Marine Heatwaves in the Eastern Bering Sea

Sea surface temperature (SST) is one of the foundational metrics often used to describe the Bering Sea environment. Combined with sea ice extent, SST and several other simple metrics (e.g., cold pool extent) are often distilled into single annual or seasonal values used to describe the environment as relatively warm, average, or cold. We did a deeper dive on the intra- and inter-annual dynamics of SST in the southeastern and northern Bering Sea, with the hopes that more detail may help to identify mechanisms or critical periods through which SST has the greatest impacts on Bering Sea ecosystems and fisheries. Specifically, we explored SST throughout the annual sea ice cycle and examined the cumulative SST within each year to better understand the annual thermal exposure experienced by the system. We also explored finer scale temporal dynamics (i.e., daily data) in the context of marine heatwaves.

Methods

Satellite SST data (source: NOAA Coral Reef Watch Program) were accessed via the NOAA CoastWatch West Coast Node ERDDAP server[2]. Daily data were averaged within the southeastern (south of 60°N and northern (60°N–65.75°N) Bering Sea shelf (10–200 m depth). Detailed methods are online[3]. We defined the annual cycle in the Bering Sea to begin on 1 September of each year and end on 31 August of the following year in order to most closely align with the seasonal sea ice cycle. Seasons were defined as fall (Sept – Nov), winter (Dec – Feb), spring (Mar – May), and summer (Jun – Aug), starting on 1 Sept 1985 and ending on 31 Aug 2020.

Marine heatwave calculations were performed using the heatwaveR package (Schlegel and Smit, 2018) with the earliest complete 30-yr period as the baseline (1 Sept 1985–31 Aug 2014).

Description of the indicators

Sea ice dynamics in the Bering Sea drive a unique and intense pattern of thermal exposure for the system throughout the year. As seen in Figure 10, the cumulative annual SST (i.e., the sum of daily SST throughout the year) does not reveal a linear pattern of increasing temperature, rather a non-linear, ice-derived pattern in both the southeastern and northern Bering Seas. In both systems, the cumulative SST increases throughout the fall as sea ice begins to form and in the north especially, persistent negative temperatures reduce the cumulative thermal exposure throughout the winter and spring. An inflection point appears around June in both regions, and a linear increase in cumulative SST persists for the remainder of the year (i.e., the end of August).

The end points, or the total cumulative SST, for each year demonstrate the stark difference in thermal exposure that each region experiences across years. These inter-annual differences in cumulative totals within each region are clearly illustrated in the form of anomalies (Figure 11). The warm stanza of the early 2000s and the recent warm years have far exceeded one standard deviation (horizontal dashed line) above average, with several years exceeding this common threshold several fold.

