Supplementary Information

Fredston et al.

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Contents

1 Supplementary tables

Table 1: Survey names used in this analysis, and corresponding codes used in figures and tables in this Supplement.

Code	Survey
BITS	Baltic Sea
DFO-QCS	British Columbia
EBS	Eastern Bering Sea
EVHOE	France
FR-CGFS	English Channel
GMEX	Gulf of Mexico
GOA	Gulf of Alaska
GSL-S	Gulf of Saint Lawrence
IE-IGFS	Ireland
NEUS	Northeast US
NIGFS	Northern Ireland
Nor-BTS	Norway
NS-IBTS	North Sea
PT-IBTS	Portugal
SCS	Scotian Shelf
SEUS	Southeast US
SWC-IBTS	Scotland
WCANN	West Coast US

Table 2: Models of biomass response to MHWs. All models were fitted to biomass log ratio values (scaled and centered within surveys) using MHW duration in days (scaled and centered within surveys). Model names correspond to: linear model, linear model including survey as a fixed effect, generalized additive model (GAM), and GAM including survey as a random effect.

	LM	LM Survey	GAM	GAM Survey
Intercept	0.00 ± 0.048	0.00 ± 0.236	0.00 ± 0.048	0.00 ± 0.048
MHW coefficient	-0.008 ± 0.049	-0.008 ± 02	NA	NA
Coefficient p-value	0.866	0.868	NA	NA
R^2	0.000	0.000	-0.002	-0.002
AIC	1185.16	1219.16	1185.16	1185.16
Degrees of freedom	420	403	420	420

Table 3: Models of biomass response to MHWs. This table is identical to Supp. Tab. 2, except rather than centering and scaling MHW duration within regions, it is centered and scaled among regions. The approach used in most of these models (centering and scaling MHW duration within regions) assumes that history matters in ecological responses to MHW responses, i.e., that biomass change should be compared to how anomalous a MHW is relative to other MHWs that occurred in the region. Here, we test the hypothesis that absolute MHW duration matters regardless of the oceangraphic history of each region (centering and scaling MHW duration among regions). All models were fitted to biomass log ratio values (scaled and centered within surveys) using MHW duration in days (scaled and centered within surveys). Model names correspond to: linear model, linear model including survey as a fixed effect, generalized additive model (GAM), and GAM including survey as a random effect.

	LM	LM Survey	GAM	GAM Survey
Intercept	0.00 ± 0.048	0.001 ± 0.236	0.00 ± 0.048	0.00 ± 0.048
MHW coefficient	-0.024 ± 0.048	-0.025 ± 02	NA	NA
Coefficient p-value	0.609	0.612	NA	NA
R^2	0.001	0.001	-0.002	-0.002
AIC	1184.926	1218.920	1184.926	1184.926
Degrees of freedom	420	403	420	420

Table 4: Models of biomass response to lagged MHW effects. All models were fitted to biomass log ratio values (scaled and centered within surveys) using MHW duration in days (scaled and centered within surveys). All models are generalized additive models (GAMs) that use a smoothed predictor matrix containing lagged MHW data for up to five years into the past.

	1-2 Years	1-3 Years	1-4 Years	1-5 Years
R^2	-0.001	-0.003	-0.002	-0.003
AIC	1124.979	1072.957	1023.707	981.090
Degrees of freedom	402	384	366	348

Table 5: Generalized linear model (GLM) of biomass as a function of MHWs and biomass from the previous time step. This Gompertz model accounts for autoregressive properties of the biomass time-series. It predicts biomass log ratios with MHW duration in days (scaled and centered within surveys) and lagged biomass (*not* scaled and centered). To account for variability and heteroskedasticity among surveys, we included survey identity as a fixed effect and allowed dispersion to vary among surveys.

	Gompertz GLM
Intercept	0.315 ± 0.241
MHW coefficient	-0.006 ± 0.011
Coefficient p-value	0.587
R^2	0.313
AIC	124
Degrees of freedom	349

Table 6: Model of biomass response to MHWs and latitude. Linear model was fitted to biomass log ratio values (scaled and centered within surveys) using MHW duration in days (scaled and centered within surveys) and median latitude of each survey (scaled and centered within surveys) as predictors.

	Linear model
Intercept	0.00 ± 0.048
MHW coefficient	-0.008 ± 0.049
Latitude coefficient	0.00 ± 0.048
MHW coefficient p-value	0.866
R^2	0.00
AIC	1187
Degrees of freedom	419

Table 7: Model of depth response to MHWs. Linear model was fitted to the weighted mean depth of the fish assemblage (scaled and centered within surveys) using MHW duration in days (scaled and centered within surveys). Model names correspond to: linear model, linear model including survey as a fixed effect, generalized additive model (GAM), and GAM including survey as a random effect.

	Linear model
Intercept	0.00 ± 0.05
MHW coefficient	-0.022 ± 0.051
Coefficient p-value	0.658
R^2	0.001
AIC	1092
Degrees of freedom	387

Table 8: Models of Community Temperature Index (CTI) response to MHWs. All models were fitted to CTI log ratio values (scaled and centered within surveys) using MHW duration in days (scaled and centered within surveys). Model names correspond to: linear model, linear model including survey as a fixed effect, generalized additive model (GAM), and GAM including survey as a random effect.

	LM	LM Survey	GAM	GAM Survey
Intercept	0.00 ± 0.048	0.00 ± 0.236	0.00 ± 0.048	0.00 ± 0.048
MHW coefficient	0.019 ± 0.049	0.019 ± 02	NA	NA
Coefficient p-value	0.691	0.697	NA	NA
R^2	0.000	0.000	-0.002	-0.002
AIC	1185.03	1219.03	1185.03	1185.03
Degrees of freedom	420	403	420	420

2 Supplementary figures

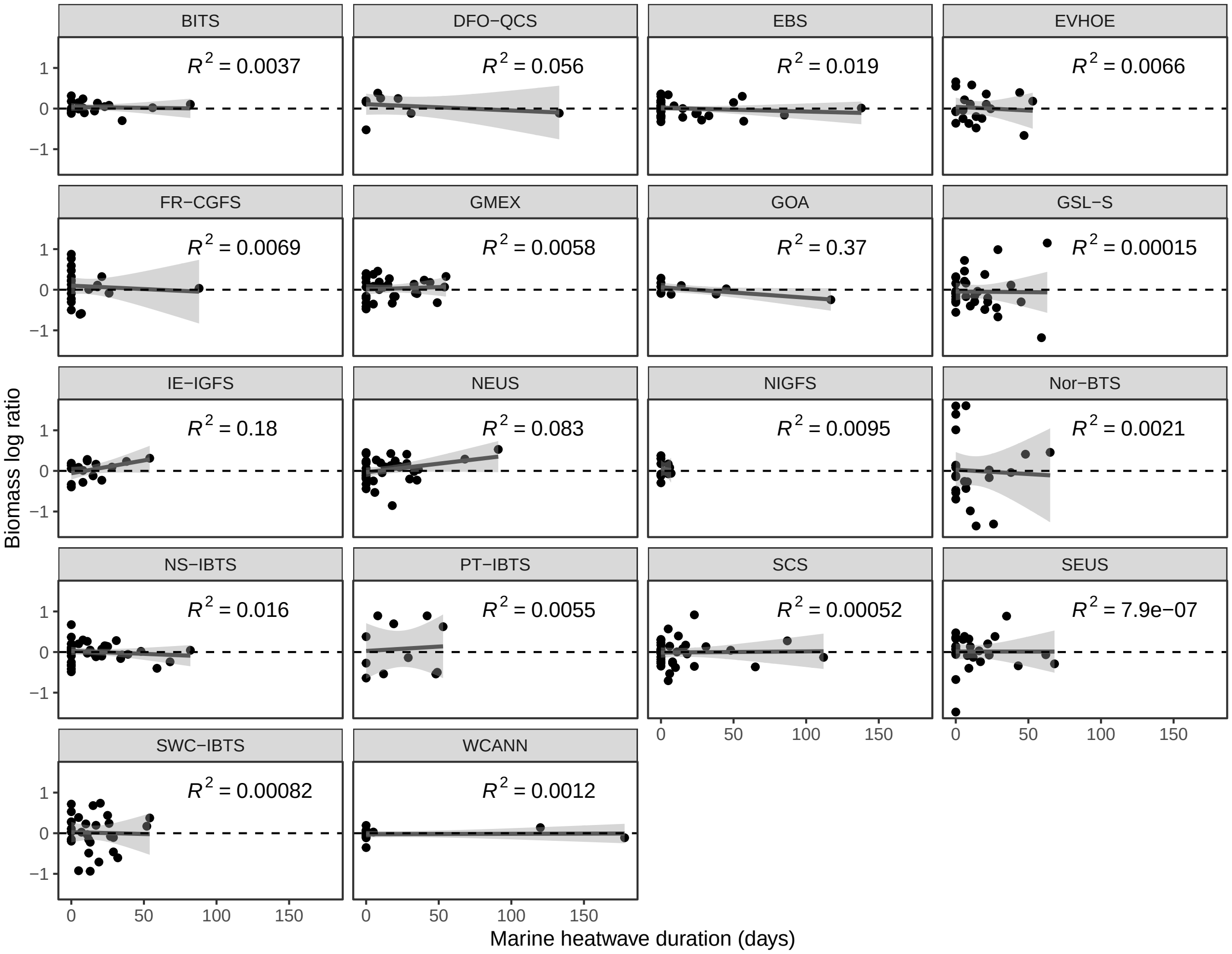

Figure 1: Alternate version of Fig. 2 from the main text, showing results by region. Longer MHWs are not associated with a decline in temperate fish biomass, and biomass is approximately as likely to increase as it is to decrease from one year to the next, regardless of whether a marine heatwave occurred. Points represent log ratios of mean biomass in a survey from one year to the next. The fitted lines are linear regressions. The shaded areas are 95% confidence intervals. Survey names are listed in Supp. Tab. 1.

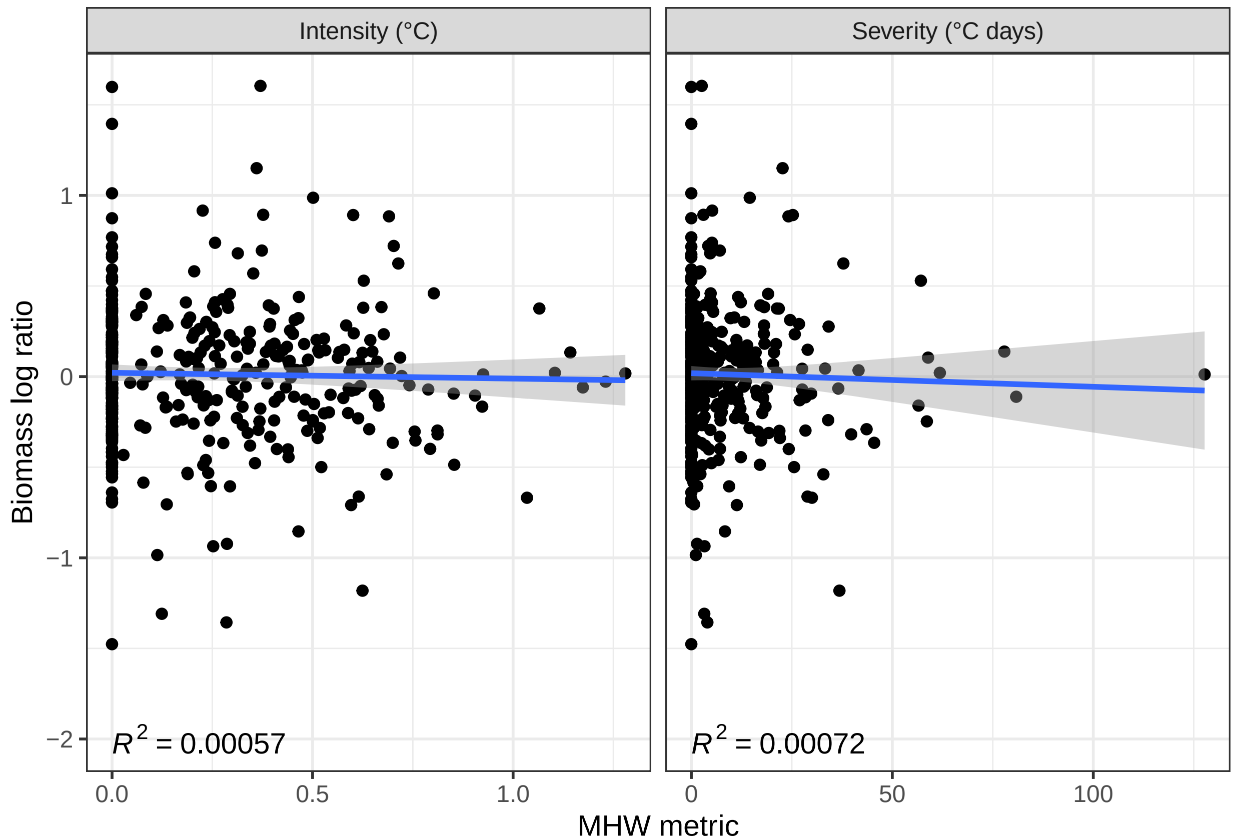

Figure 2: Biomass change (log ratio) and two alternative metrics of MHW impacts: severity (total anomaly in °C days), and intensity (severity divided by number of days, i.e., the average anomaly over the course of the MHW in °C). The fitted lines are linear regressions. The shaded areas are 95% confidence intervals.

