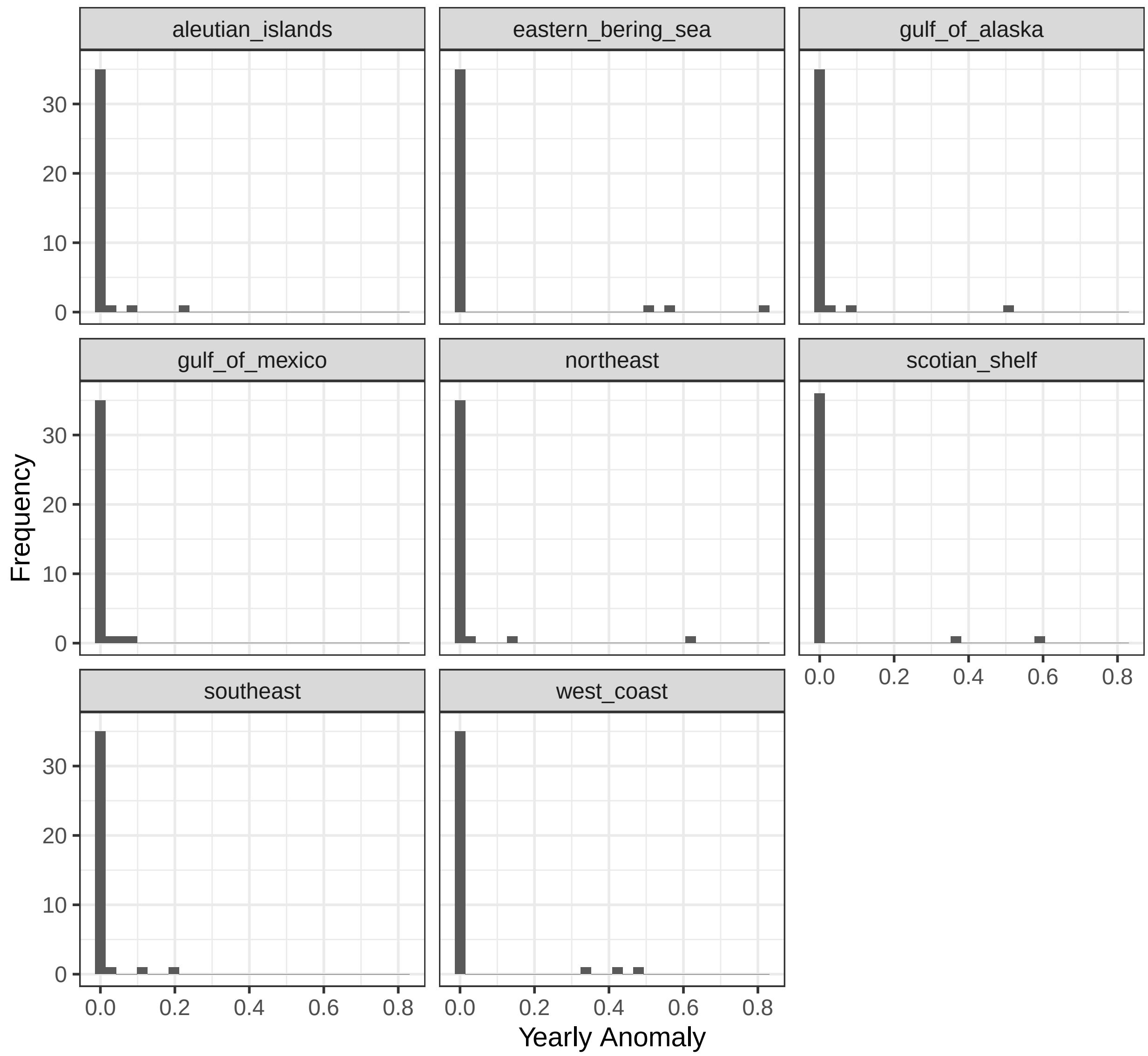


Figure 7: Distributions of Yearly MHW Estimates Across Regions

This approach calculated exactly 3 MHW-years per region, I think because we took the 90th percentile of the same number of years:

```
## # A tibble: 18 x 2
##    region             mhw_years
##    <chr>                  <int>
##  1 aleutian_islands           3
##  2 bits                       3
##  3 eastern_bering_sea         3
##  4 evhoe                      3
```

```
##   5 fr_cgfs                     3
##   6 gulf_of_alaska              3
##   7 gulf_of_mexico              3
##   8 ie_igfs                     3
##   9 nigfs                       3
##  10 norbts                      3
##  11 northeast                   3
##  12 ns_ibts                     3
##  13 pt_ibts                     3
##  14 rockall                     3
##  15 scotian_shelf               3
##  16 southeast                   3
##  17 swc_ibts                    3
##  18 west_coast                  3
```

Let's see what happened to CPUE in those regions in those years; these are the same plots as above but now MHW years are indicated with an asterisk. In plots with fewer than three asterisks, there aren't trawl data available in the MHW year.

