Kaitlyn Nichols June 2024

Defining Marine Heat Waves in the Southern California Bight:

Implications for California Sea Lion Population Trends

Master of Advanced Studies in Climate Science and Policy
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ABSTRACT

Marine heat waves (MHWs), extended periods of unusually high ocean temperatures that significantly impact marine ecosystems, are prevalent in the Southern California Bight (SCB), increased thermal stratification has intensified these events over recent decades, affecting California sea lions by disrupting prey availability, leading to malnutrition and higher mortality rates. Rising atmospheric CO2 levels have exacerbated this issue, contributing to the warming of surface waters. Climate models predict that MHWs will continue to increase in frequency, severity, and duration, posing further risks to marine life. Despite the presence of a significant sea lion colony off the coast of San Diego, little research has been conducted on MHWs in the SCB impact on the local sea lion population. This research examines various aspects of MHWs at San Diego, including defining MHWs, historical occurrences, current trends, and their implications for California sea lions, while exploring potential policy and mitigation strategies to protect Southern California's marine ecosystems. Daily sea Surface Temperature (SST) measurements from La Jolla Scripps Pier (1916-2023) are used to quantify local MHWs relative to a shifting baseline (i.e., one that adjusts for the long-term warming trend), and to a fixed baseline (i.e., the warming trend alone increases MHW occurrences). We investigate critical questions about MHW evolution and duration, considering the continuous warming of the oceans. We consider what the two definitions of MHWs imply for upwelling and nutrient supply to the ocean surface, and the implications for California sea lion prey availability. We identify future research priorities, particularly improved measures of sea lion population counts, and the need for better indicators of MHW impacts beyond SST.

OUTLINE

I. INTRODUCTION

I.1 History of Marine Heat Waves in California

Abnormal SST anomalies occurred during the 1982-1983 El Niño and the 1997-1998 El Niño, marking significant episodes in the history of MHWs along the Southern California coast (Edwards et al., 2006; Quinn et al., 1986). Along the west coast of North America, the 1982-1983 El Niño was associated with anomalously warm sea temperatures and high sea levels, enhanced poleward and onshore transport, depression of the thermocline, and suppressed coastal upwelling (Simpson et al., 1984; Norton et al., 1985; Huyer and Smith, 1985). Similarly, the 1997-1998 event saw elevated SSTs and changes in marine species distributions (Chaves et al., 2002; Hayward et al., 2000).

In the winter of 2013/2014, a significant MHW, termed "The Blob," occurred in the Northeast Pacific, with temperatures 2–5°C above normal (Amaya et al., 2020; Hernández-Camacho et al., 2021). This event, driven by a persistent atmospheric ridge and weakened surface winds, led to substantial coastal warming and ecosystem impacts along the North American coastline (Amaya et al., 2020). In summer 2015, the Blob developed a "split" structure, with stronger SST anomalies along the California coast due to atmospheric ridging and persistent wind relaxation patterns (Fewings et al., 2019; Edwards et al., 2002). In spring 2014, the Southern California Warm Anomaly (SCWA) emerged as a band of warm surface water along the shelf break, following a sequence of warming events in the Northeast Pacific (Leising et al., 2015). This anomaly intensified in fall 2014 and winter 2015, affecting the SCB due to changes in atmospheric forcing and decreased coastal upwelling.

The August 2018 MHW set new temperature records along the Southern California coast, with daily mean water temperatures at Scripps Pier reaching 26.4°C (Wei et al., 2021; Fumo et al., 2020). This event resulted from reduced upwelling, tropical cyclones, and local forcing factors, leading to significant warming and ecosystem impacts (Wei et al., 2021). In summer 2019, the North Pacific experienced another significant MHW, "Blob 2.0," resulting from weakened wind-driven mixing and a shallow mixed layer depth (Amaya et al., 2020). This event continued a recent trend of increased stratification and reduced ocean mixing, which have been linked to anthropogenic global warming (Capotondi et al., 2012).

I.2 Current Understanding of MHWs in the SCB

In the SCB, increased thermal stratification with MHWs has led to a reduction in the vertical mixing of colder deep waters with surface waters, effectively reducing the nutrient fluxes up to the euphotic zone and deepening the nutricline (Zaba and Rudnick, 2016). Upwelling plays a critical role along the California coast in driving nutrient-rich waters from the ocean depths to the surface, supporting thriving biological activity (Xiu et al., 2018). However, the recent MHW events have been associated with increased thermal stratification, impeding the mixing of colder deep waters with surface waters. As a result, wind-driven nutrient fluxes to the euphotic zone are disrupted. These changes can intensify warming trends, complicate upwelling dynamics, and reduce food availability for marine ecosystems in the Bight.