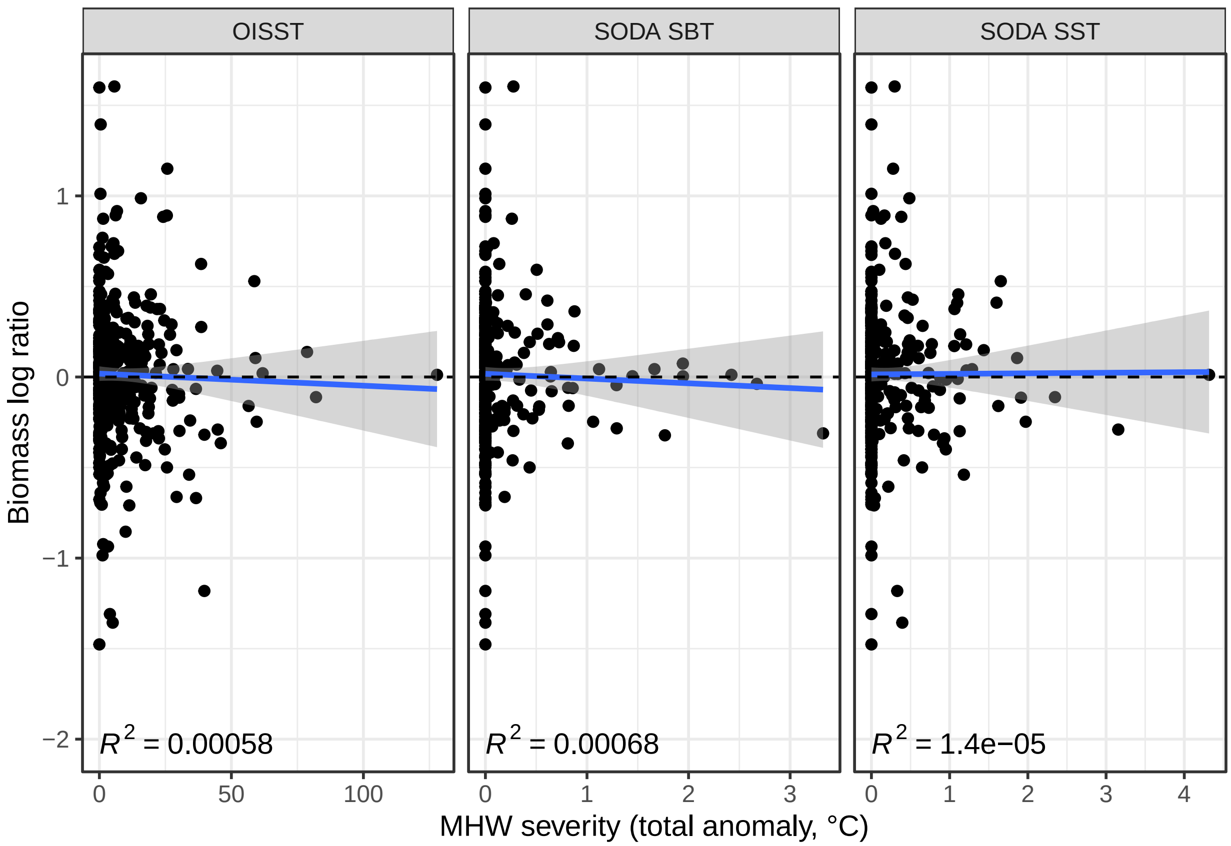

Figure 3: Biomass change (log ratio) and MHW severity from three data products: daily satellite SST (OISST), monthly bottom temperatures from a data reanalysis product (SODA SBT), and monthly surface temperatures from a data reanalysis product (SODA SST). Here, we consider all anomaly-days in OISST to be MHWs. Severity is calculated as the total anomaly (°C) over the 12-month interval to which each biomass log ratio is paired. Note that the greater magnitude of severity values in OISST (see x-axis) are due to its higher (daily) temporal resolution revealing greater temperature anomalies than those that appear in the monthly SODA datasets. The fitted lines are linear regressions. The shaded areas are 95% confidence intervals.

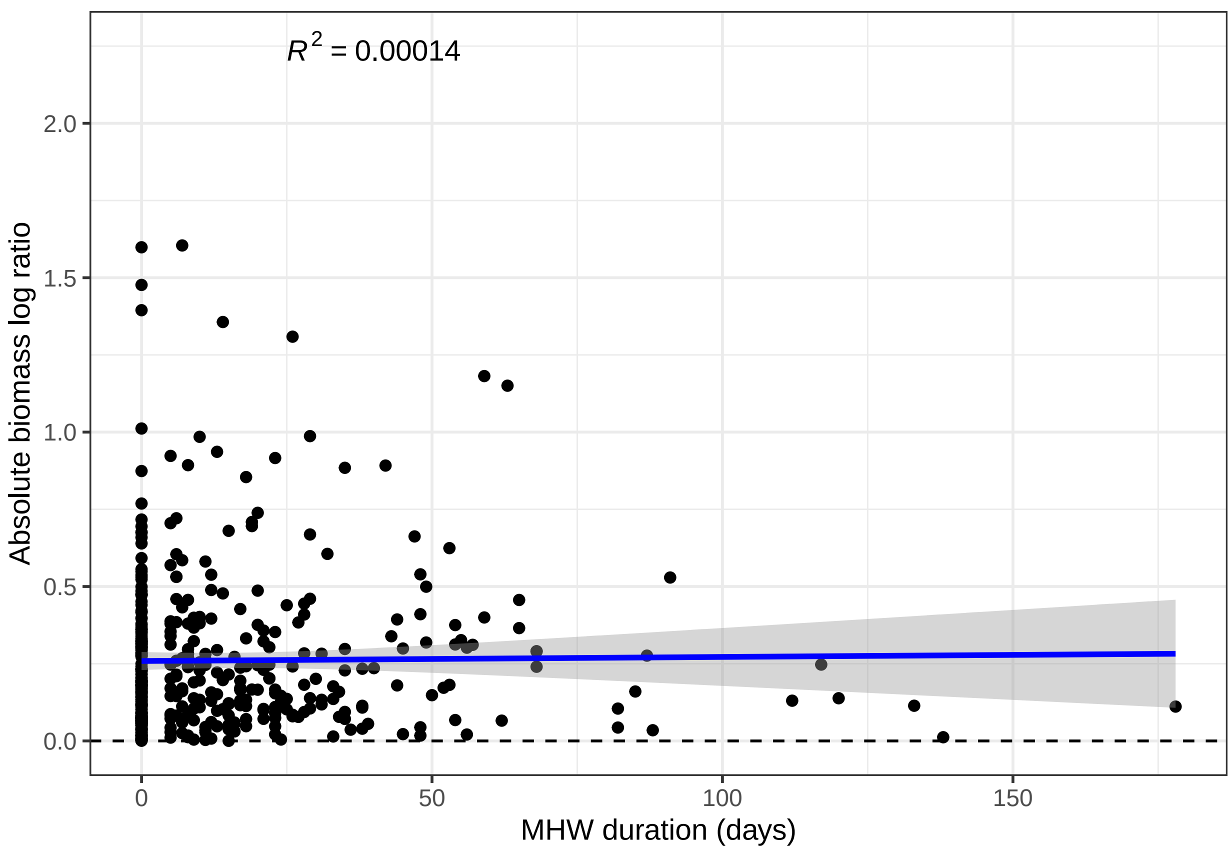

Figure 4: MHW duration and absolute value of biomass log ratio. The fitted line is a linear regression. The shaded area is its 95% confidence interval.

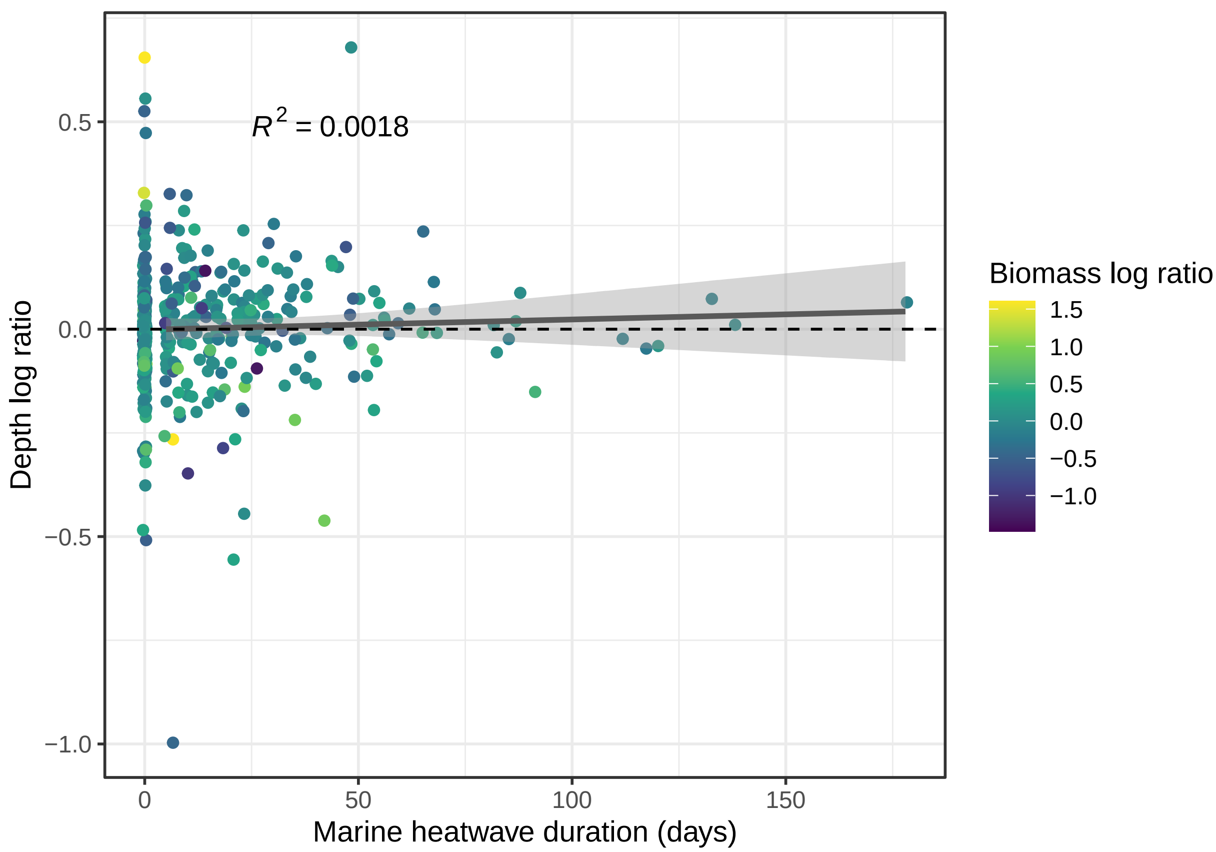

Figure 5: Fish assemblage depth change (log ratio) and MHW duration. The fitted line is a linear regression. The shaded area is its 95% confidence interval.

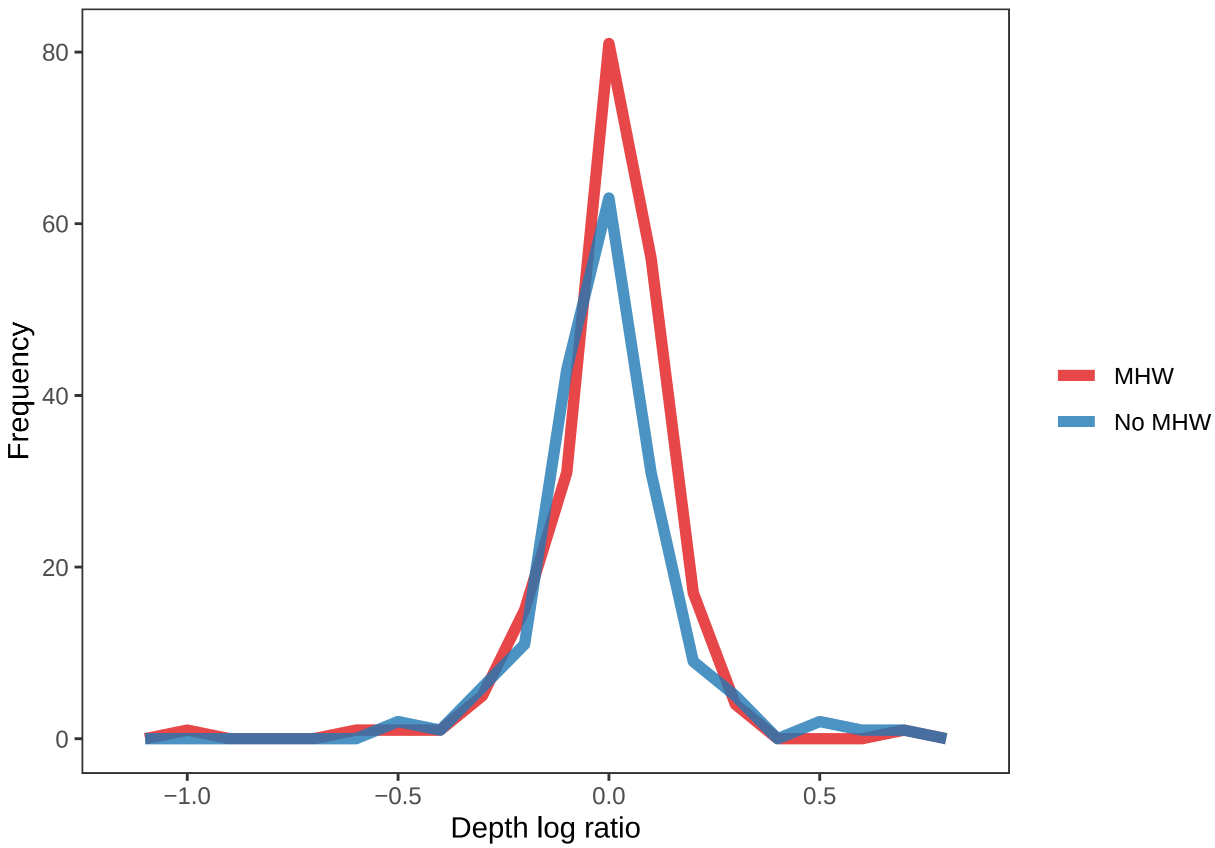

Figure 6: Fish assemblage depth change (log ratio) and MHW occurrence.

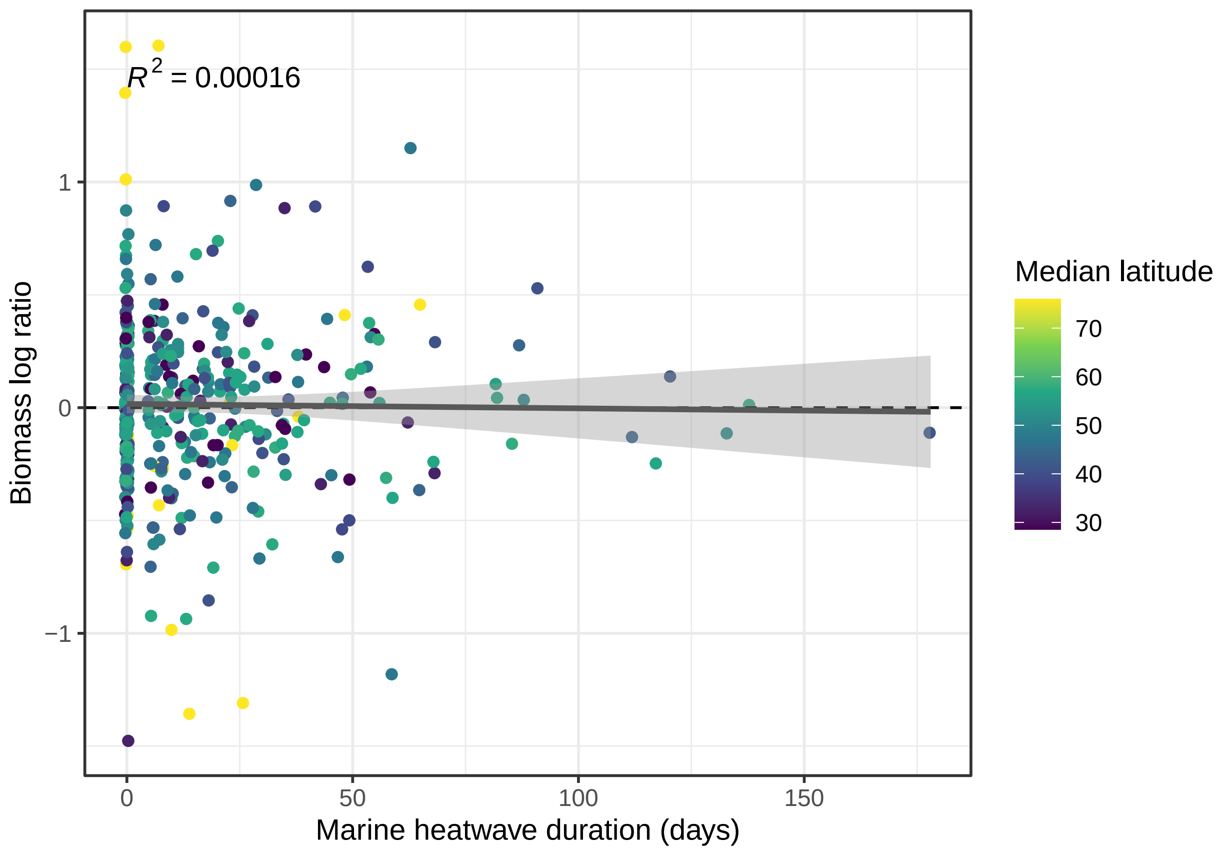

Figure 7: Biomass change (log ratio) and MHW duration, color-coded by median latitude of each survey region. The fitted line is a linear regression. The shaded area is its 95% confidence interval.