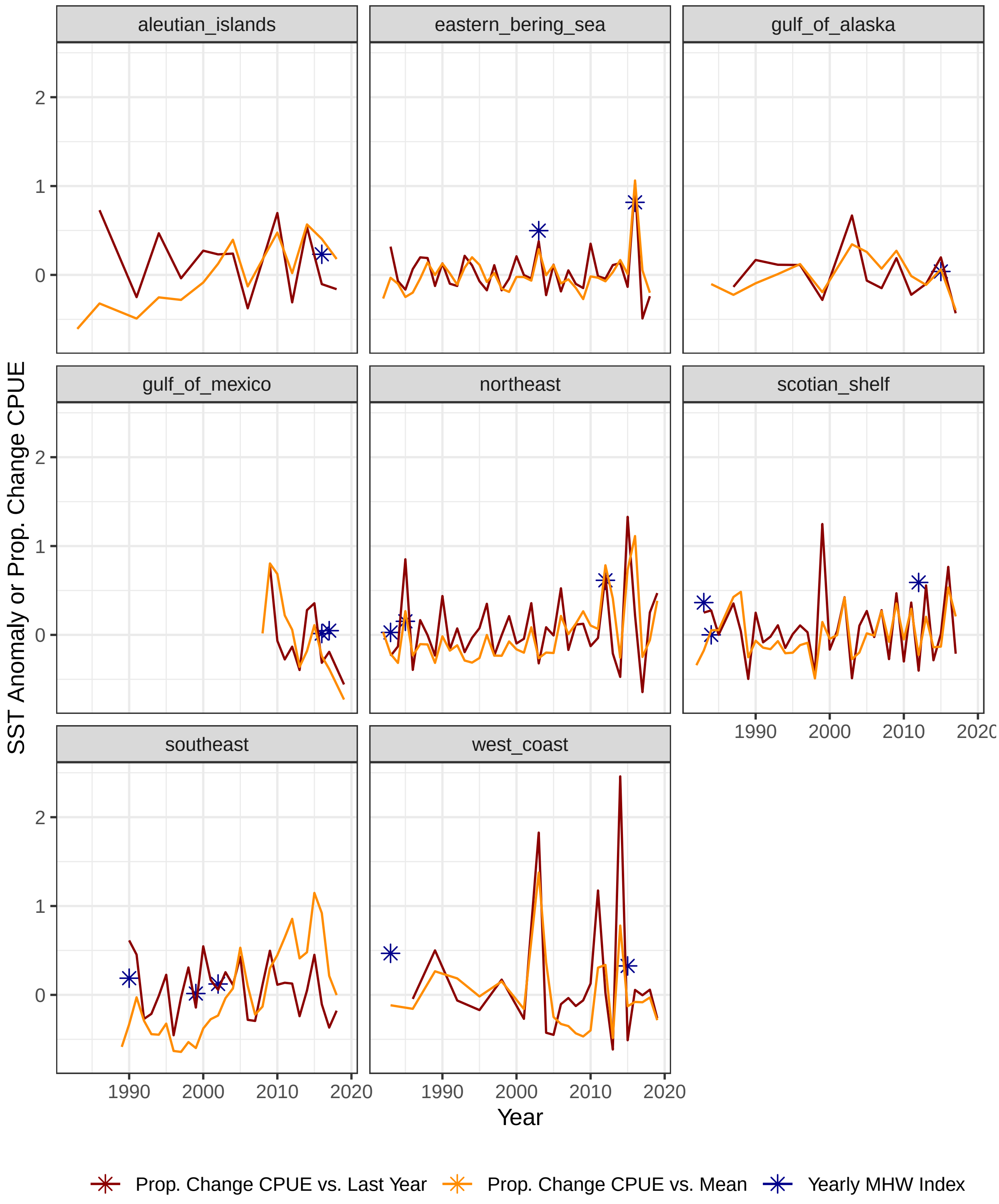


Figure 8: Yearly MHWs and Change in Total CPUE Over Time

How does catch vary in MHW years vs. non-MHW years?