The present understanding of MHWs poses considerable challenges for the future. Research indicates that MHW intensity and the number of annual MHW days are expected to dramatically increase, with many ocean regions predicted to experience near-permanent MHW conditions by the late 21st century (Smale et al., 2019; Frölicher et al., 2018). These projections are supported by a global increase in the count of annual MHW days, which has risen by over 50% since 1925, and a notable escalation in MHW intensity since the beginning of satellite observations in 1982 (Oliver et al., 2018). Climate models suggest that anthropogenic climate change will substantially raise the probability of MHWs worldwide, leading to longer and more severe events in the coming decades (Oliver et al., 2019; Cheung et al., 2020).

During the August 2018 MHW event, record-high SSTs were observed at La Jolla, California. A study by Fumo et al., (2020) utilized the Scripps Institution of Oceanography daily temperature time series (SIOT) data in La Jolla to examine characteristics and impacts of this MHW event along the Southern California coast. Two separate stacked bar plots were utilized to illustrate the frequency of MHWs overtime by adjusting the data in one plot to remove long-term warming trends, and the other plot was left unadjusted. The adjusted data revealed no significant trend in the number of MHW days, whereas the unadjusted plot indicated an increase of 38 MHW days per century. This rise reflects the influence of human-induced climate change on the dataset over time, with temperatures climbing by 0.12°C per decade (Fumo et al., 2020). We aim to build upon Fumo et al.'s (2020) methodology by utilizing similar approaches to analyze the SST data.

I.3 MHW Impacts on California Sea Lions

California sea lions (Zalophus californianus) are central residents of the highly dynamic California Current System (CCS), an eastern boundary upwelling system known for its role in shaping the marine environment along the Pacific coast of North

America. These pinnipeds exhibit intricate ecological relationships within this ecosystem, breeding on the California Channel Islands as well as the La Jolla Cove off the coast of San Diego and exhibiting a wide foraging range throughout coastal and offshore habitats within the CCS. Due to their reliance on prey availability and oceanographic conditions, California sea lions serve as sentinel species, serving as an indicator of environmental changes or health within trophic levels and the broader CCS ecosystem (Melin et al., 2012). The distribution and abundance of California sea lions are linked to environmental variability, particularly fluctuations in SST and prey availability (Weise et al., 2008). Environmental changes, such as those induced by MHWs, can significantly impact the foraging success, health, and population dynamics of these marine mammals.

During MHWs, coastal winds that drive upwelling and nutrient transport are weakened, leading to reduced primary productivity and altered prey distribution (Hernández-Camacho et al., 2021; Weise and Harvey, 2008). This can result in shifts in prey availability and composition, forcing California sea lions to adapt their foraging behaviors and diet preferences (Robinson et al., 2018). The outcomes of these changes in diet can be significant, potentially affecting the nutritional condition and overall well-being of sea lion populations. For instance, during the "Blob" MHW event, California sea lions exhibited significant changes in their diet composition, with a shift from energy-rich prey like Pacific sardines and Northern anchovies to less nutritious alternatives such as rockfishes and market squid (Robinson et al., 2018).

Furthermore, MHWs have been associated with increased mortality and strandings of California sea lions, particularly among young pups. For example, during the MHW in 2013–2017, there was a surge in pup strandings along the California coast, accompanied by signs of dehydration and malnutrition due to changes in prey availability (NOAA). Additionally, harmful algal blooms triggered by MHWs, such as those producing the neurotoxin domoic acid, pose additional threats to sea lion health. Consumption of contaminated prey can lead to domoic acid poisoning, resulting in neurological symptoms and mortality which was observed in colonies during the "Blob" (Gulland et al., 2002; Goldstein et al., 2008).

I.4 MHW Socio-economic Impacts

Understanding how marine organisms adapt to these shifts in population and ecological processes is crucial, alongside proactive management to mitigate socio-economic consequences. MHWs pose substantial challenges for human communities and economies, resulting in loss of fisheries income, erosion of ecosystem services, and mass mortalities of iconic species. Economic losses from MHWs can exceed hundreds of millions of dollars annually, with some events causing losses exceeding $3.1 billion (Smith et al., 2021). Mass die-offs of marine species and harmful algal blooms further impact fisheries and tourism. Despite short-term opportunities such as increased tourism or fisheries prospects, the negative impacts outweigh the benefits. The presence of California Sea Lions at locations like La Jolla Cove attracts tourism revenue, with visitors purchasing sea lion merchandise and flocking to the cove to see them. However, a cautious approach is needed due to limited data reliability. This caution is necessary to ensure that tourism activities and other human interactions with marine ecosystems are managed sustainably and with consideration for the potential long-term consequences, especially given the uncertainty stemming from insufficient data. Effective policy and mitigation strategies, including proactive preparation, adjusting catch based on weather predictions, and integrating climate change responses into marine protected areas (MPAs), are essential. Integrating MPAs with restoration or stock enhancement can enhance resilience to MHWs and protect the economic stability of coastal communities reliant on marine resources (Smith et al., 2021).

