**Title**: Sea Surface Temperature and Marine Heatwaves in the Gulf of Alaska Ecosystem Regions

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**Description of indicator**: Sea surface temperature (SST) is a foundational characteristic of the marine environment and temperature dynamics can impact many biological processes. Changes in temperatures can influence physiological processes of fish (e.g., metabolic rates and growth rates), fish distribution (e.g., Yang et al. 2019), trophic interactions, availability of spawning habitat (e.g., Laurel et al 2020), and energetic value of prey (von Biela et al. 2019). Extended periods of increased SST can lead to marine heat waves (Bond et al. 2015; Hobday et al. 2016). We describe trends in sea surface temperature throughout the Gulf of Alaska (GOA) ecosystem regions.

In recent years, warm water events have become so frequent in the world’s oceans that a new method for describing them has been formalized. We consider marine heatwaves (MHWs) 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 MHW 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 considered *moderate*, *strong* (2 times the difference between then threshold and normal), *severe* (3 times the difference), or *extreme* (>=4 times the difference) (Hobday et al., 2018).

Satellite SST data from the NOAA Coral Reef Watch Program were accessed via the NOAA Coast Watch West Coast Node ERDDAP server (<https://coastwatch.pfeg.noaa.gov/erddap/griddap/NOAA_DHW.html>) for January 1985 - September 2020. Daily SST data were averaged within the western (147 ̊W - 163 ̊W) and eastern (133 ̊W – 147 ̊W) Gulf of Alaska (WGOA and EGOA, respectively) for depths from 10m – 200m (i.e., on the shelf). Detailed methods are online, including maps of the spatial strata and processing the data in R (github.com/jordanwatson/EcosystemStatusReports/tree/master/SST).

We use the earliest complete 30-year time series as the baseline period for mean and standard deviation comparisons although the guidance on such choice varies across studies (e.g., Hobday et al., 2018; Schlegel et al., 2020). Three notable differences exist between the current marine heatwave indicators and those previously presented to the North Pacific Fishery Management Council (detailed in Barbeaux et al., 2020). First, the current indicator uses a different NOAA SST dataset, with a slightly different time period (beginning 1985 instead of mid-1982) and spatial resolution (the current indicator has finer spatial resolution and thus, more data points within the same region). Given the shorter time series, the 30-year baseline period is necessarily different (1985-2014 instead of the previous 1983-2012). Finally, the previous indicator was bounded spatially to target management of Pacific cod in the GOA, whereas the current indicator is bounded spatially by the ESR regions for a broader comparison.

**Status and trends**: Much of 2021 has been cooler than the previous few years, with temperatures in both the western and eastern GOA often hovering close to the long term average. Despite this generally cooler pattern, the year started out relatively warm in the western GOA before trending more towards typical temperatures (Fig. 1).

The western GOA remained below marine heatwave status throughout 2021 so far, while the eastern GOA had several brief and moderate events (Fig. 2-3). In comparison to the overall time series of marine heatwave events (Fig. 3), 2021 stands out from the previous half decade as having remarkably few days in marine heatwave status.

An important ecological consideration with marine heatwaves is the extent of a particular area that experiences the warm conditions, and whether there may be thermal refugia for species within that domain. For the brief marine heatwave in April, ~84% of the satellite pixels analyzed experienced a marine heatwave that week, suggesting that most of the eastern GOA experienced such warming.

**Factors influencing observed trends**: The time period illustrated here includes the well-documented “warm blob” period (Bond et al., 2015; Hu et al., 2017) and recent marine heatwaves (2014-2016, 2019) (Barbeaux et al., 2020), which are characterized by anomalously warm winters. In 2021, conditions overall were less remarkable. The spike in April SST in the eastern GOA coincided with unusually warm and calm weather throughout Alaska and thus, these events may be related.

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 of baseline years (1985-2014). 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 MHWs (Jacox 2019; Schlegel et al., 2020). The more warm years that are included in the baseline, the warmer that baseline will appear.

**Implications**: Barbeaux et al. (2020) provide tangible evidence for the potential implications of warming conditions on groundfish, in particular Pacific cod. Holsman et al. (2020) further emphasize the risk of warming conditions on gadid populations but highlight the value of an ecosystem-based management approach for buffering the impacts of projected temperature increases and more frequent marine heatwaves. The approximately average 2021 winter and spring SST values across GOA, and summer SST in EGOA, provide improved conditions over 2019 for spawning, zooplankton quality and quantity, and fish metabolic demands. While the WGOA summer SST was oscillating around the heat wave threshold, the duration and intensity of warm temperatures does not equate to previous heatwave years and it is uncertain how and if the warmth will impact the marine environment.

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**Figure 1.** Seasonal sea surface temperatures (SST) for Gulf of Alaska ecosystem regions. Lines illustrate the 2021 SST (orange), 2020 SST (blue), 30-year mean SST (black), and each of the 1985-2018 SST (gray) time series.

**Figure 2.** Marine heatwave (MHW) status during the last three years. Filled (yellow) areas depict MHW events. Black lines represent the 30-year baseline (smoothed line) and observed daily sea surface temperatures (jagged line). Faint grey dotted lines illustrate the MHW severity thresholds in increasing order (moderate, strong).

**Figure 3.** Number of days during which marine heatwave conditions persisted in a given year. Seasons are summer (Jun - Aug), fall (Sept – Nov), winter (Dec – Feb), spring (Mar – Jun). Years are shifted to include complete seasons so December of a calendar year is grouped with the following year to aggregate winter data (e.g., Dec 2020 occurs with winter of 2021).