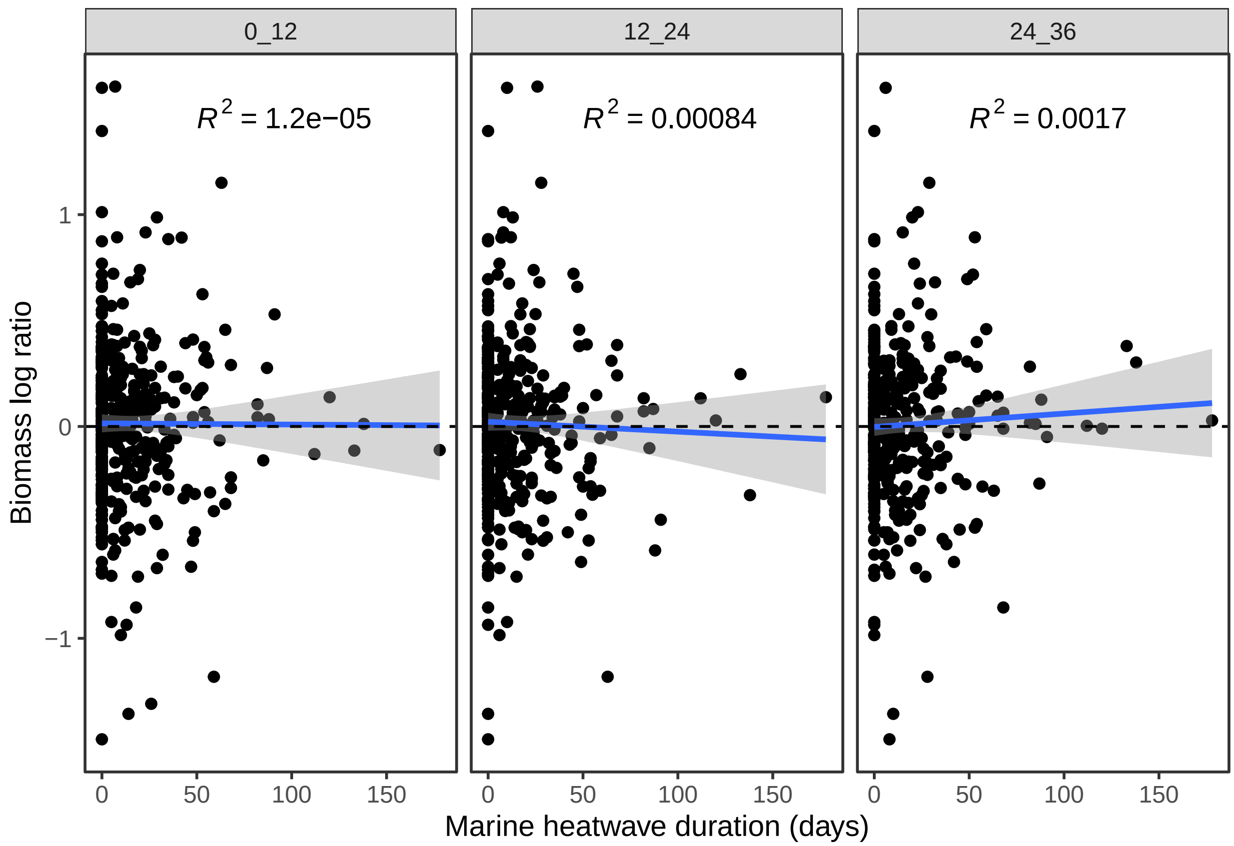

Figure 8: Biomass change (log ratio) and MHW duration calculated the preceding year as in the main text (0-12 months), a one-year lag (12-24 months), and a two-year lag (24-36 months). Fitted lines are linear regressions. Shaded areas are 95% confidence intervals.

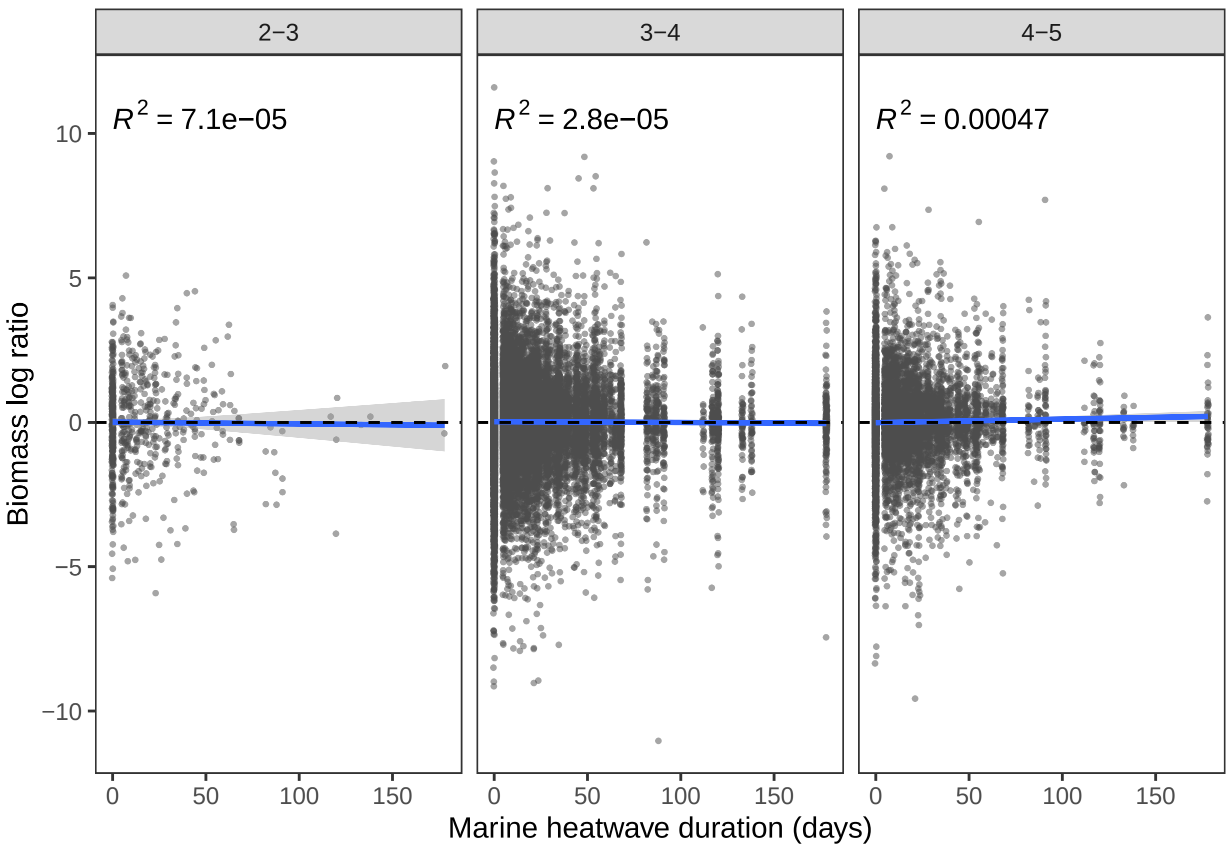

Figure 9: Biomass log ratio and MHW duration grouped by trophic level of each taxon. Trophic levels are binned (2-3, 3-4, and 4-5). Fitted lines are linear regressions. Shaded areas are 95% confidence intervals.

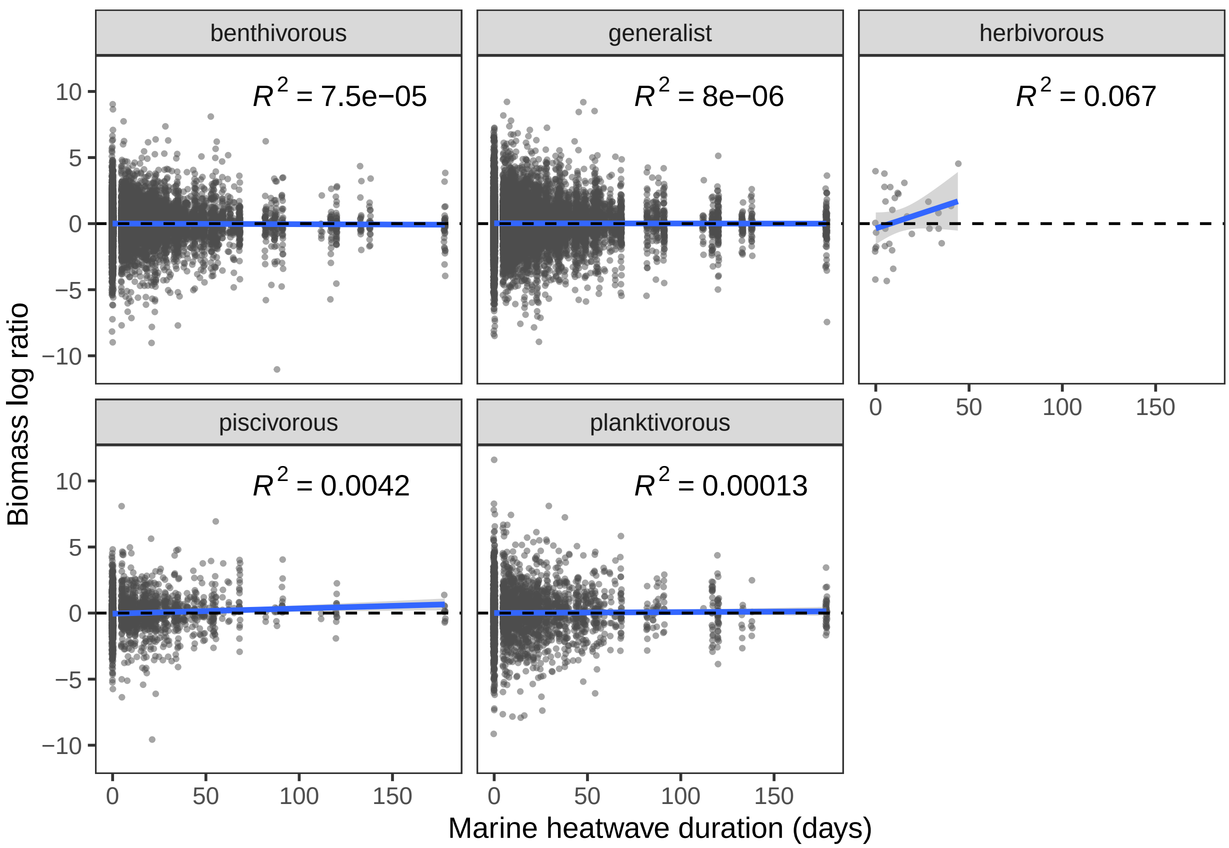

Figure 10: Biomass log ratio and MHW duration grouped by feeding mode of each taxon. Fitted lines are linear regressions. Shaded areas are 95% confidence intervals.

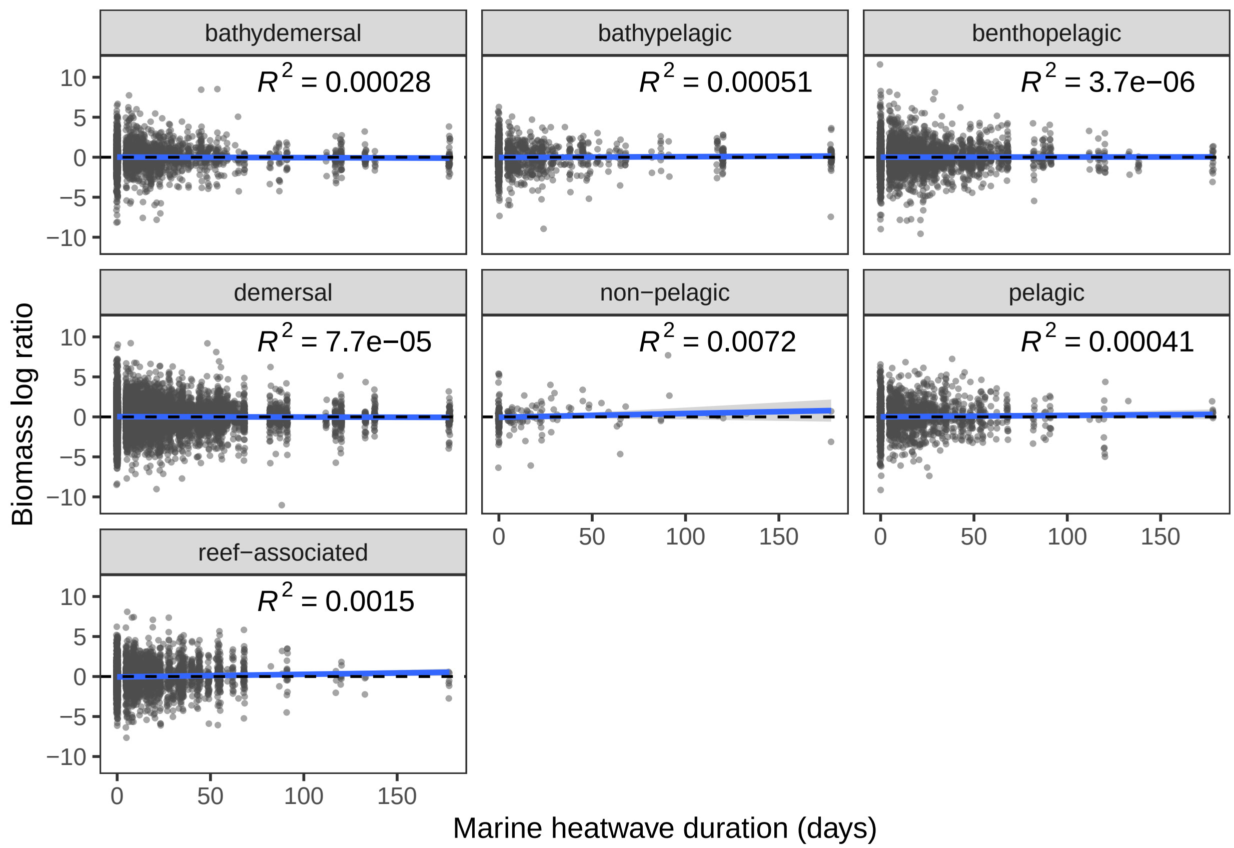

Figure 11: Biomass log ratio and MHW duration grouped by habitat preference of each taxon. Fitted lines are linear regressions. Shaded areas are 95% confidence intervals.