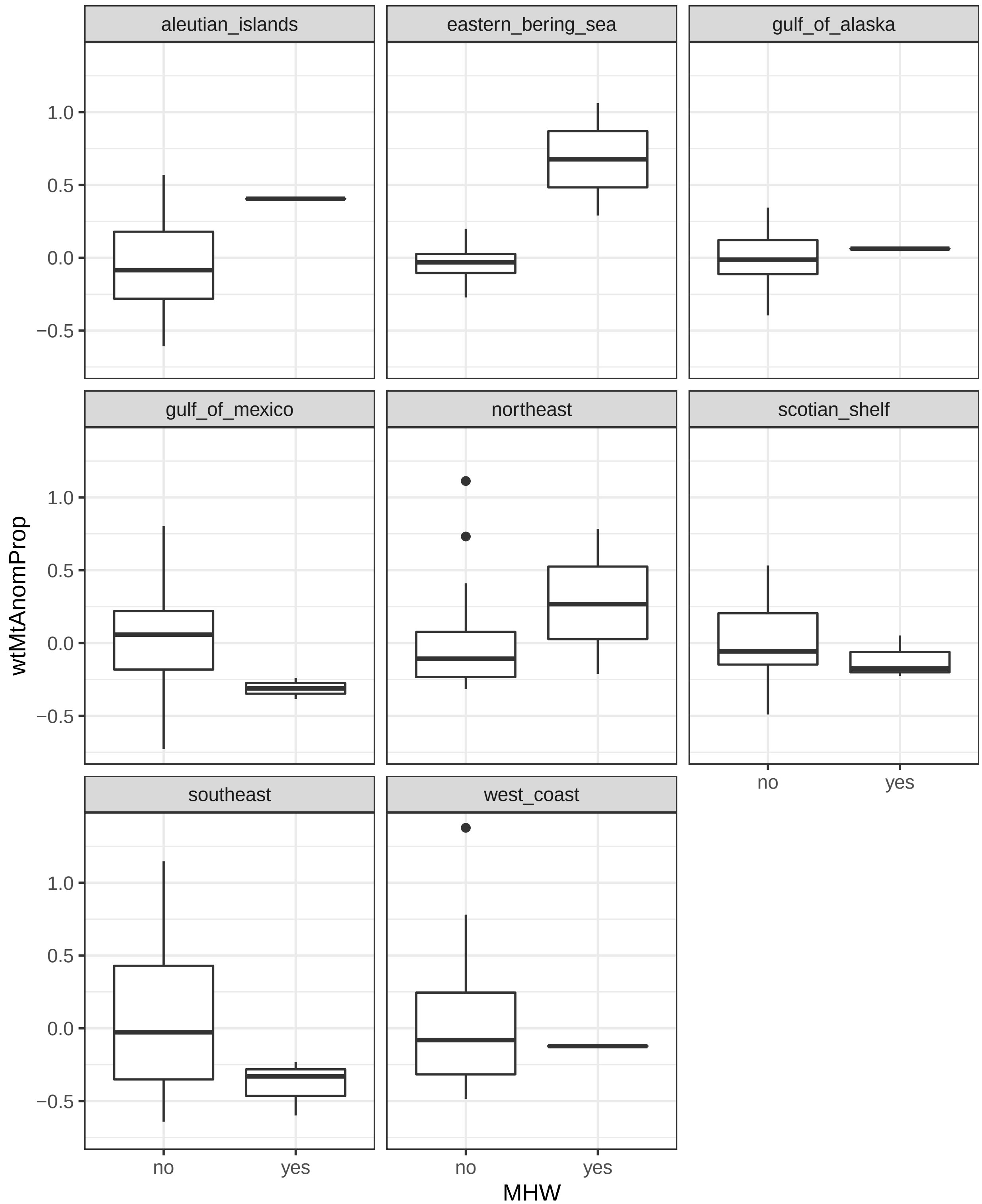


Figure 9: CPUE Proportional Anomaly in MHW vs. non-MHW years

Here are the same plots using proportional difference from the last year instead of CPUE anomaly.