I.5 Mitigation and Policy for California Sea Lions

The California sea lion populations along the U.S. west coast are attributed to protective measures under the Marine Mammal Protection Act of 1972 (MMPA), aiming to maintain populations within optimal sustainable ranges. Studies by Berkson and DeMaster (1985) and Laake et al. (2018) emphasize the need for robust population assessment models, accounting for environmental impacts such as MHWs and El Niño events. According to the classification criteria (Endangered, Threatened, and Vulnerable) proposed by the International Union for Conservation of Nature (IUCN 2012), most of these colonies currently should be classified as Endangered or Vulnerable (Hernández-Camacho et al., 2021). However, California sea lions are not listed as Endangered or Threatened under the Endangered Species Act (since 1986) or as Depleted under the Marine Mammal Protection Act because the population is within the range that US government agencies have defined as an optimum sustainable population (Carretta et al. 2015). In contrast, the species has been granted Special Protection under Mexican Official Standard. Globally, California sea lions are considered to be of Least Concern according to the Red List of the IUCN (Hernández-Camacho et al., 2015). Strandings and unidentified mortality events (UME), monitored under the

MMPA, provide insights into oceanic health during MHWs, with volunteer networks aiding investigations. Conservation efforts, supported by groups like the Sierra Club and Seal Society of San Diego, advocate for protecting sea lion habitats, but balancing conservation and economic interests is crucial for sustainable resource management (Hanan et al., 2016). Effective policies must consider both ecological conservation and economic sustainability to address the complex interactions between marine mammal protection, tourism, and local economies especially for the La Jolla colony.

The Seal Society of San Diego has been actively involved in advocating for the protection of California sea lions and seals in the La Jolla area. Their efforts began with initiatives such as getting Children's Pool closed for pupping season and partnering with organizations like the Sierra Club San Diego Chapter. They train docents to educate the public about seals and sea lions, study factors like haul-out locations and interactions between humans and wildlife, and collect data, particularly focusing on sea lions which have had limited research on their populations. Utilizing professional drone operators and docent counters, they have gathered around two years of data. Their objective is to raise awareness and work with authorities such as NOAA, Park and Recreation, the City of San Diego, and the Coastal Commission to protect sea lions. Successes include the closure of Point La Jolla during pupping season and year-round closure last year due to collaboration with the California Coastal Commission. However, La Jolla Cove remains open despite colonies residing and reproducing in the area. In the face of obstacles such as limited NOAA staff for enforcement and the inefficacy of signage in altering behavior, the Seal Society continues to advocate for responsible viewing practices and protection of these sentinel species in the face of urban tourism pressures.

I.6 Purpose of Report

The impacts of MHWs on California sea lions illustrate how environmental changes, prey availability, and marine mammal health interact in the CCS. By analyzing long temperature records, we gain a clearer understanding of how MHW events have evolved over time, and how they may change in the future with ocean warming. Here we use the 107-year record of SST collected at the Scripps Pier to assess how the mean temperature of each heat wave event and the number of heat wave days are changing over time, similar to the analysis of Fumo et al. (2018). MHW conditions represent a warm surface layer that is not replenished by colder, nutrient rich water at depth by vertical mixing or upwelling. This occurs during periods of wind relaxation when mixing and upwelling are curtailed. Intensified upwelling potentially mitigates MHW impacts by cooling surface waters, while weakened upwelling conditions may exacerbate MHW severity (Bogard et al., 2003). In addition, the stratification of the water column is an important factor contributing to MHWs. A more stratified ocean, i.e., a stronger vertical gradient between surface layer temperatures compared to temperatures at depth, suppresses vertical mixing and upwelling. That is, as the stratification increases, stronger winds are needed to mix or upwell cold waters to the surface. One consequence of global warming is that ocean stratification is expected to increase, which would contribute to a rise in MHWs (ref). Rising atmospheric CO2 levels have exacerbated this issue, with the upper ocean layers absorbing over 90% of excess heat from human activities, warming surface waters by 0.15°C per decade over the past 40 years (Smith et al., 2021). To the extent that the detection of MHWs also provides an indicator of when upwelling may be reduced, they can provide insights into prey movement patterns and help anticipate whether sea lions will need to adapt, relocate, or face potential mortality in the Southern California region. MHW conditions have affected California sea lions by disrupting prey availability, leading to malnutrition and higher mortality rates. Climate models predict that the frequency, severity, and duration of MHWs will continue to increase, posing further risks to marine life, including strandings and decreased reproduction (Ziegler et al., 2023; Shanks et al., 2019). Using the Scripps SST time series, we seek to determine what information can be inferred about local MHWs, upwelling, and nutrient supply, which in turn may lead to improved mitigation and policy strategies for California sea lions in the SCB amidst the growing concern of ocean warming.