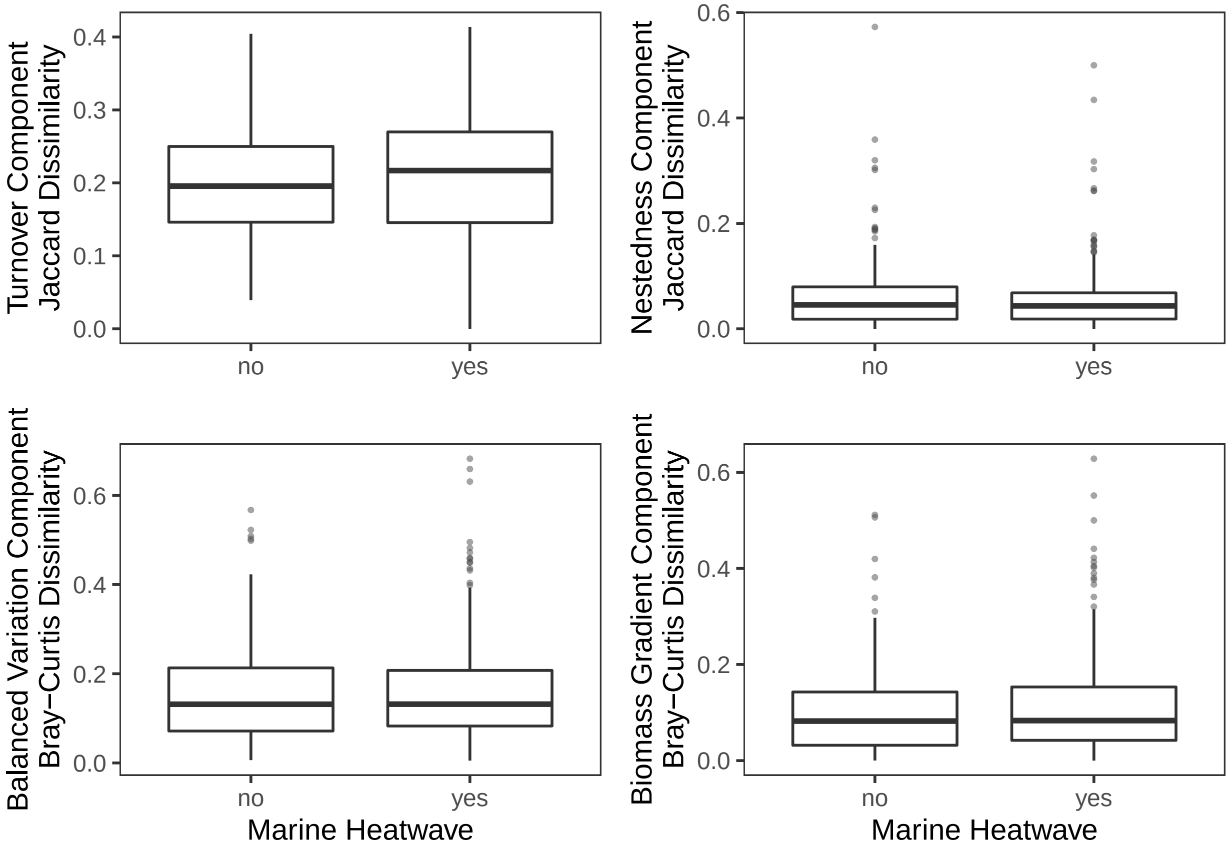

Figure 12: Box-and-whisker plots of temporal community dissimilarity and MHW event for partitioned occurence-based beta diversity metrics (Jaccard turnover and nestedness; top) and partitioned biomass-based beta diversity metrics (Bray-Curtis balanced variation and biomass gradient; bottom).

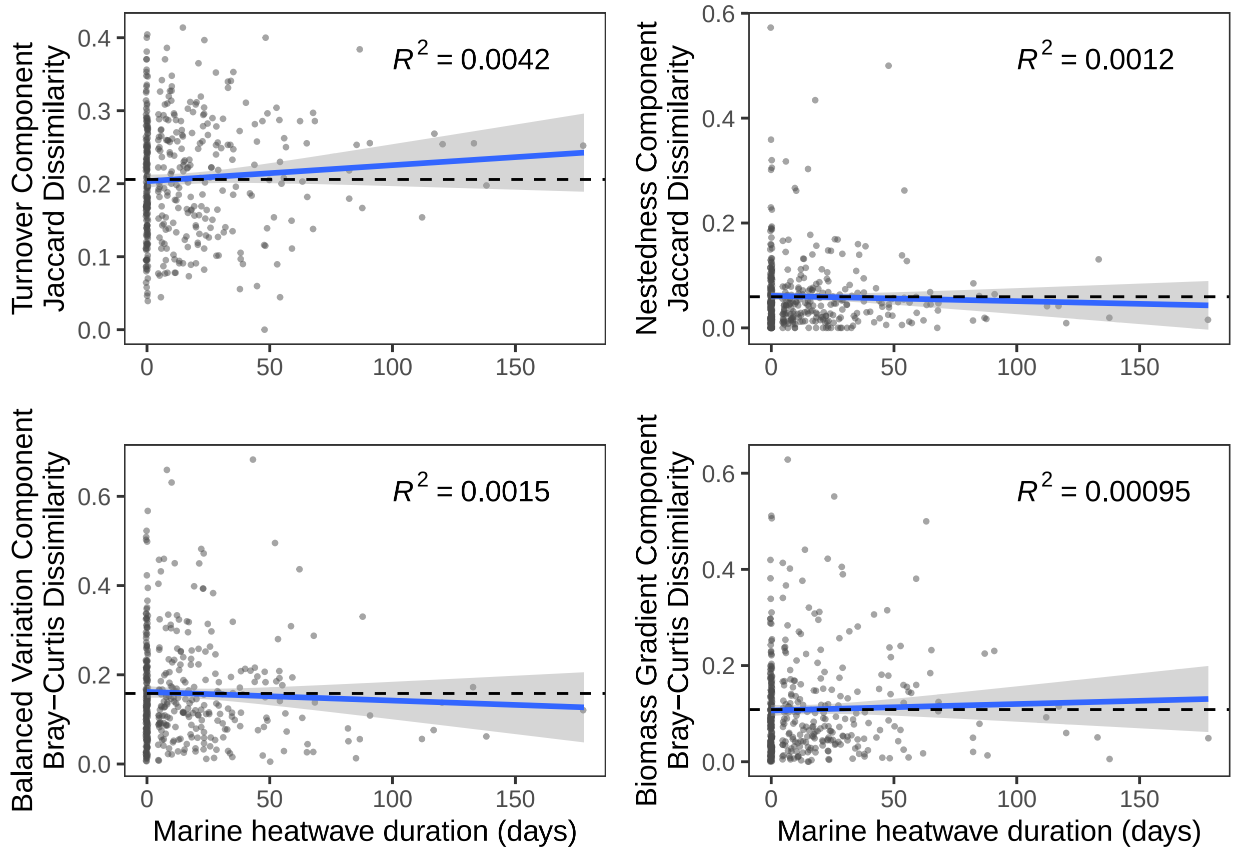

Figure 13: Temporal community dissimilarity and MHW duration for partitioned occurrence-based beta diversity metrics (Jaccard turnover and nestedness; top) and partitioned biomass-based beta diversity metrics (Bray-Curtis balanced variation and biomass gradient; bottom). Fitted lines are linear regressions. Shaded areas are 95% confidence intervals.

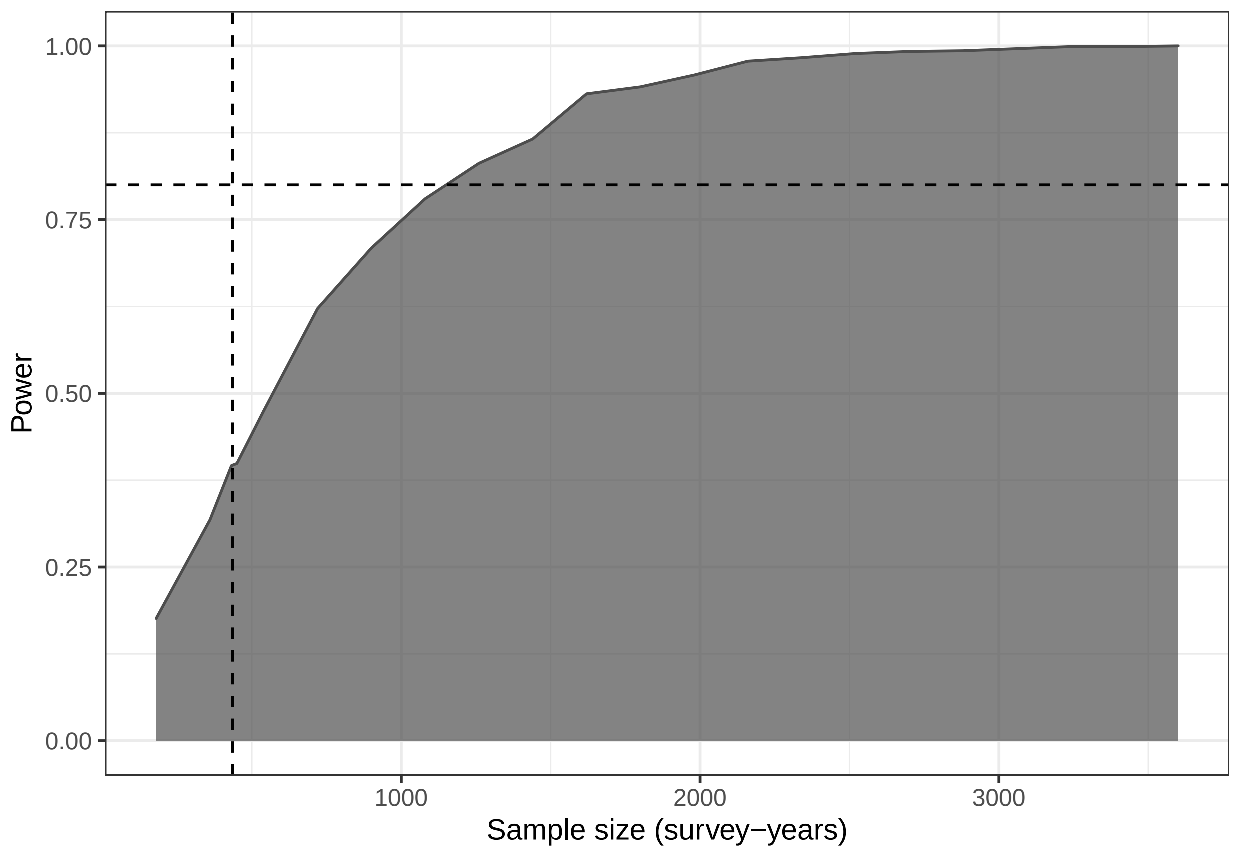

Figure 14: Results from a power analysis applying our methods to a simulated dataset in which MHWs reduce biomass by 6% and study duration is varied. The sample sizes plotted are total survey-years across all regions. Dashed vertical line shows the sample size of our actual dataset. Dashed horizontal line denotes one conventionally accepted threshold for power (0.8).

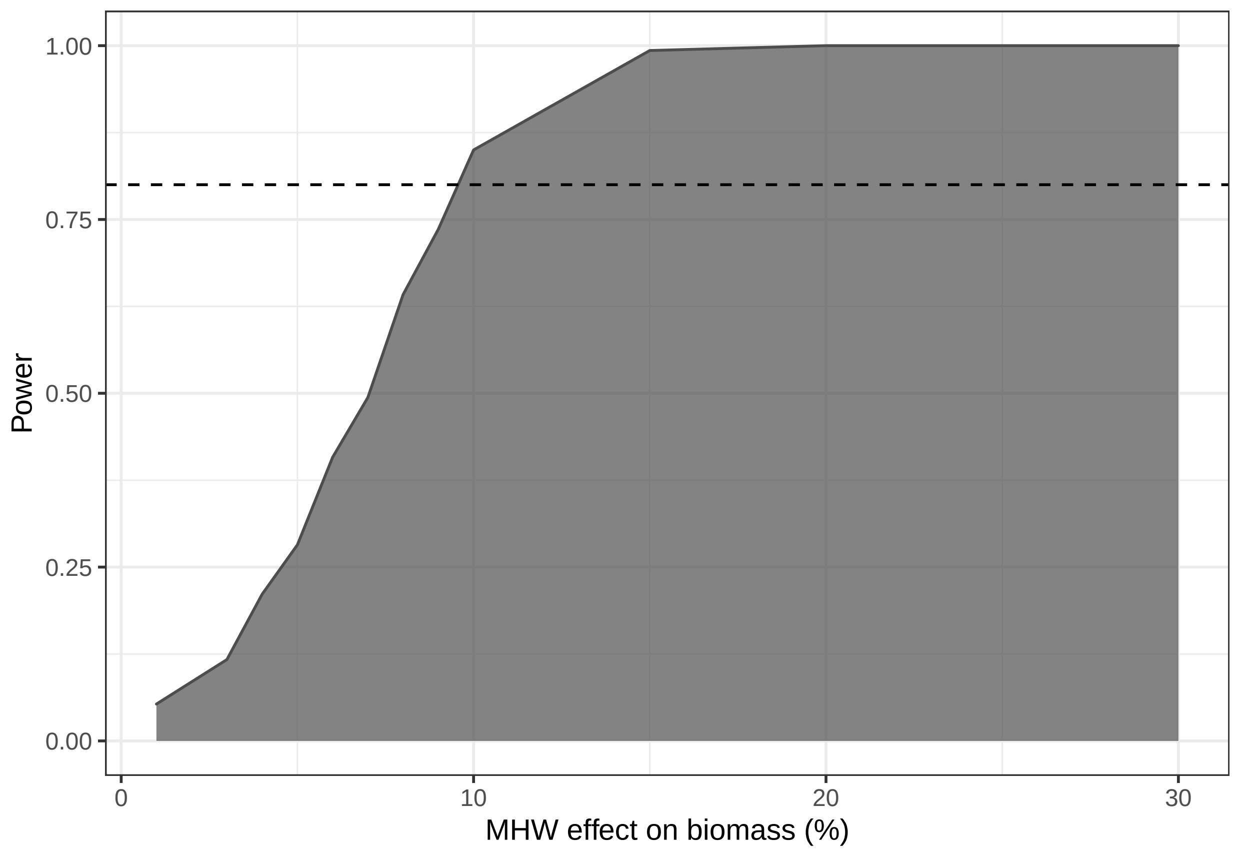

Figure 15: Results from a power analysis applying our methods to a simulated dataset that varied the MHW effect on biomass over the true number of survey-years for each region in our dataset. The sample sizes plotted are total survey-years across all regions. Dashed horizontal line denotes one conventionally accepted threshold for power (0.8).