[2] `https://coastwatch.pfeg.noaa.gov/erddap/griddap/NOAA_DHW.html`

[3] `github.com/jordanwatson/EcosystemStatusReports/tree/master/SST`

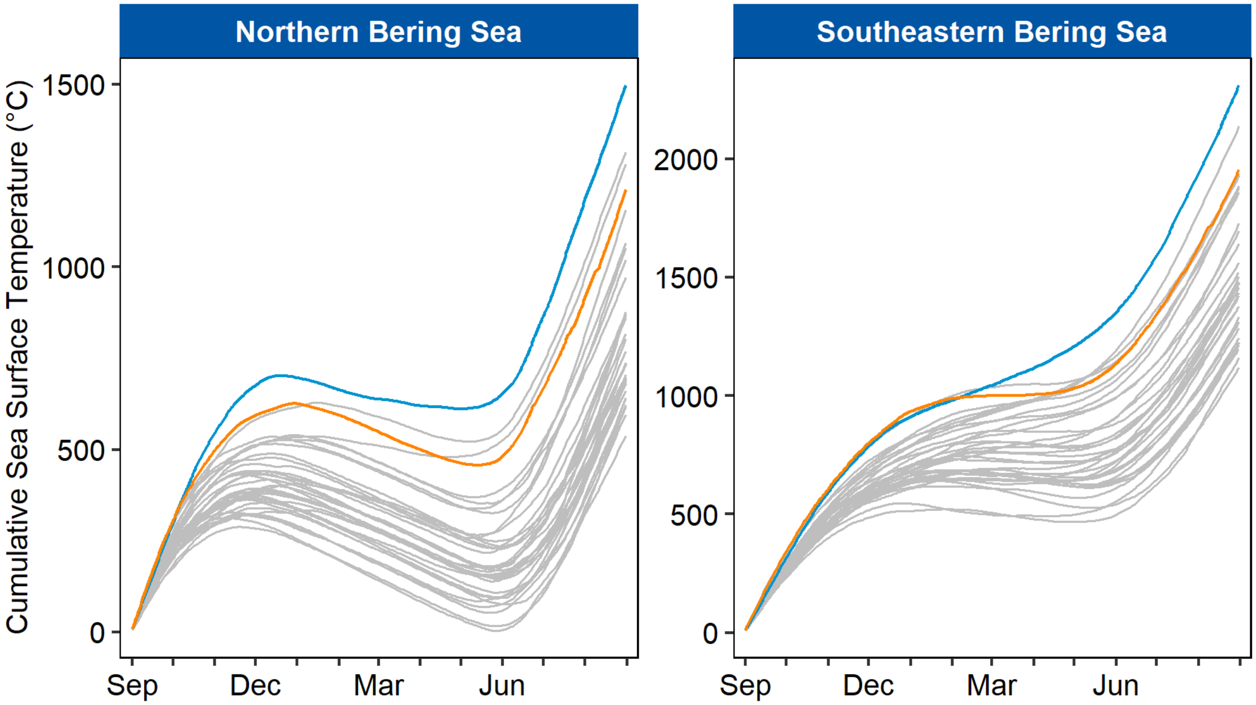

Figure 10: Cumulative sea surface temperatures (sum of daily temperatures) for years ending in 1986–2020 (annual cycles from 1 Sept–31 Aug of the following year). Orange lines are 2020 (i.e., 1 Sept 2019–31 Aug 2020), blue lines are 2019, and gray lines are all previous years.

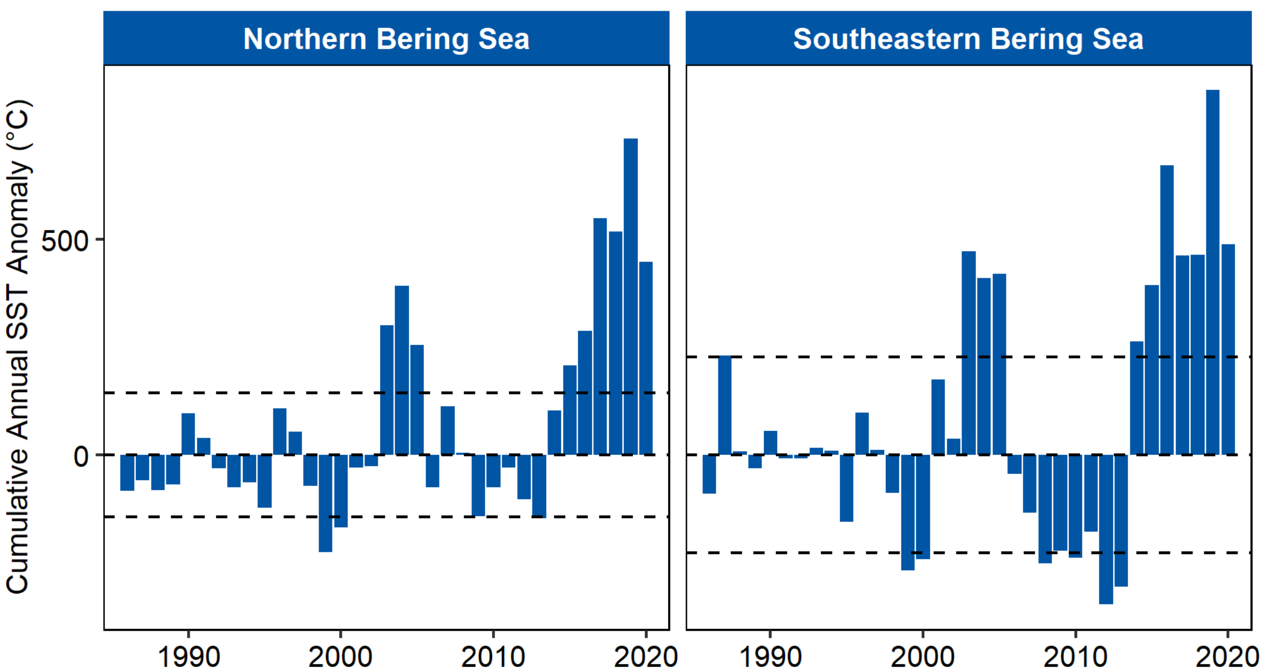

Figure 11: Anomaly of the total cumulative sea surface temperature (sum of daily temperatures) at the end of each year. Horizontal lines are ±1 SD from the mean during the 30-yr baseline period (1 Sept 1985–31 Aug 2014).