II. METHODS

II.1. Study Area

The SCB is situated within the broader California Current System, spanning from British Columbia, Canada, to Baja California, Mexico (Smith et al., 2021). In this region, thermal stratification, characterized by distinct temperature gradients within the water column, is influenced by seasonal upwelling driven by prevailing northerly winds (García-Reyes et al., 2010). Upwelling, a vital process, transports nutrient-rich, cold waters from the deeper ocean to the surface, supporting high biological productivity (Xiu et al., 2018).

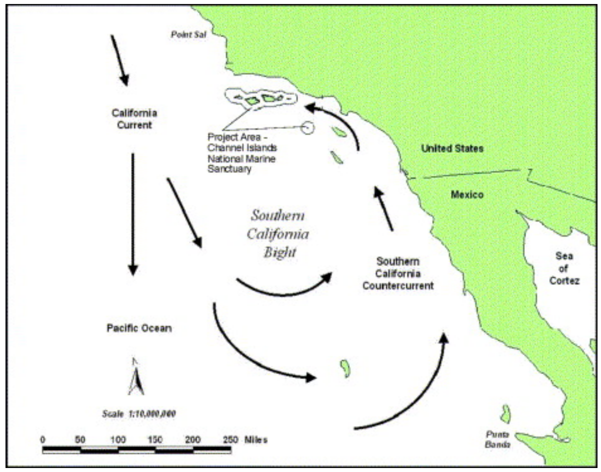


Image 1: (McGinnia et al., 2006)

II.2. Data Collection

Sea surface temperature data spanning from 1916 to 2023 was sourced from the Scripps Pier SST Data, obtained from the Shore Stations Program (website). An insulated sampling bucket is used to collect surface water (approximately 0.5 meter depth) daily, and a calibrated digital thermometer is immediately placed inside the bucket to measure SST to the nearest 0.01ºC. Temperature measurements are then rounded and reported to 0.1ºC.

The California sea lion data utilized in this study was provided by the Seal Society of San Diego and analyzed by Bridgett Spencer. This dataset is collected through a combination of volunteer docent counts and drone footage analysis. The volunteers conduct regular counts to assess sea lion haul-out populations, while drone footage captures aerial views of the coastline, including various areas from Boomer Beach through the Cove and further north where sea lions are observed. Additionally, the data includes haul-out counts from La Jolla Cove by year, although this dataset is limited due to the relatively small amount of available data. The dataset includes a range of variables, such as sea lion population trends, haul-out locations, and drone counts, which provide insights into the distribution and behavior of sea lions along the Southern California coastline.

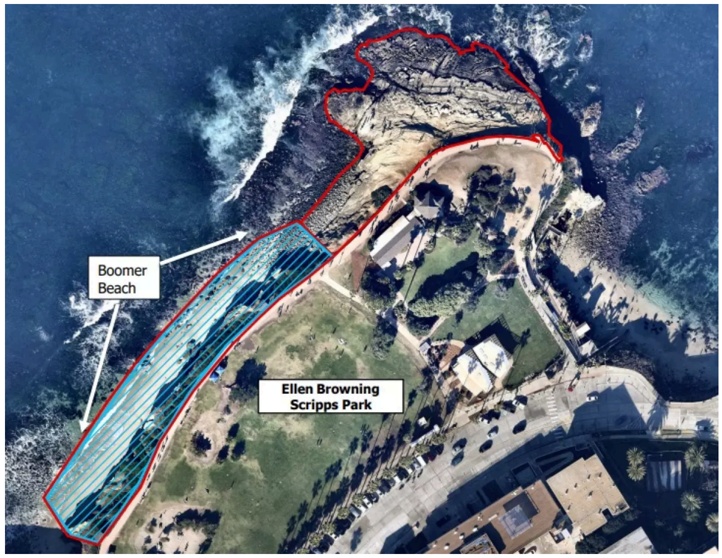


Image 2: (The San Diego Union-Tribune)

II.3 Defining Marine Heat Waves

In discussions of MHWs, it's essential to grasp two primary definitions. The standard definition characterizes MHWs as periods where ocean temperatures exceed a seasonally varying extreme percentile threshold for at least five consecutive days (Hobday et al,. 2016). A fixed threshold is useful for assessing impacts in which exceeding a specific temperature level is a concern (Amaya et al., 2023). This would be particularly relevant if an organism were sensitive to a specific thermal stress (e.g., corals), or if negative ecological impacts developed at certain temperature levels (e.g., HABs). Conversely, a shifting baseline approach incorporates ongoing ocean warming into the definition of 'normal' temperatures. 'Normal' temperatures are conventionally defined by historical temperature variations over a fixed period, usually about 30 years (Hobday et al., 2016). However, this method overlooks the ongoing warming trend attributed to climate change. This distinction is crucial for accurately identifying and understanding historical MHWs and their impacts. The shifting baseline approach addresses this by redefining 'normal' conditions to include long-term ocean warming, necessitating further temperature anomalies to surpass this adjusted baseline and qualify as an MHW (Amaya et al., 2023). The determined categories of MHWs are defined as moderate (1-2x the 95th percentile, Category I), strong (2-3x, Category II), severe (3-4x, Category III), and extreme (>4x, Category IV) (Hobday et al., 2018). Understanding the differences between these definitions is critical for evaluating the ecological impacts and management strategies associated with ocean temperature fluctuations. Long-term temperature trends describe gradual ocean warming over decades, offering insights into climate change's effects on ecosystem dynamics and biodiversity.