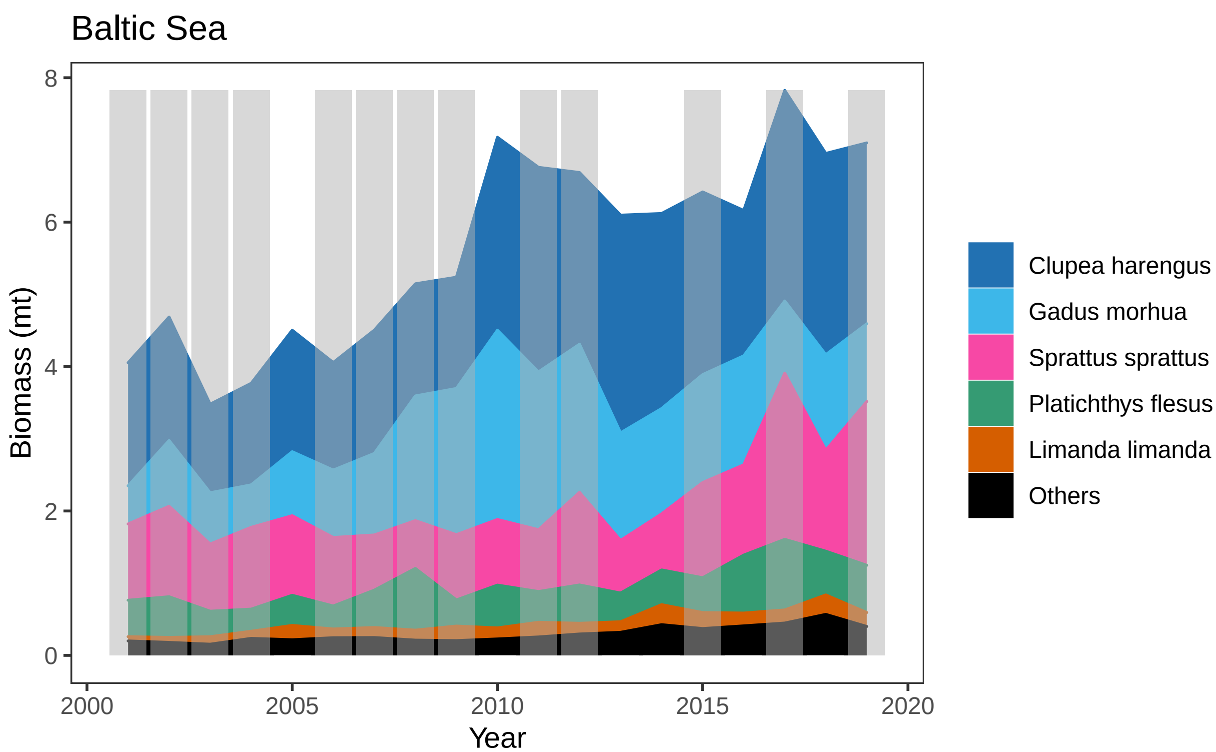

Figure 16: Biomass trends and historical MHWs by region. The top five taxa by biomass are highlighted. Shaded grey rectangles denote when any MHWs occurred in the preceding survey-year (e.g., 2015 in the Eastern Bering Sea time-series corresponds to the survey that began in June 2015, and MHW data from June 2014 - May 2015). British Columbia and the Gulf of Alaska are biennial surveys; all others are annual.

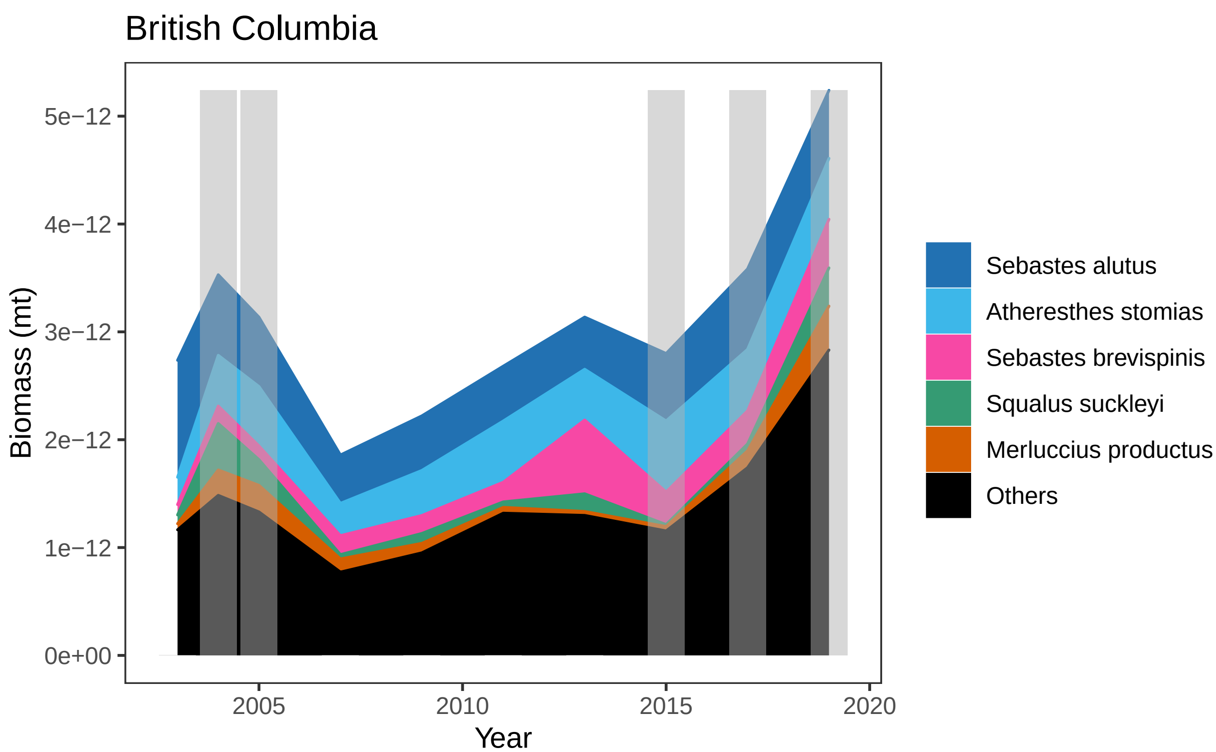

Figure 17: Biomass trends and historical MHWs by region. The top five taxa by biomass are highlighted. Shaded grey rectangles denote when any MHWs occurred in the preceding survey-year (e.g., 2015 in the Eastern Bering Sea time-series corresponds to the survey that began in June 2015, and MHW data from June 2014 - May 2015). British Columbia and the Gulf of Alaska are biennial surveys; all others are annual.

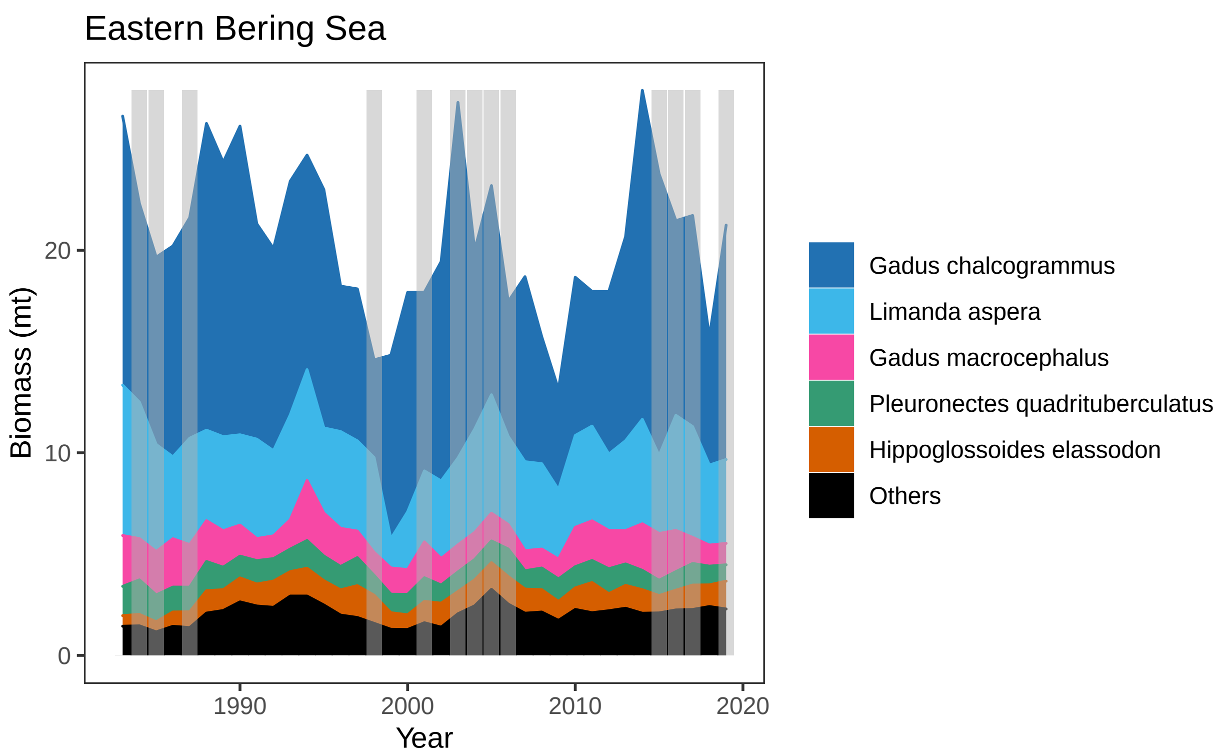

Figure 18: Biomass trends and historical MHWs by region. The top five taxa by biomass are highlighted. Shaded grey rectangles denote when any MHWs occurred in the preceding survey-year (e.g., 2015 in the Eastern Bering Sea time-series corresponds to the survey that began in June 2015, and MHW data from June 2014 - May 2015). British Columbia and the Gulf of Alaska are biennial surveys; all others are annual.

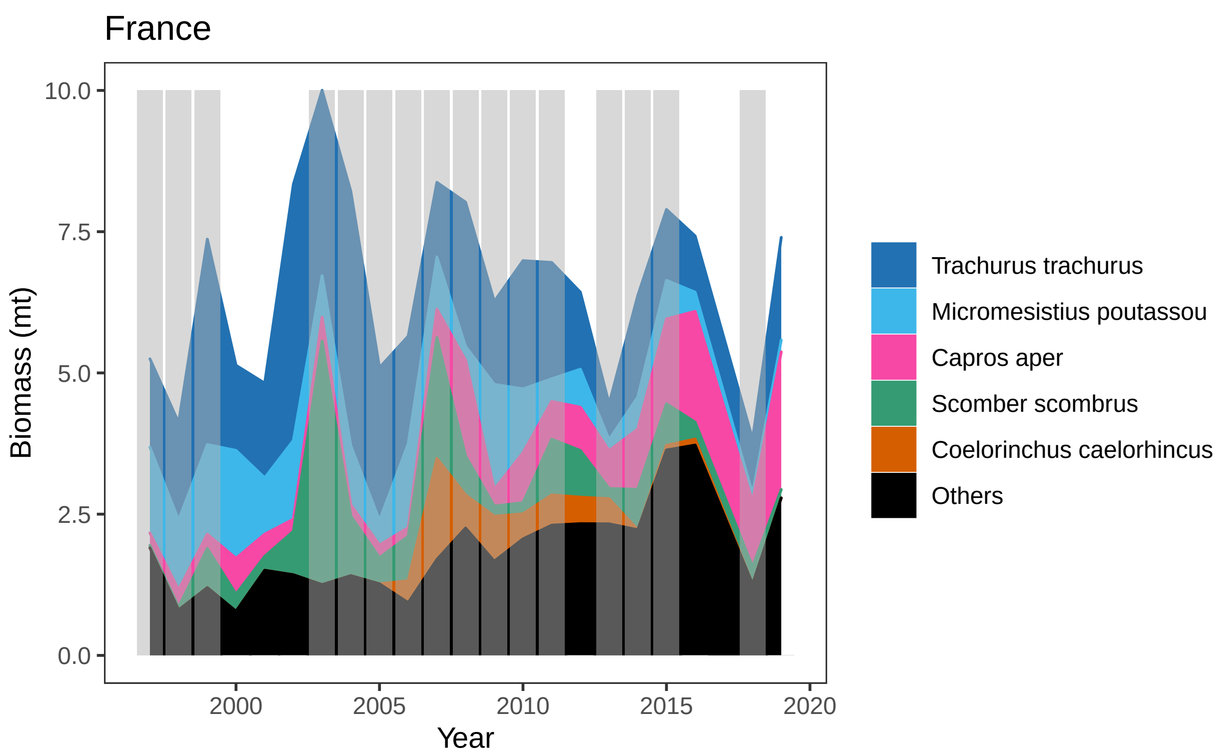

Figure 19: Biomass trends and historical MHWs by region. The top five taxa by biomass are highlighted. Shaded grey rectangles denote when any MHWs occurred in the preceding survey-year (e.g., 2015 in the Eastern Bering Sea time-series corresponds to the survey that began in June 2015, and MHW data from June 2014 - May 2015). British Columbia and the Gulf of Alaska are biennial surveys; all others are annual.