Ecologically, it is important to identify anomalous conditions relative to thermal exposure and compare oceanographic trends to stock dynamics. For example, Figure 12 summarizes the total cumulative SST for each year by the seasonal contribution to the thermal exposure. In the northern Bering Sea, predominantly negative SST in the winter and spring served to reduce the total cumulative SST in the earlier years, whereas more recently, there was negligible negative forcing from these seasons. Meanwhile, along the southeastern Bering Sea shelf, spring appears to have undergone much more variable inter-annual contributions to the cumulative SST, with a greater positive contribution in the recent warm years.

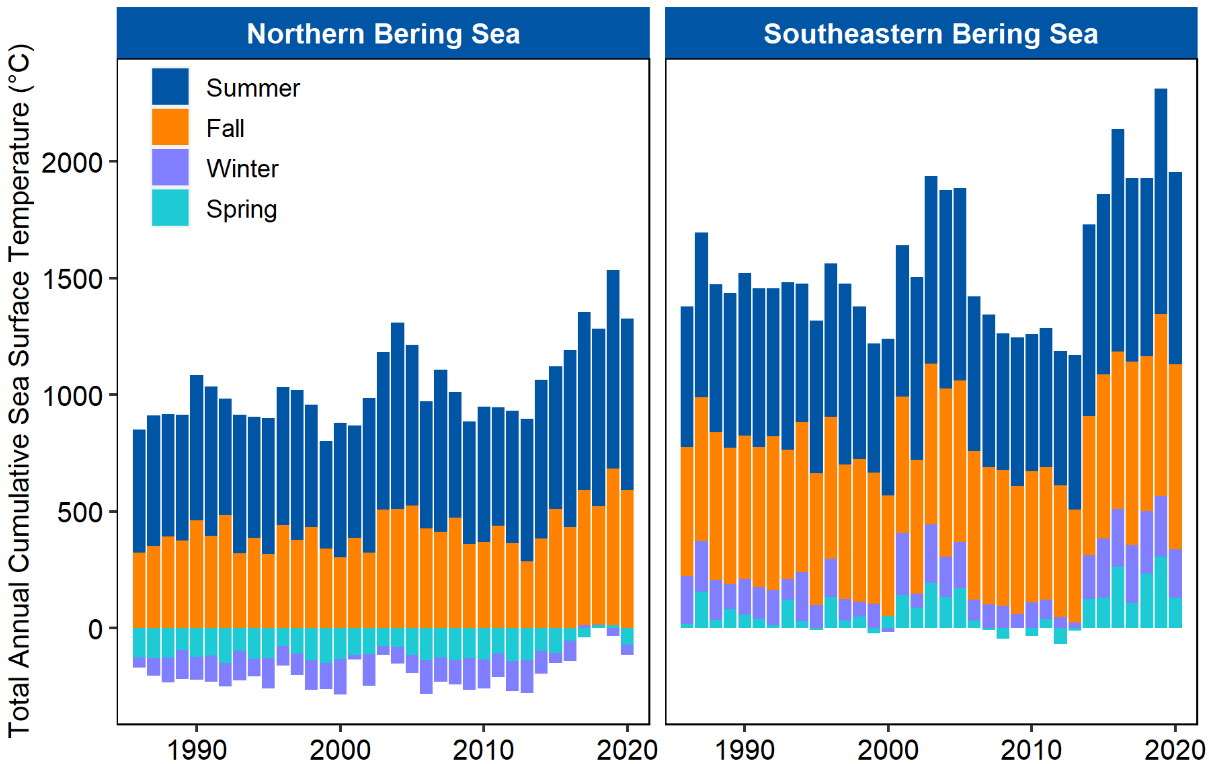

Figure 12: Total cumulative sea surface temperature (sum of daily temperatures) for each year, apportioned by season: summer (Jun-Aug), fall (Sept-Nov), winter (Dec-Feb), spring (Mar-May). Negative values are the result of sea surface temperatures below zero.