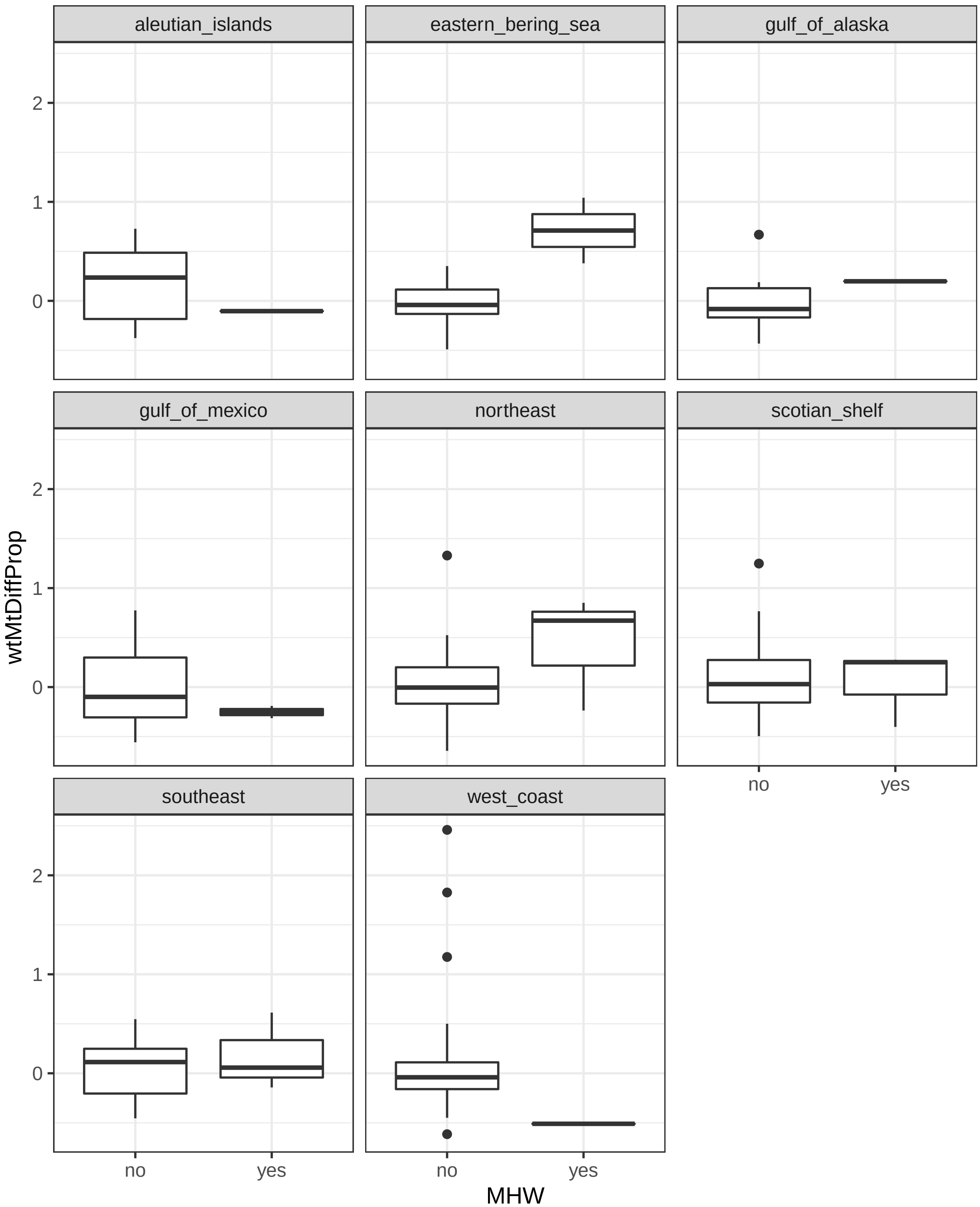


Figure 10: CPUE Proportional Year-Over-Year Difference in MHW vs. non-MHW years

Fitting a mixed-effects model to all the species-level data (not just top species) with random slopes and intercepts for species and region, `wtMtDiffPropAbs ~ sstYrAnom + (1 + sstYrAnom|spp) + (1 + sstYrAnom|region)` (note this is *absolute* change, so we are treating species that had increases or decreases in biomass as equivalent):