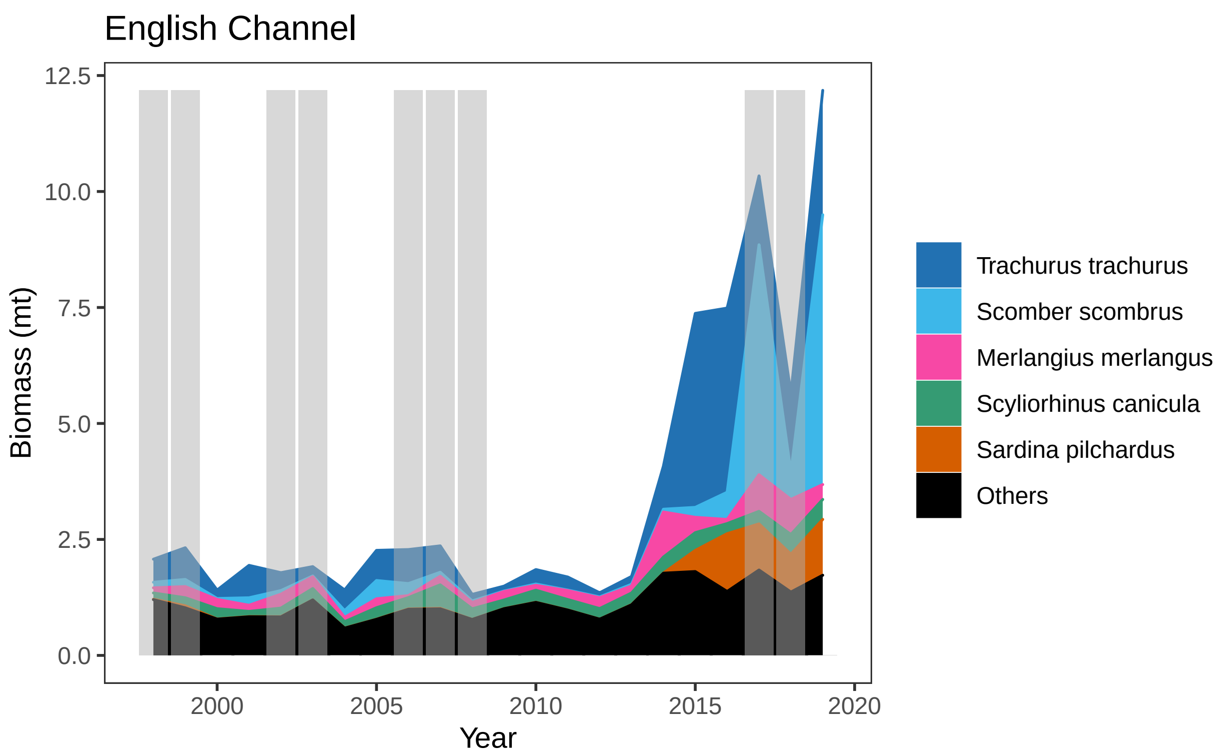

Figure 20: Biomass trends and historical MHWs by region. The top five taxa by biomass are highlighted. Shaded grey rectangles denote when any MHWs occurred in the preceding survey-year (e.g., 2015 in the Eastern Bering Sea time-series corresponds to the survey that began in June 2015, and MHW data from June 2014 - May 2015). British Columbia and the Gulf of Alaska are biennial surveys; all others are annual.

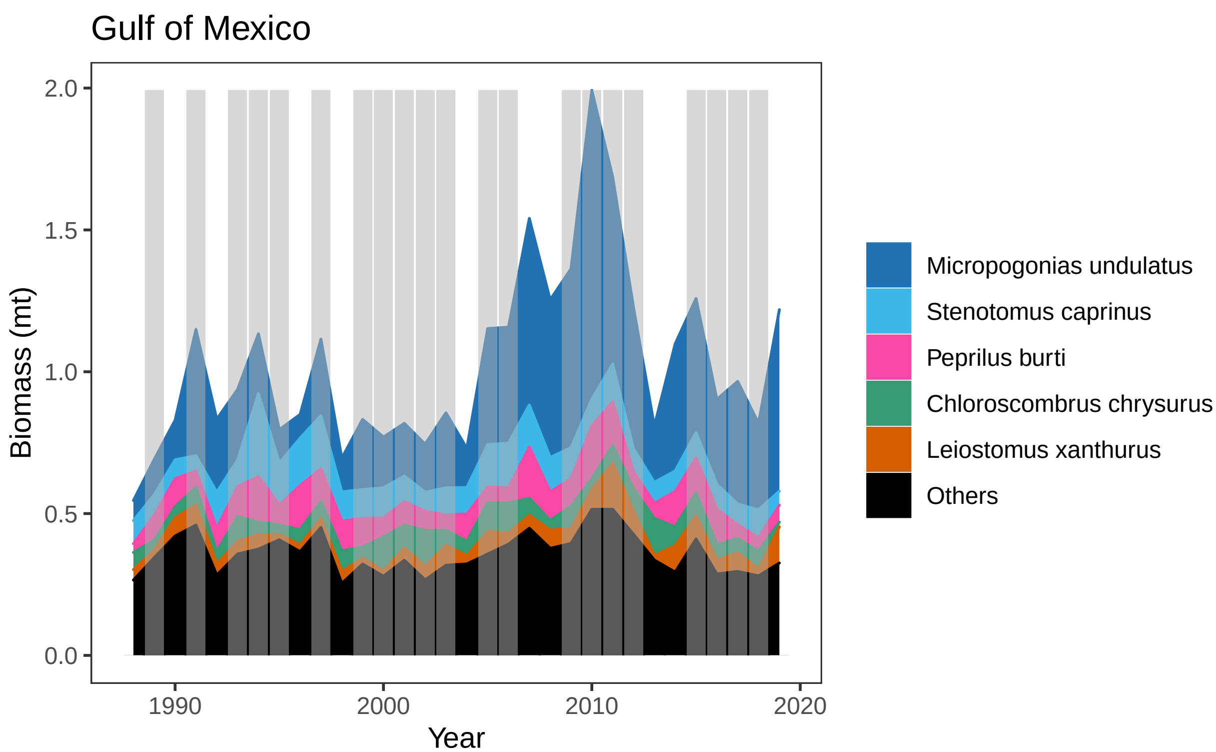

Figure 21: Biomass trends and historical MHWs by region. The top five taxa by biomass are highlighted. Shaded grey rectangles denote when any MHWs occurred in the preceding survey-year (e.g., 2015 in the Eastern Bering Sea time-series corresponds to the survey that began in June 2015, and MHW data from June 2014 - May 2015). British Columbia and the Gulf of Alaska are biennial surveys; all others are annual.

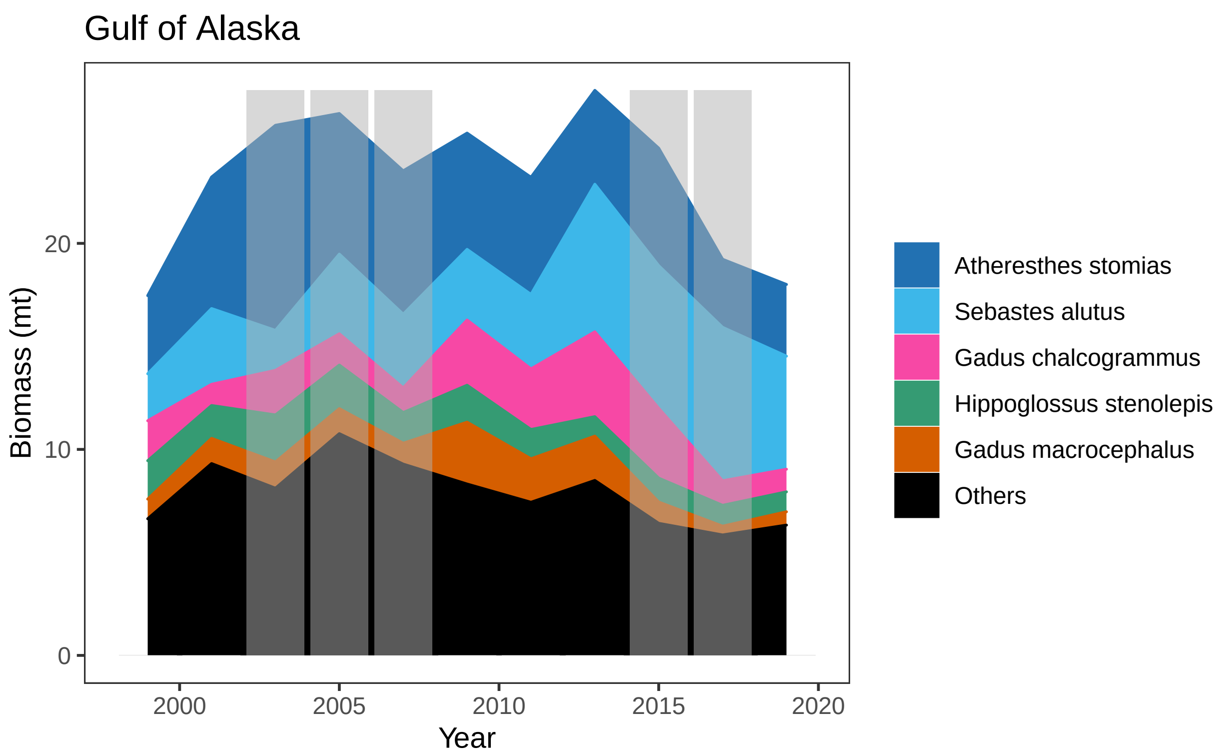

Figure 22: Biomass trends and historical MHWs by region. The top five taxa by biomass are highlighted. Shaded grey rectangles denote when any MHWs occurred in the preceding survey-year (e.g., 2015 in the Eastern Bering Sea time-series corresponds to the survey that began in June 2015, and MHW data from June 2014 - May 2015). British Columbia and the Gulf of Alaska are biennial surveys; all others are annual.

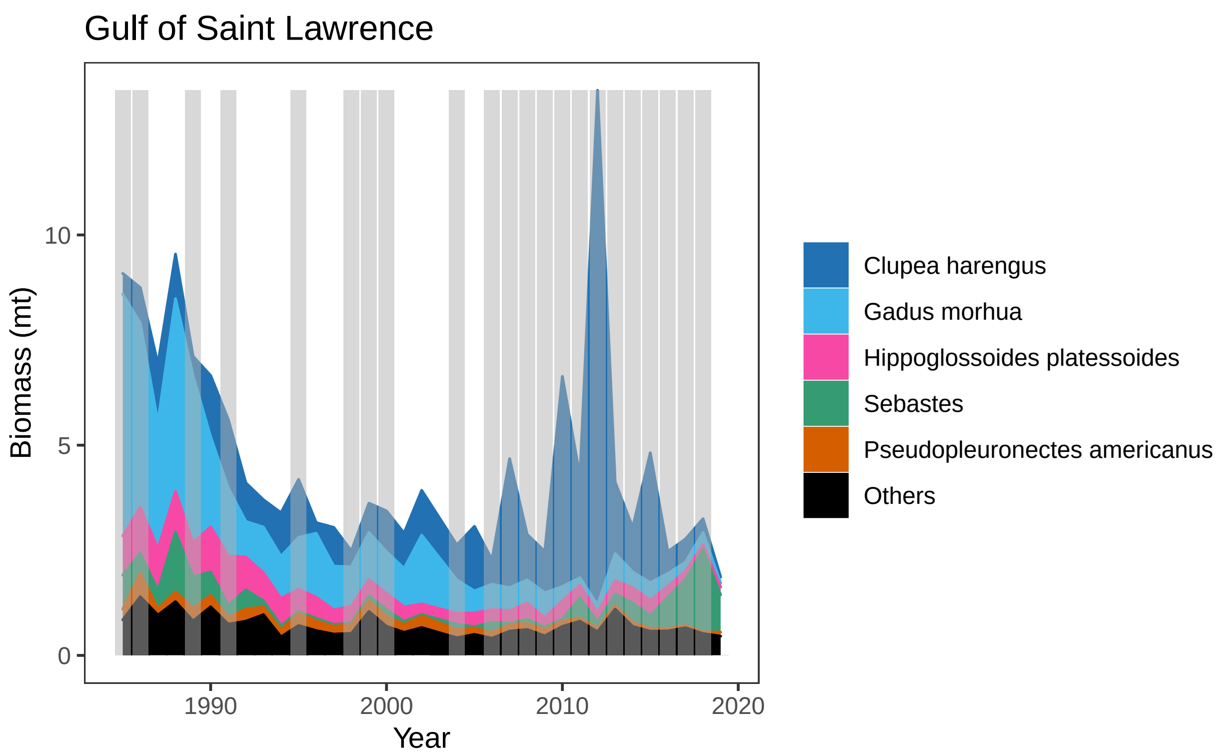

Figure 23: Biomass trends and historical MHWs by region. The top five taxa by biomass are highlighted. Shaded grey rectangles denote when any MHWs occurred in the preceding survey-year (e.g., 2015 in the Eastern Bering Sea time-series corresponds to the survey that began in June 2015, and MHW data from June 2014 - May 2015). British Columbia and the Gulf of Alaska are biennial surveys; all others are annual.

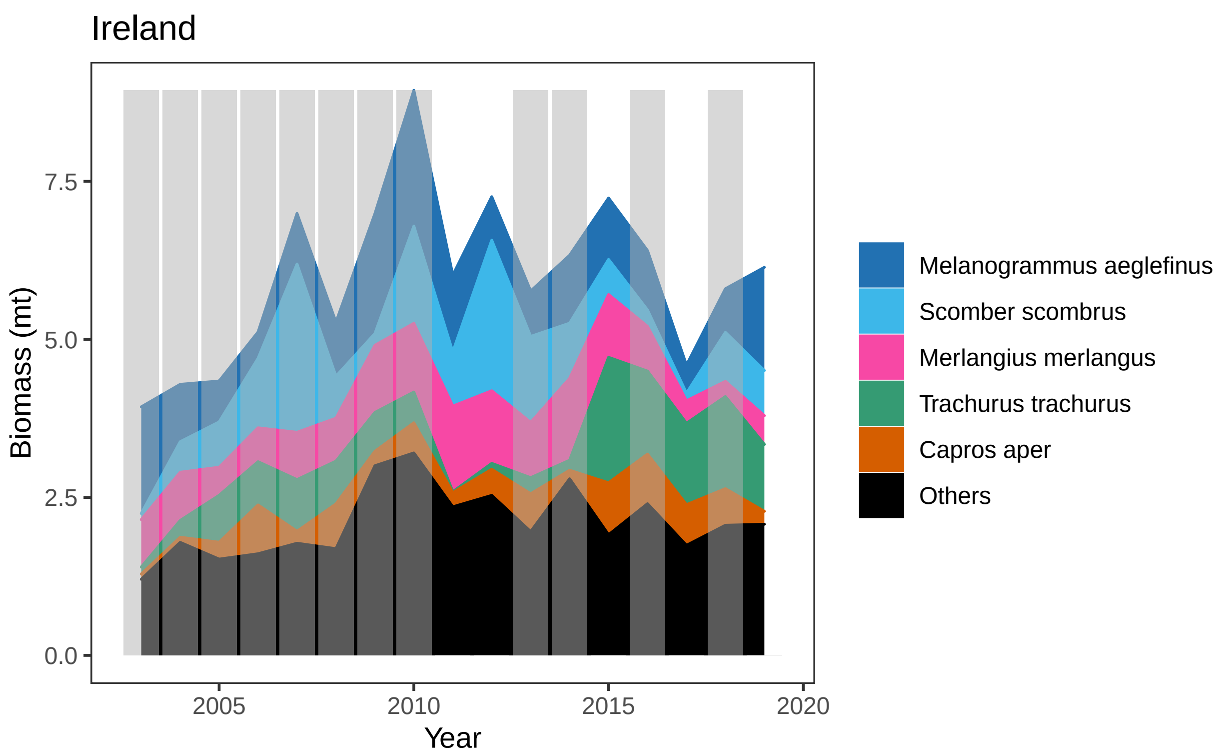

Figure 24: Biomass trends and historical MHWs by region. The top five taxa by biomass are highlighted. Shaded grey rectangles denote when any MHWs occurred in the preceding survey-year (e.g., 2015 in the Eastern Bering Sea time-series corresponds to the survey that began in June 2015, and MHW data from June 2014 - May 2015). British Columbia and the Gulf of Alaska are biennial surveys; all others are annual.