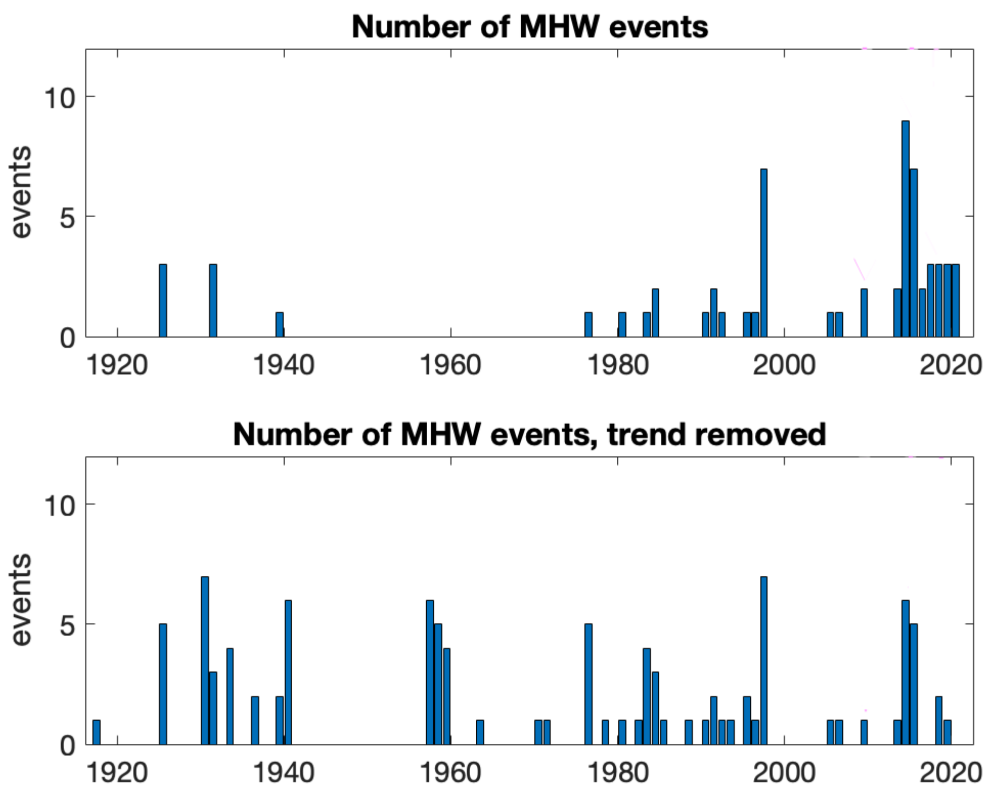
II.4 Statistical/Data Analyses

The daily SST time series from the Scripps pier was used to determine the number and intensity of MHWs over time A MHW is defined as an event lasting at least five consecutive days in which the daily temperature exceeds a seasonal threshold. In our case we used the 95th percentile for each day of the year during the baseline period 1983-2012. The values were smoothed over time following Hulley et al. (2020). The duration of the MHW is the number of days above threshold, and the intensity of the MHW is the mean temperature above threshold over the event multiplied by the duration of the event (units of °C days). MHWs were considered for a "fixed baseline", in which the raw time series was used including a notable trend over time owing to global warming, and for a "shifting baseline", achieved by removing a second-order trend from the time series and adding back the mean temperature during the 1983-2012 baseline period. The detrending process removes the background warming trend, enabling an assessment of MHW occurrence not linked to global warming.