While the patterns from Figure 12 can be helpful for summarizing seasonal effects in aggregate, they may obscure annual or intra-annual patterns. Flamingo plots (Figure 13) illustrate the intra-annual variability more clearly. These figures show the same line plots as Figure 10, but displayed in chronological order instead of overlaid. Qualitative differences across years are readily discerned via the height at which inflection points begin, and the depth of the downward trend (a greater downward extent points to a more protracted period of cooling within the system). The most prominent feature in the northern Bering Sea is the shallowing of the inflection during recent years, as the cooling effect of sea ice dissipates. Meanwhile, in the south, there is a striking absence of a turning point (i.e., no downward turn) during the warm years (those ending in 2003–2005 and 2014–2020). **Note:** the red portions of each line represent periods defined as marine heatwaves (see more on marine heatwaves below).

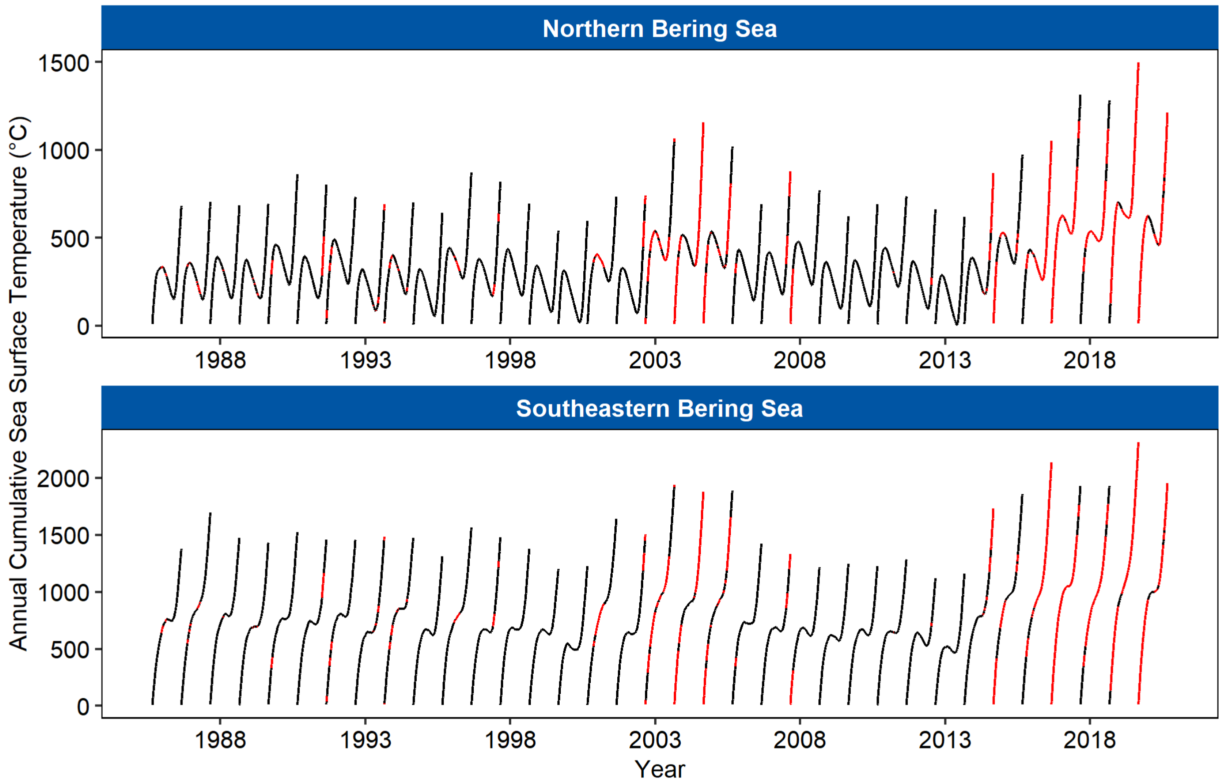

Figure 13: Cumulative sea surface temperatures (sum of daily temperatures) for years ending in 1986–2020 (annual cycles from 1 Sept–31 Aug of the following year). For each year, lines illustrate the accumulation of thermal exposure throughout the year, with downturns representing sea surface temperatures below zero. Red portions of each line represent periods defined as marine heatwaves.