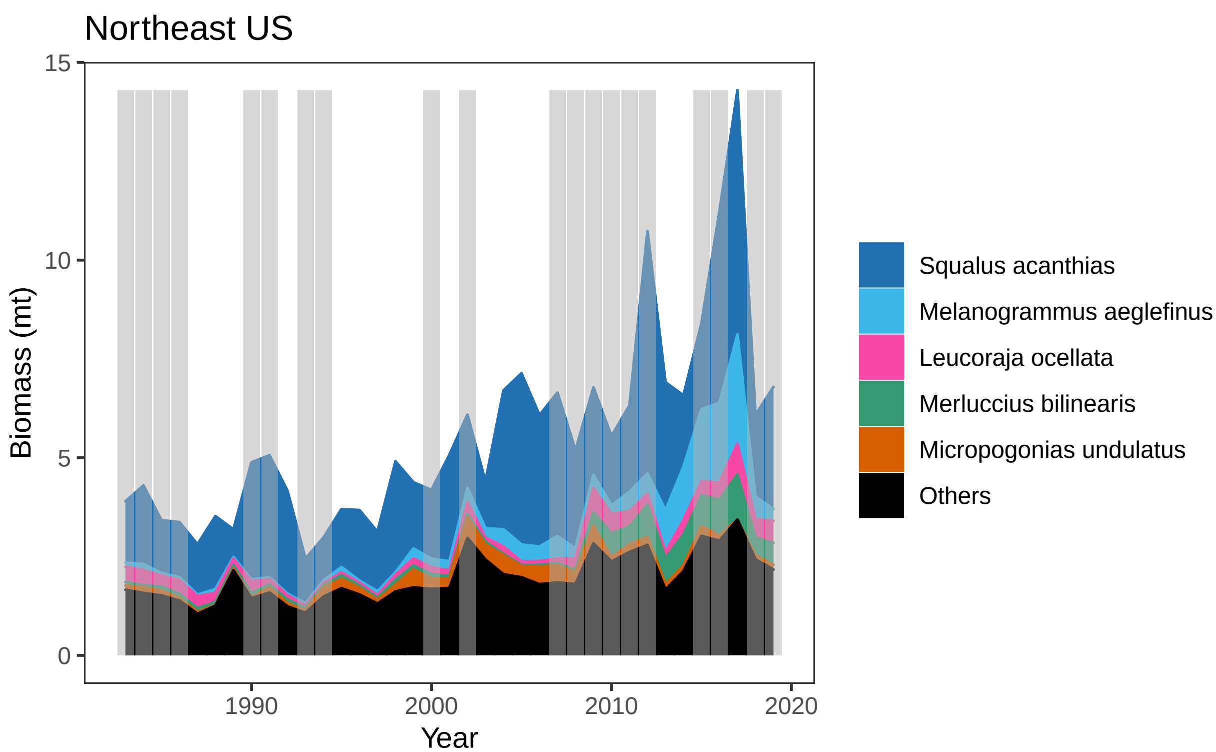

Figure 25: Biomass trends and historical MHWs by region. The top five taxa by biomass are highlighted. Shaded grey rectangles denote when any MHWs occurred in the preceding survey-year (e.g., 2015 in the Eastern Bering Sea time-series corresponds to the survey that began in June 2015, and MHW data from June 2014 - May 2015). British Columbia and the Gulf of Alaska are biennial surveys; all others are annual.

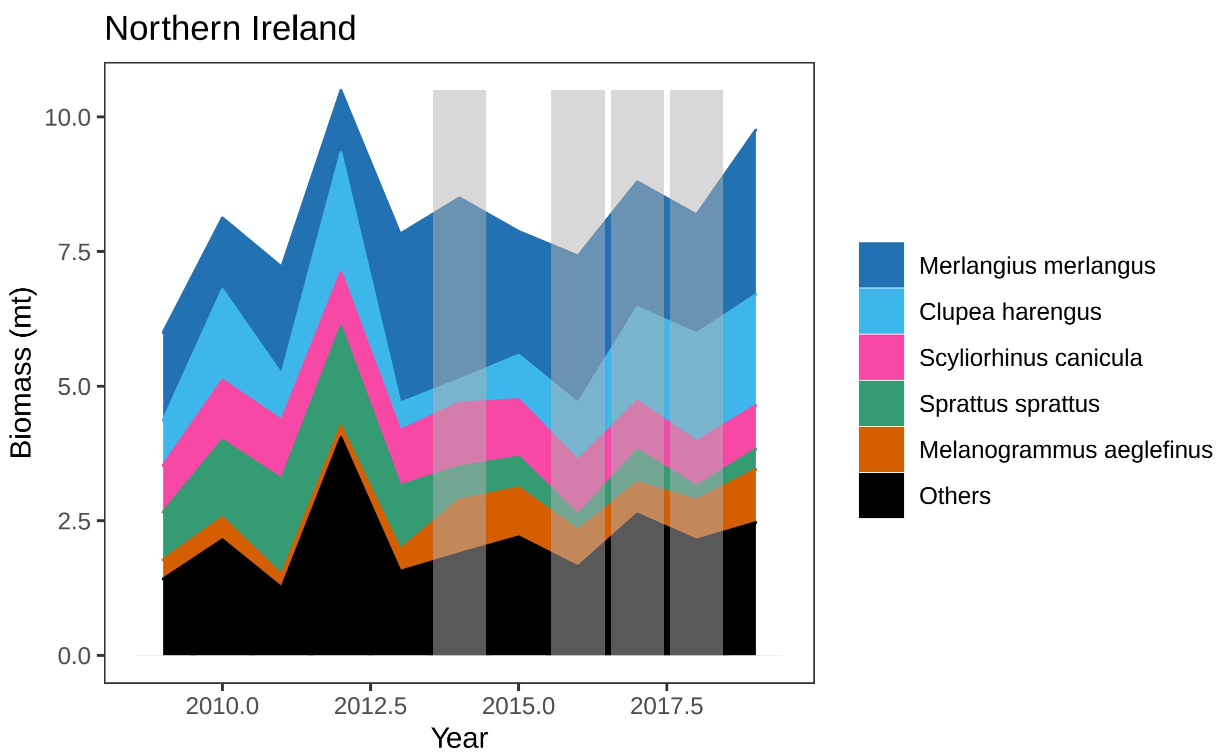

Figure 26: Biomass trends and historical MHWs by region. The top five taxa by biomass are highlighted. Shaded grey rectangles denote when any MHWs occurred in the preceding survey-year (e.g., 2015 in the Eastern Bering Sea time-series corresponds to the survey that began in June 2015, and MHW data from June 2014 - May 2015). British Columbia and the Gulf of Alaska are biennial surveys; all others are annual.

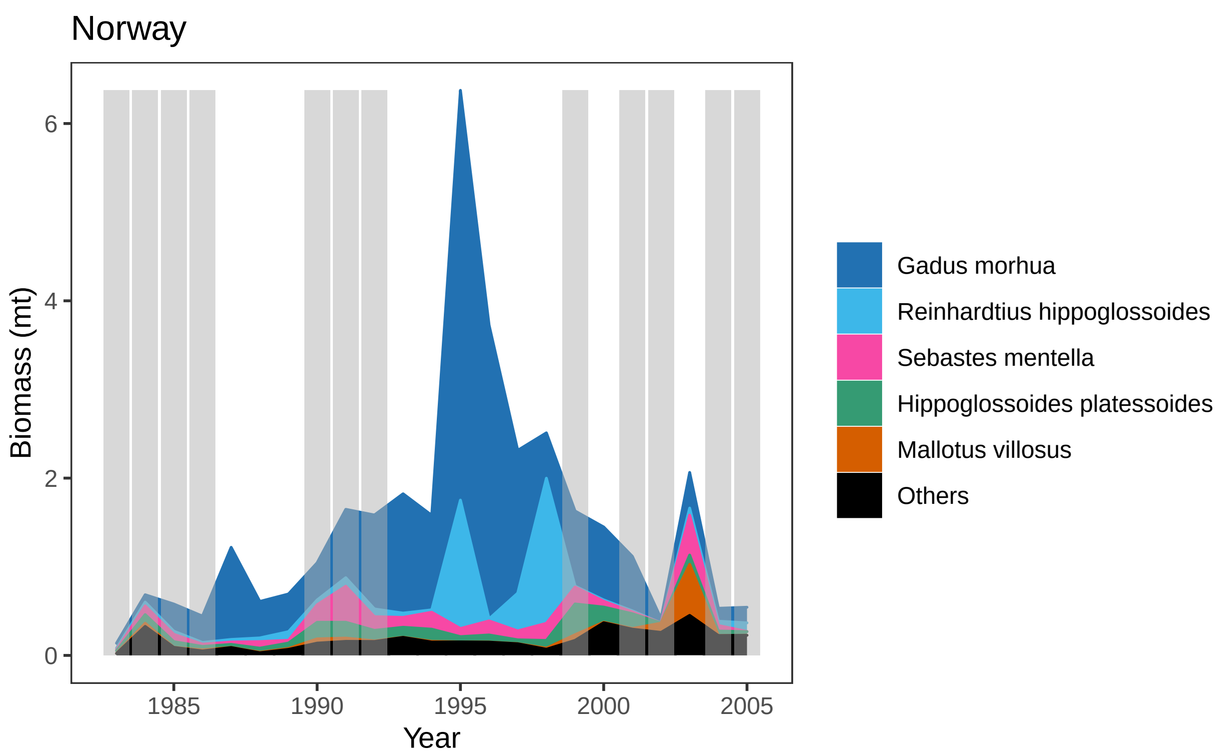

Figure 27: Biomass trends and historical MHWs by region. The top five taxa by biomass are highlighted. Shaded grey rectangles denote when any MHWs occurred in the preceding survey-year (e.g., 2015 in the Eastern Bering Sea time-series corresponds to the survey that began in June 2015, and MHW data from June 2014 - May 2015). British Columbia and the Gulf of Alaska are biennial surveys; all others are annual.

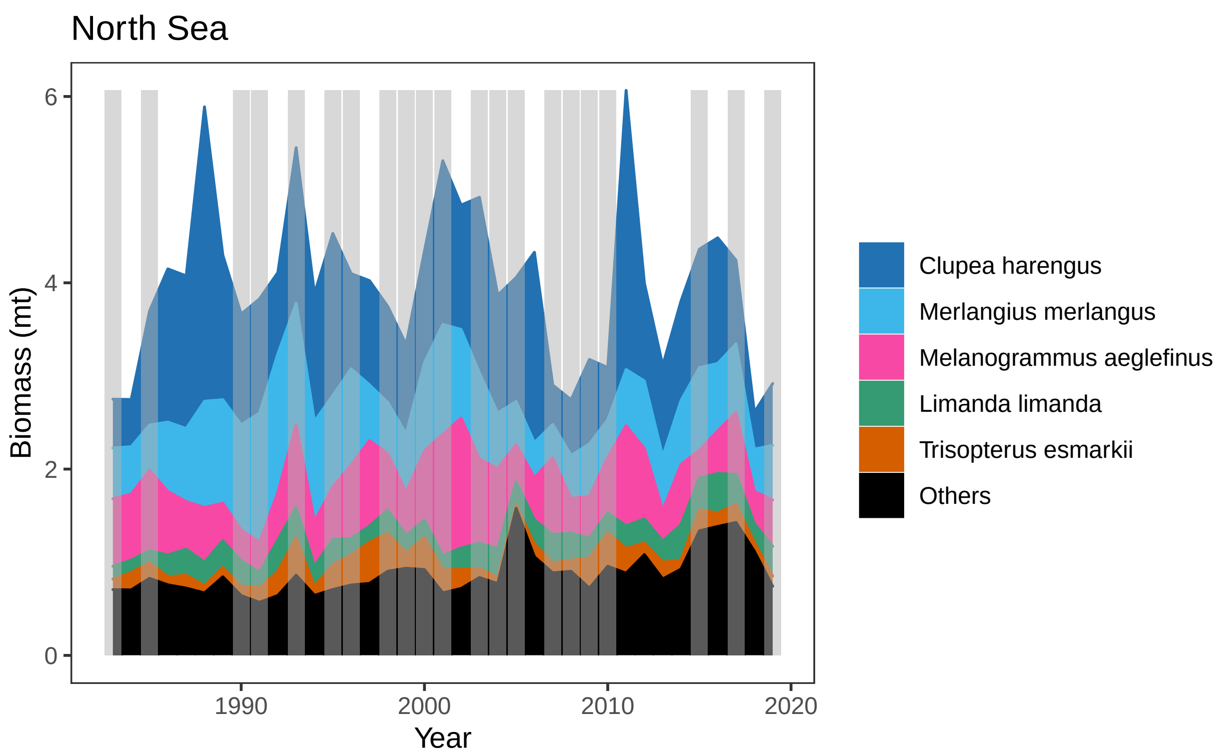

Figure 28: Biomass trends and historical MHWs by region. The top five taxa by biomass are highlighted. Shaded grey rectangles denote when any MHWs occurred in the preceding survey-year (e.g., 2015 in the Eastern Bering Sea time-series corresponds to the survey that began in June 2015, and MHW data from June 2014 - May 2015). British Columbia and the Gulf of Alaska are biennial surveys; all others are annual.