III. RESULTS

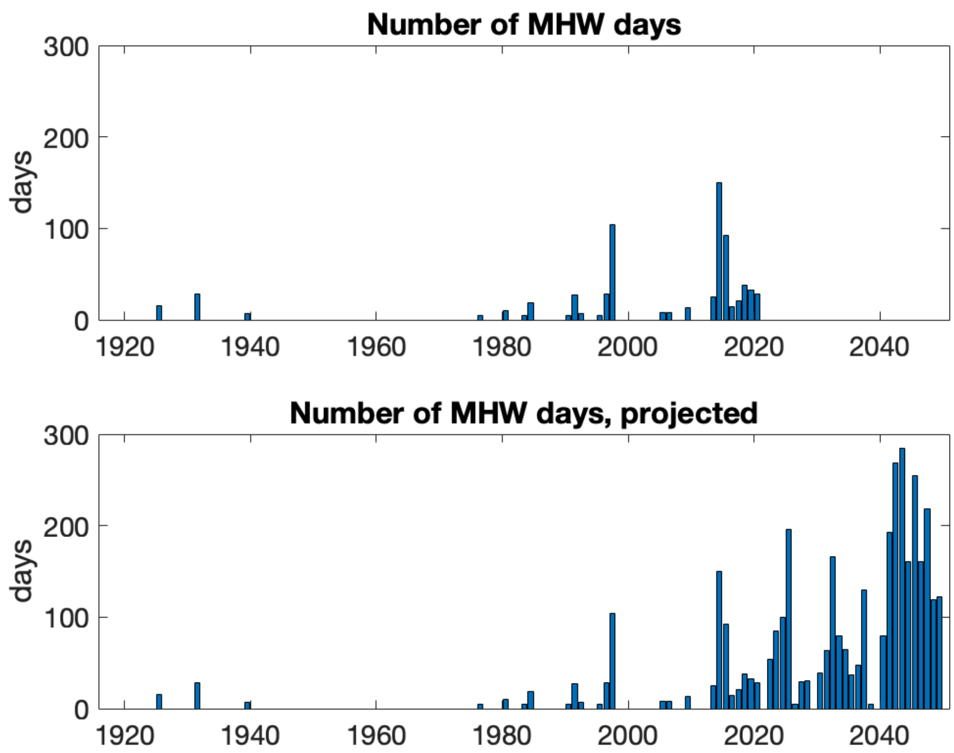
III. 1 MHW Events in the Southern California Bight

FIGURE 1: Frequency of Marine Heat Wave Events (≥ 5 Days) from 1916 to 2023



(Figure 3) The top and bottom plots illustrate the number of MHW days, defined as consecutive periods of at least 5 days with elevated sea surface temperatures, spanning from 1916 to 2023. The y-axis depicts the count of MHW days ranging from 0 to 10, while the x-axis represents decades. In the top plot we have MHW days overtime including the global warming trend. In the early decades, there were intermittent spikes, reaching up to almost 5 MHW events, before a general decrease in 1940 until around 1980. From this point onward, there is a notable increase, with a peak of about 7 MHW events in the late 1990s to early 2000s. Subsequently, there is a slight drop in MHW events around 2010 before another significant spike in the early 2020s, reaching up to approximately 9 MHW events. Towards the late 2020s, the count begins to decrease again, stabilizing at around 4 MHW events. The bottom plot shows MHW events overtime with the global trend removed. We now see more fluctuations in MHW events over time.

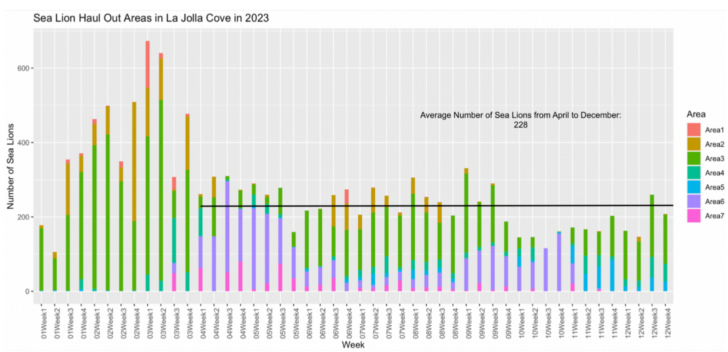
FIGURE 2: Number of Marine Heat Wave Days Projected to 2040



(Figure 4) The plot illustrates the number of MHW days lasting at least 5 consecutive days from 1916 to 2023, with the y-axis representing the number of MHW days (ranging from 0 to 300) and the x-axis denoting decades. The top plot illustrates the current warming trend up to 2020 with a gradual upward trend. The bottom plot illustrates the projected warming with the global trend out to year 2040 with the upward trend continuing, reaching almost 300 MHW days and then gradually decreasing toward then end.