We consider marine heatwaves to occur when SST exceeds a particular threshold for five or more days. That threshold is the 90th percentile of temperatures for a particular day of the year based on a 30-year baseline (Hobday et al., 2016). The intensity of a heatwave can be further characterized by examining the difference between the 90th percentile threshold for a given day and the baseline ("normal") temperature for that day. If the threshold is exceeded, the event is characterized as: moderate, strong (2 times the difference between then threshold and normal), severe (3 times the difference between the threshold and normal), or extreme (>=4 times the difference) (Hobday et al., 2018).

The recent marine heatwaves observed in Figure 13 have been particularly persistent and intense, reaching into the extreme category in the winters of 2018 and 2019 in the northern Bering Sea (Figure 14). While the extreme periods were relatively brief, heatwaves have been persistent in both the southeastern and northern Bering Sea for much of the last five years. These total annual heatwave durations are summarized in Figure 15, with the cumulative heatwave days by season. While heatwaves occurred during early years of the time series, the frequency and durations have increased dramatically, especially in the northern Bering Sea, where residual heat and low sea ice extent result in dramatically increased cumulative annual thermal exposure.

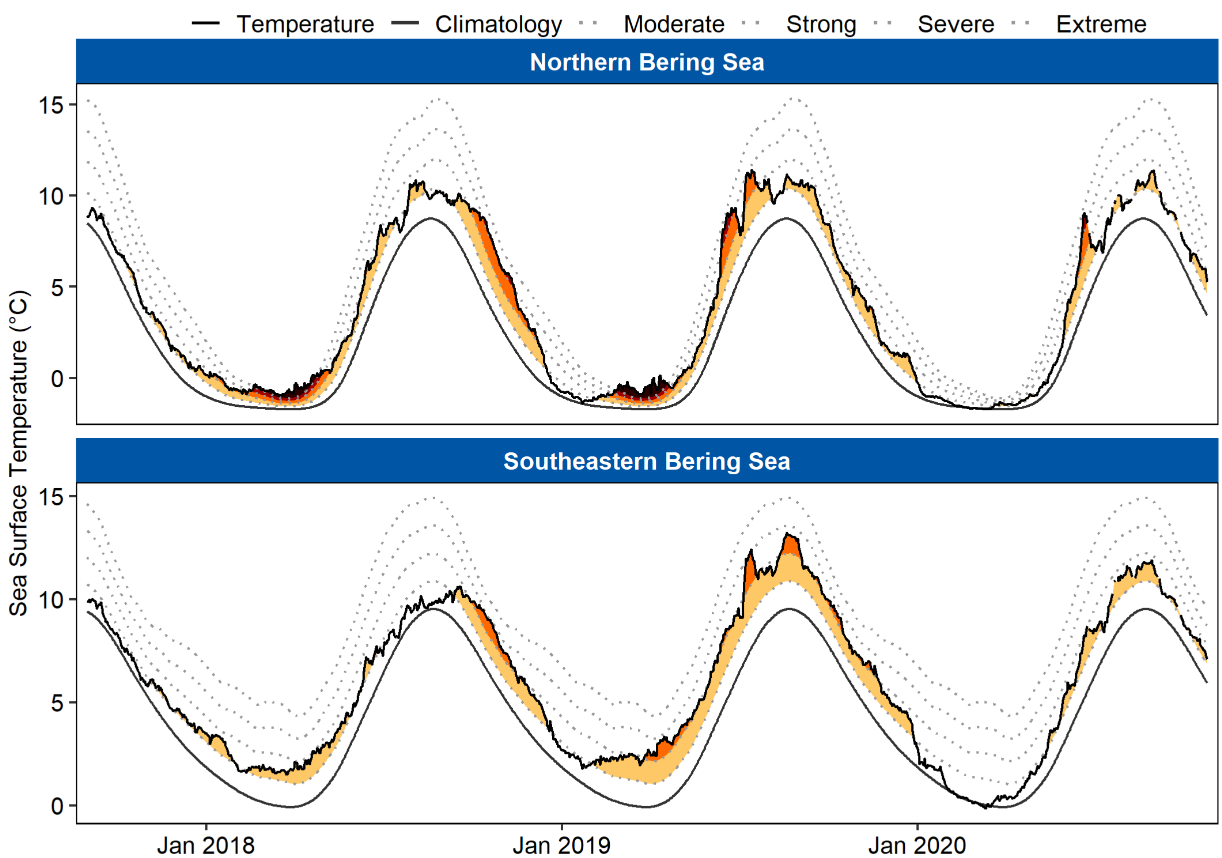

Figure 14: Marine heatwaves in the southeastern and northern Bering Sea since September 2017. Smoothed solid black line represents the baseline average temperature (i.e., climatology) for each day during the 30-yr baseline period (1 Sept 1985–31 Aug 2014). Jagged solid black line is the observed (satellite-derived) sea surface temperature for each day. Dotted lines illustrate thresholds for increasing heatwave intensity categories (moderate, strong, severe, extreme). Colored portions indicate periods during which marine heatwaves occurred, with lightest colors indicating moderate intensity heatwave events and intensity increasing as colors darken.