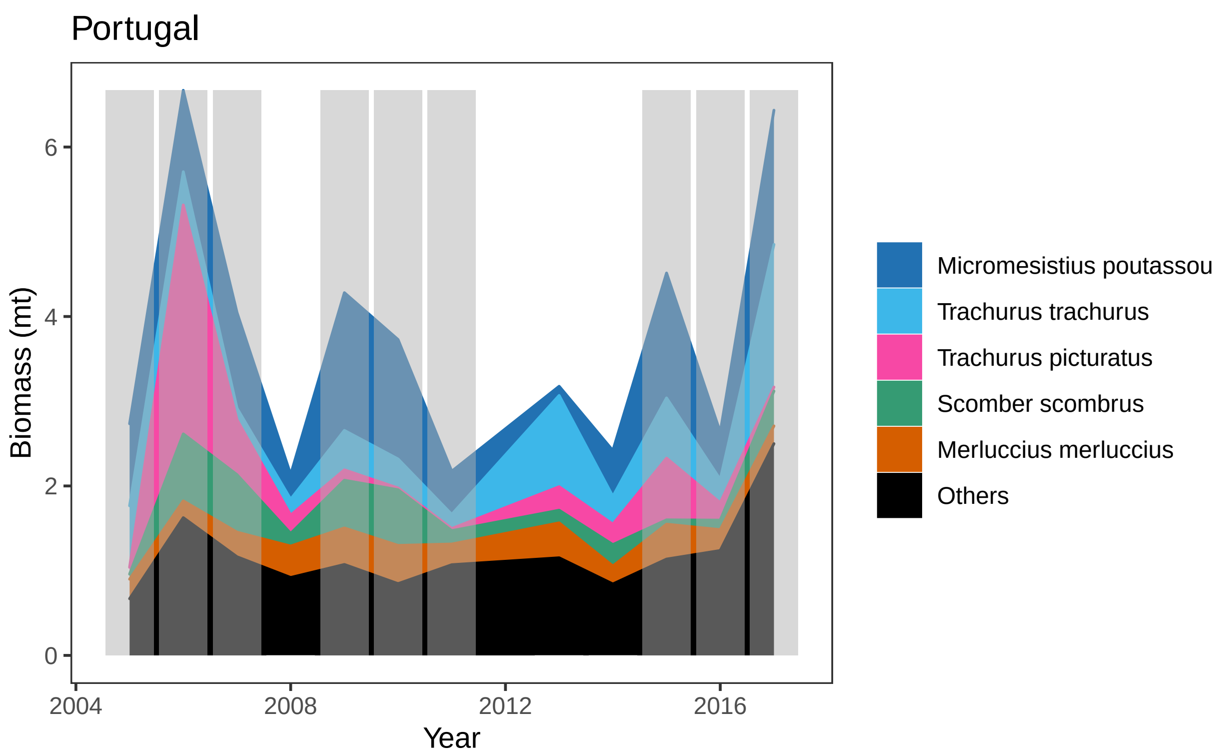

Figure 29: Biomass trends and historical MHWs by region. The top five taxa by biomass are highlighted. Shaded grey rectangles denote when any MHWs occurred in the preceding survey-year (e.g., 2015 in the Eastern Bering Sea time-series corresponds to the survey that began in June 2015, and MHW data from June 2014 - May 2015). British Columbia and the Gulf of Alaska are biennial surveys; all others are annual.

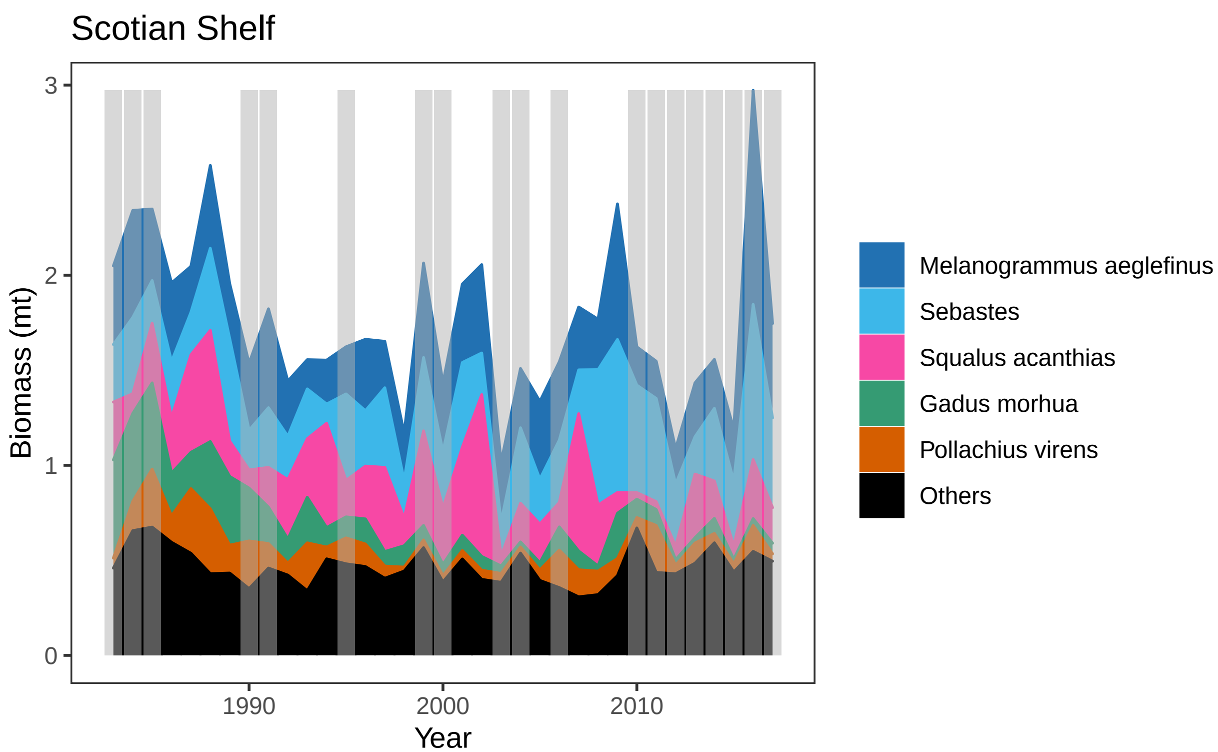

Figure 30: Biomass trends and historical MHWs by region. The top five taxa by biomass are highlighted. Shaded grey rectangles denote when any MHWs occurred in the preceding survey-year (e.g., 2015 in the Eastern Bering Sea time-series corresponds to the survey that began in June 2015, and MHW data from June 2014 - May 2015). British Columbia and the Gulf of Alaska are biennial surveys; all others are annual.

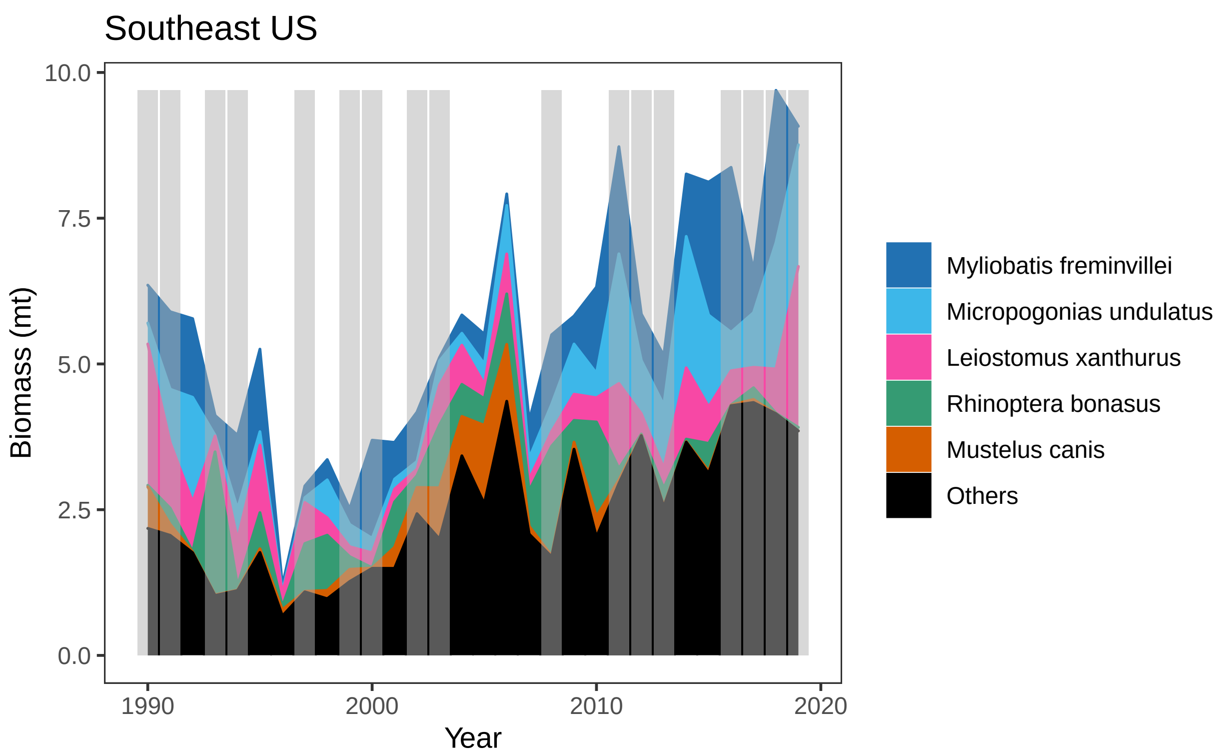

Figure 31: Biomass trends and historical MHWs by region. The top five taxa by biomass are highlighted. Shaded grey rectangles denote when any MHWs occurred in the preceding survey-year (e.g., 2015 in the Eastern Bering Sea time-series corresponds to the survey that began in June 2015, and MHW data from June 2014 - May 2015). British Columbia and the Gulf of Alaska are biennial surveys; all others are annual.

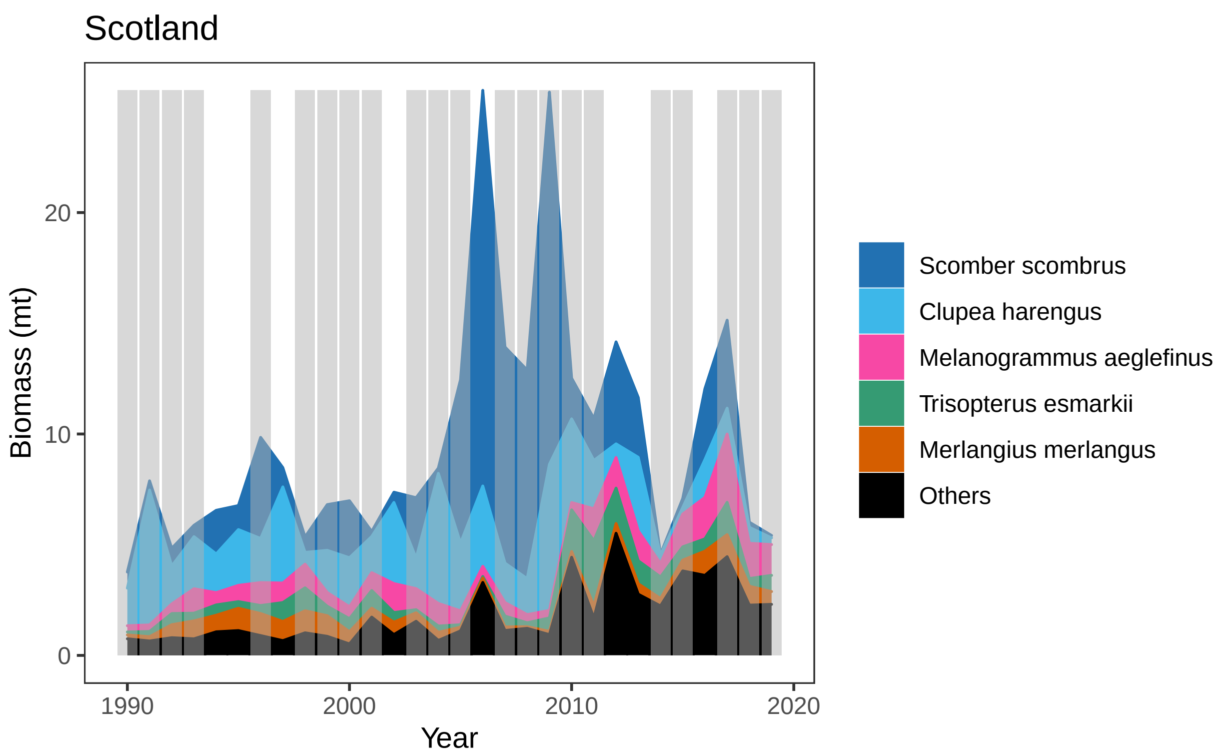

Figure 32: Biomass trends and historical MHWs by region. The top five taxa by biomass are highlighted. Shaded grey rectangles denote when any MHWs occurred in the preceding survey-year (e.g., 2015 in the Eastern Bering Sea time-series corresponds to the survey that began in June 2015, and MHW data from June 2014 - May 2015). British Columbia and the Gulf of Alaska are biennial surveys; all others are annual.

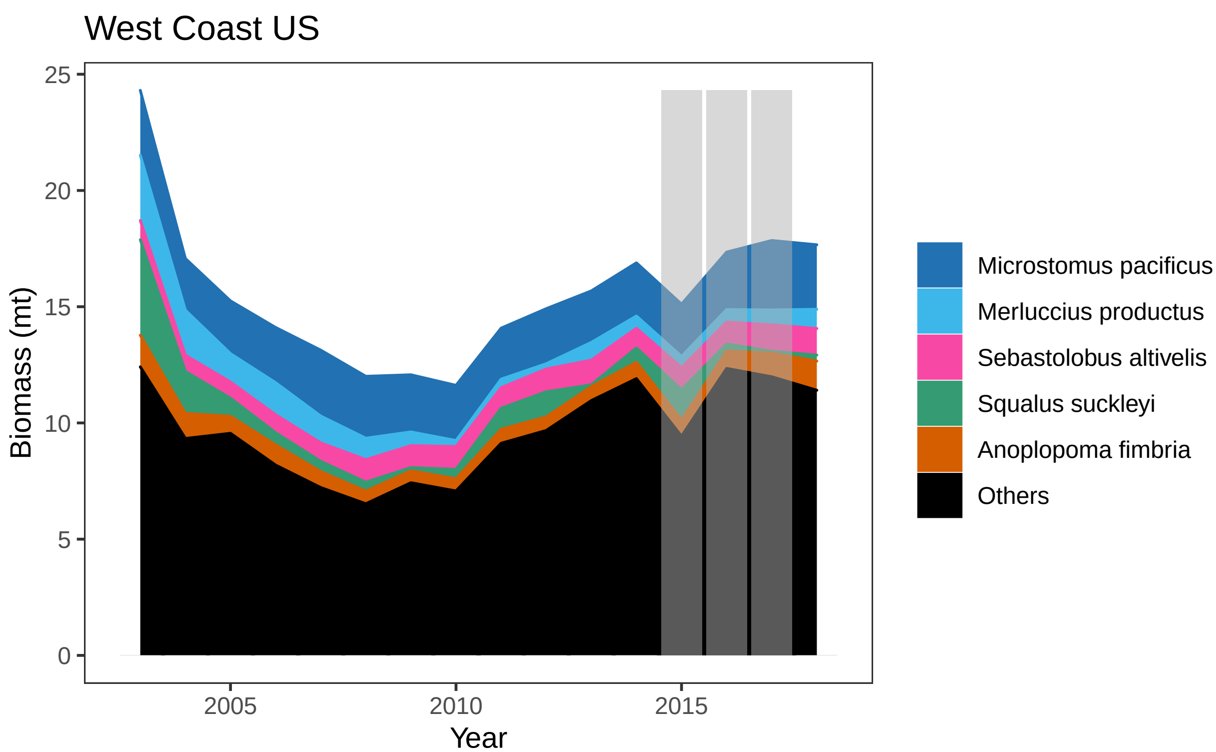

Figure 33: Biomass trends and historical MHWs by region. The top five taxa by biomass are highlighted. Shaded grey rectangles denote when any MHWs occurred in the preceding survey-year (e.g., 2015 in the Eastern Bering Sea time-series corresponds to the survey that began in June 2015, and MHW data from June 2014 - May 2015). British Columbia and the Gulf of Alaska are biennial surveys; all others are annual.