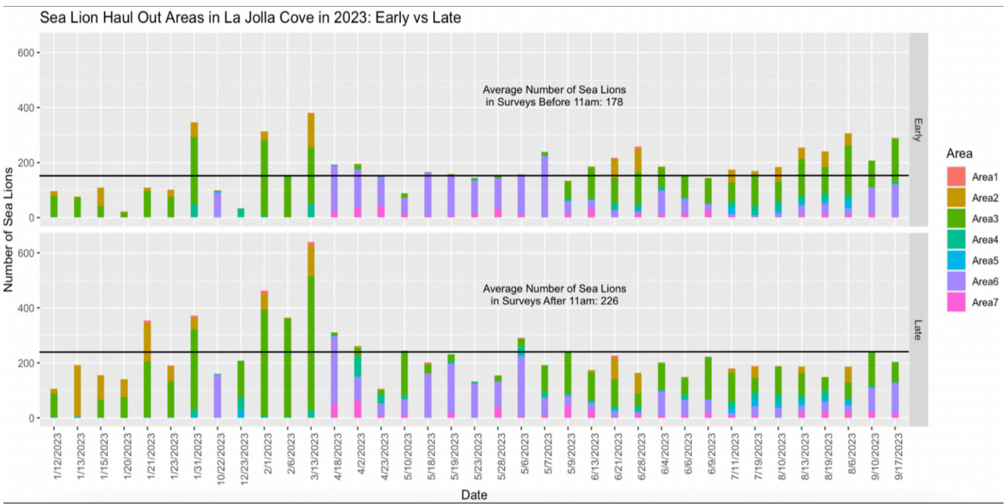
III.2 Establishing a baseline for the La Jolla Sea Lion Population (Seal Society Data)

FIGURE 3: Sea Lion Population Data in La Jolla Cove 2023



(Figure 1): The combined data from drone and docent surveys revealed trends in the usage of different areas by California sea lions. Analyzing the average number of sea lions from April to December, which incorporates data from both drone and docent surveys, it was found an average of 228 sea lions. This suggests that the population of sea lions residing in various areas of La Jolla Cove year-round is between 200 and 300 individuals when accounting for animals in the water. Notably, there was a significant increase in the number of sea lions during mid-winter (February-March). This spike is likely due to sea lions moving around after storms and staying in the area due to the abundance of squid, indicating that these individuals are likely not local residents. The areas surveyed include: Sea Lions on Boomer Beach (Ocean access area), Sea Lions on Boomer Beach (no access), Sea Lions on Point La Jolla, Sea Lions on Rocks between Point LJ and the Cove, Sea Lions on La Jolla Cove Beach, Sea Lions on Bluffs below Brockton Villa, and Sea Lions Further North.

FIGURE 2: Sea Lion Population Data in La Jolla 2023, Early vs. Late



(Figure 2): Comparing drone footage and volunteer survey data showed discrepancies, with drone counts often being lower. Since drone footage was primarily collected early in the morning (around 7am), we investigated whether the time of day influenced the counts. By splitting the day into two periods—before 11am and after 11am—and analyzing days with both early and late surveys, it was found that early surveys had an average of 178 sea lions, while late surveys had an average of 226. This variation, particularly the lower counts in the summer months during late surveys, shows the importance of conducting surveys at different times of the day to capture the full range of sea lion activity. Areas surveyed are listed in the description of Figure 1

IV. DISCUSSION

IV.1 Overview

In our study, we observed changes in MHWs over time in the SCB using the shifting baseline approach, which incorporates ongoing ocean warming into the definition of 'normal' temperatures. Regarding the duration of MHWs, our detrended analysis showed that these events persist for varying lengths of time, with some lasting several days to weeks. While the duration of individual MHW events may vary, our findings suggest that MHWs have been occurring all along, however they are becoming hotter with global warming. This trend aligns with the observed increase in MHW frequency, indicating more frequent occurrence of these extreme heat events in the marine environment. By studying how nutrients fluctuate alongside MHWs, we can better understand how prey species move and predict potential effects on marine ecosystems. This holistic approach will help us grasp the ecological implications of MHWs and forecast whether sea lions and other marine species in Southern California might have to adjust their behavior, move to new habitats, or face risks to their survival.

IV.2 Fixed Baseline SST vs. Shifting Baseline SST

The comparison between the unadjusted (non-detrended) data and the detrended data shows how MHW dynamics change over time. The unadjusted data, depicting raw data, reveals an uptrend pattern, with peaks observed in the late 1990s to early 2000s and again in the early 2020s, which coincides with the gradual warming of the ocean. While the fixed baseline is useful for measuring the impact of temperature changes on organisms over time, it fails to account for the continuous rise in sea temperatures due to global warming. In contrast, the detrended data provides a depiction of MHW anomalies independent of long-term warming trends and is better used to assess nutrient fluxes and prey availability with MHW events. The data shows

MHW fluctuations all along the time series, indicating these events have been happening overtime, not just recently. During MHWs, upwelling is suppressed, reducing the influx of cold, nutrient-rich water from the deep ocean to the surface. This reduction in nutrients affects the entire marine food web, starting with primary producers like phytoplankton and cascading up to higher trophic levels, including marine mammals such as sea lions. The detrended data, by highlighting these anomalies, also indicates periods of lower nutrient availability. This is critical for understanding ecological impacts, as reduced nutrients force marine species to adjust their behavior and distribution.