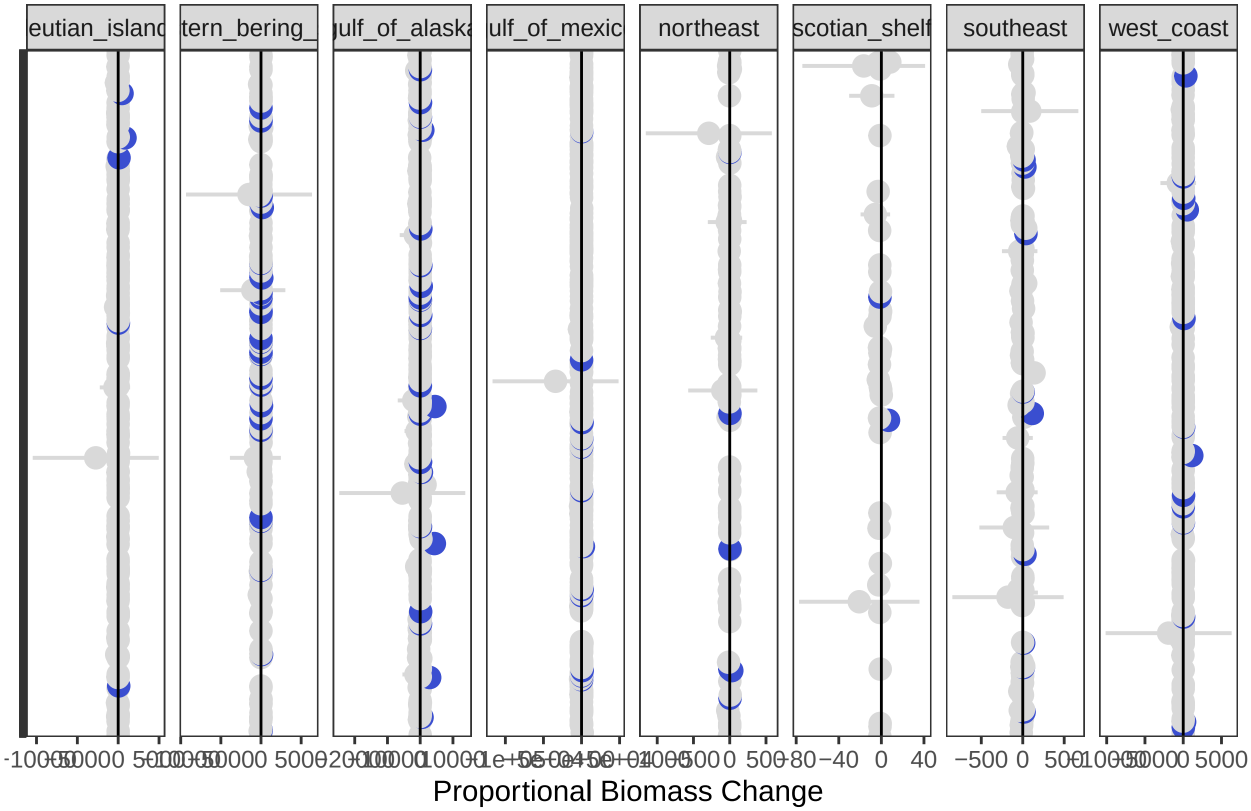
Note that the previous runs of this model had `NA` for years when there was no SST anomaly; replacing those values with 0 changed the results.

effect	group	term	estimate	std.error	statistic
fixed	NA	(Intercept)	8.2967243	2.320903	3.5747828
fixed	NA	sstYrAnom	-10.7937127	15.171198	-0.7114608
ran_pars	spp	sd___(Intercept)	21.3892968	NA	NA
ran_pars	spp	cor___(Intercept).sstYrAnom	-0.9999999	NA	NA
ran_pars	spp	sd___sstYrAnom	41.9714381	NA	NA
ran_pars	region	sd___(Intercept)	4.3841422	NA	NA
ran_pars	region	cor___(Intercept).sstYrAnom	-0.9997964	NA	NA
ran_pars	region	sd___sstYrAnom	3.4782437	NA	NA
ran_pars	Residual	sd___Observation	228.4465083	NA	NA