Many factors can influence sea surface temperatures, and subsequently the formation of marine heatwaves, including a suite of weather, climatic, and oceanographic factors (Holbrook et al., 2019). Meanwhile, defining or contextualizing heatwaves depends upon the selection of baseline years (in this case, 1 Sept 1985–31 Aug 2014). As long-term climate change leads to warmer temperatures, the baseline used to define 'normal' will change as well, requiring consideration of how baseline selection affects our interpretation of deviations from normal and thus, events like marine heatwaves (Jacox, 2019; Schlegel and Smit, 2018).

Contributed by Jordan Watson (NOAA/AFSC)

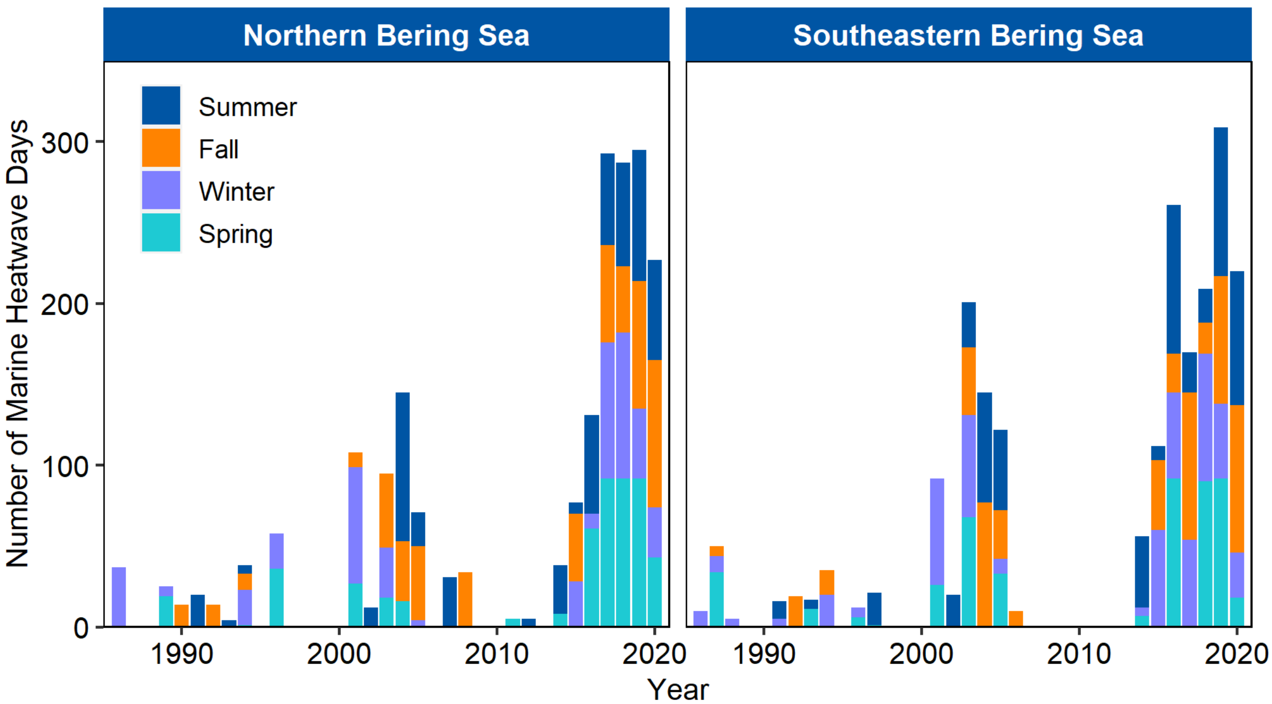

Figure 15: Number of days per year during which marine heatwaves occurred, by season: summer (Jun-Aug), fall (Sept-Nov), winter (Dec-Feb), spring (Mar-May).