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 north and southeastern 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 (ie., 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 (<https://coastwatch.pfeg.noaa.gov/erddap/griddap/NOAA_DHW.html>). Daily data were averaged within the southeastern (south of 60 ̊N) and northern (60 ̊N – 65.75 ̊N) Bering Sea shelf (10 m – 200 m depth). Detailed methods are online (github.com/jordanwatson/EcosystemStatusReports/tree/master/SST). We defined the annual cycle in the Bering Sea to begin on 1 Sept. of each year and end on 31 Aug. 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 tortuous pattern of thermal exposure for the system throughout the year. As seen in **Figure 1**, the cumulative annual SST (ie., 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 northern and southeastern 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 (ie., the end of August).

The end points, or the total cumulative SST, for each year demonstrate the stark differences 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 (**Fig. 2**). 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.

Ecologically, it is likely more important to identify when the thermal exposure within a system may diverge from more typical patterns. For example, **Figure 3** 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. While the patterns from **Figure 3** can be helpful for summarizing seasonal effects in aggregate, they may obscure some of the patterns. Flamingo plots (**Fig. 4**) illustrate the intra-annual variability more starkly. These figures show the same line plots as **Figure 1**, but instead displayed in chronological order instead of overlain. Qualitative differences across years are readily discerned via the height at which inflection points (the neck of the flamingo) begin, and the depth of the downward trend (a greater downward extent points to a more protracted period of negative temperatures). The most prominent feature in the northern Bering Sea is the shallowing of the flamingo neck during recent years, as the cooling contribution of sea ice dissipates. Meanwhile, in the south, there is a striking absence of a flamingo neck (ie., no downward turn) during the warm years (those ending in 2003-2005 and 2014 – 2020). The red portions of each flamingo represent periods during which marine heatwaves were observed.

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 marine heatwaves observed in **Figure 4** have been particularly persistent and intense during recent years, reaching into the *extreme* category in the winters of 2018 and 2019 in the north (**Fig. 5**). While the *extreme* periods were relatively brief, heatwaves have been persistent in both the north and southeastern Bering Sea for much of the last five years. These total annual heatwave durations are summarized in **Figure 6**, 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 insufficient sea ice remains to buffer against dramatically increased cumulative annual thermal exposure.

Many factors can influence sea surface temperatures and subsequently, the formation of MHWs, including a suite of weather, climatic, and oceanographic factors (Holbrook et al., 2019). Meanwhile, defining or contextualizing heatwaves depends upon the selection baseline years (1986-2015). 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 MHWs (Jacox 2019; Schlegel et al., 2020).

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