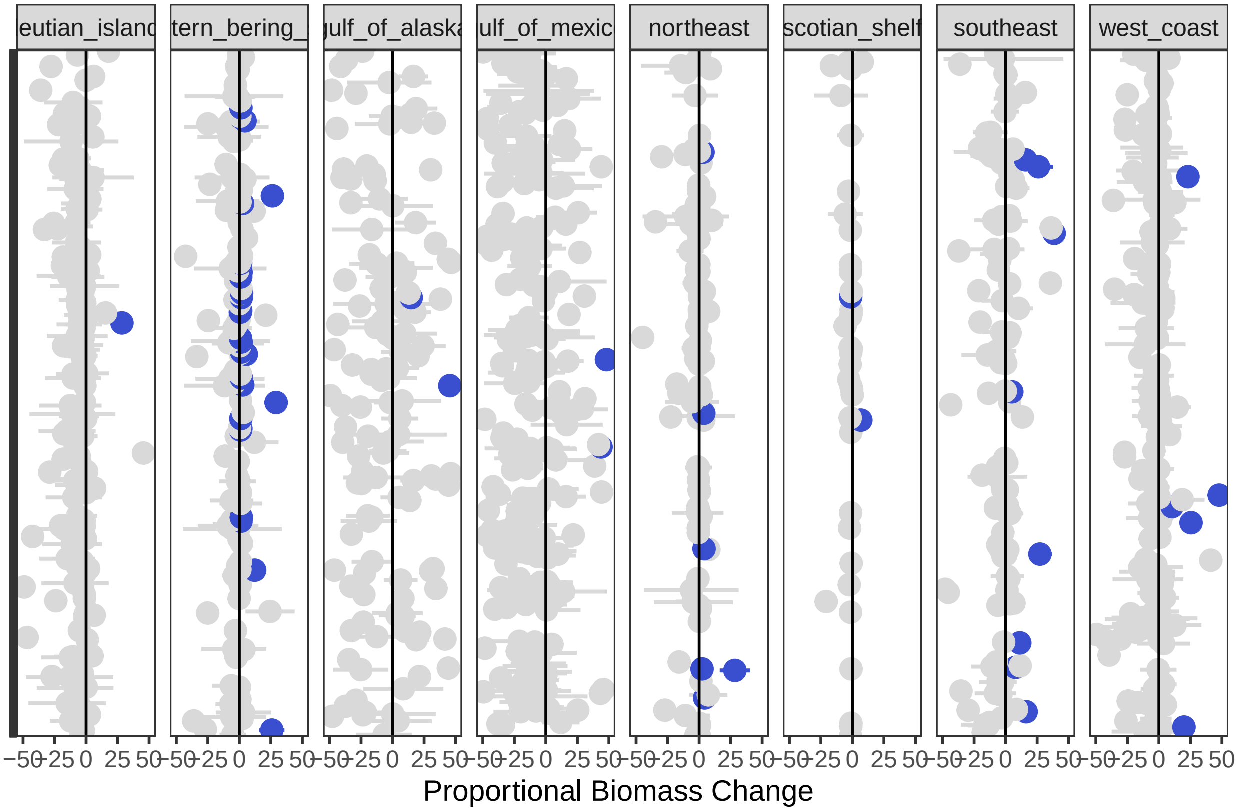
With the response variable on a log scale: `wtMtDiffPropAbsLog ~ sstYrAnom + (1 + sstYrAnom|spp) + (1 + sstYrAnom|region)`

effect	group	term	estimate	std.error	statistic
fixed	NA	(Intercept)	-0.4198672	0.0446527	-9.402956
fixed	NA	sstYrAnom	-0.0955101	0.1990283	-0.479882
ran_pars	spp	sd___(Intercept)	0.5021783	NA	NA
ran_pars	spp	cor___(Intercept).sstYrAnom	-1.0000000	NA	NA
ran_pars	spp	sd___sstYrAnom	0.1138408	NA	NA
ran_pars	region	sd___(Intercept)	0.1113150	NA	NA
ran_pars	region	cor___(Intercept).sstYrAnom	-0.9999997	NA	NA
ran_pars	region	sd___sstYrAnom	0.4694128	NA	NA
ran_pars	Residual	sd___Observation	1.4591519	NA	NA

Fitting a series of single-species models and plotting the results



I already removed one major outlier, but it's still hard to see what's going on around the zero line. Let's zoom in:


eutian_island
tern_bering_
ulf_of_alaska
ulf_of_mexic
northeast
scotian_shelf
southeast
west_coast
−50 −25 0 25 50
Proportional Biomass Change