IV.3 MHW Future Outlook

In the top plot of Figure 4, we observe the SST data from Scripps Pier alongside its long-term warming trend. Projecting this trend forward to 2040 suggests a scenario of pronounced warming, as seen in the bottom plot, prompting critical inquiries into its implications for the potential impacts on sea lions in La Jolla and the Southern California Bight. The projected warming raises questions about whether these species will face habitat challenges or potential northward migrations towards cooler waters in the future.

IV.4 MHW Upwelling Dynamics and Climate Change

The impact of upwelling dynamics on MHW events and their consequences on marine ecosystems is a critical aspect to consider in the context of climate change. Studies have suggested that increased greenhouse gas forcing may lead to intensified upwelling, bringing more cold water up to the surface and potentially counteracting the warming effects of MHWs (Mogollón et al., 2023). Observations have supported this hypothesis, demonstrating increased upwelling intensity associated with stronger alongshore winds in coastal regions, particularly in central California (García-Reyes et al., 2010; Xiu et al., 2018). However, the relationship between upwelling and MHWs is complex. While intensified upwelling may mitigate the severity of MHWs by cooling surface waters, it can also have cascading effects on marine food webs and ecosystems. Increased upwelling has the potential to alter food dynamics by affecting the distribution and abundance of planktonic species, which form the base of marine food chains (Bogard et al., 2002). Changes in water-column stability can render upwelling less biologically effective, contributing to declines in zooplankton biomass and disrupting trophic interactions (Kennedy et al., 2002). Changes in nutrient availability and productivity associated with upwelling variations can impact the reproductive success and survival of marine organisms, including sea lions that rely on specific prey types for sustenance (Hughes et al., 2013). Conversely, if upwelling were to decrease with climate change, the warming effects of MHWs could exacerbate, further altering the availability and distribution of prey species. Evidence suggests that reductions in upwelling-favorable wind stress can lead to anomalies such as warm water, low nutrient levels, and decreased productivity, affecting recruitment and population dynamics of intertidal organisms (Barth et al., 2007). Furthermore, increased upper-ocean warming and stratification resulting from climate change may limit the effectiveness of upwelling in cooling surface waters, exacerbating the impacts of MHWs on marine ecosystems (Bogard et al., 2003). Irregularities in upwelling patterns, like postponed early-season upwelling and intensified late-season upwelling, have been associated with the impacts of global warming on coastal upwelling regions. This gives an outlook to the intricate relationship between climate change, the dynamics of upwelling, and occurrences of MHWs (Barth et al., 2007).

IV.5 Sea Lion Population Data

Linking these findings to sea lion population dynamics observed in La Jolla Cove, potential correlations between MHW events and sea lion behavior emerge. The increase in MHW days coincides with shifts in sea lion abundance and distribution, potentially influencing foraging behavior. The analysis of sea lion population data in La Jolla Cove reveals consistent usage of various areas throughout the year, with an estimated population range of 200 to 300 individuals. A notable increase in sea lion numbers occurs during mid-winter, likely influenced by post-storm movement and abundant squid availability. Differences observed between drone and volunteer survey data emphasize the significance of accounting for variables such as time of day and survey methods when analyzing population trends. This indicates that sea lion behavior may dynamically shift in response to environmental factors like temperature and prey abundance. Increasing marine heat waves may further impact sea lion behavior and distribution, emphasizing the need for continued monitoring and adaptive management strategies to ensure the conservation of these iconic marine mammals.

V. CONCLUSIONS AND RECOMMENDATIONS

V.1 The Shifting Baseline Approach

Our study contributes to understanding how marine heatwaves (MHWs) are changing over time in the Southern California Bight by utilizing the shifting baseline approach. This method, which redefines 'normal' temperatures by incorporating ongoing ocean warming trends, is crucial for assessing MHWs and their impacts on marine ecosystems. By incorporating detrended data and considering the influence of upwelling dynamics on nutrient availability and prey distribution, we gain deeper insights into the drivers and impacts of MHWs in this region. The shifting baseline approach helps future studies account for the escalating frequency and intensity of MHW events, providing a more nuanced understanding of their ecological implications. Additionally, recalibrating 'normal' temperatures enables researchers to discern long-term trends and assess the effectiveness of conservation measures in mitigating the impacts of climate change. Future studies would benefit from comparing early natural El Niño events to the global warming signal to evaluate the impacts on California sea lions under projected extreme future warming. Collecting more population data for La Jolla sea lions is also crucial for assessing changes in population dynamics and the effects of MHWs. This data is essential for developing protective measures for sea lions against the growing concerns of climate change. Therefore, integrating the shifting baseline method into future studies is essential for understanding behavioral impacts on marine organisms due to changing nutrient availability with MHW events, thereby informing adaptive management strategies to safeguard marine mammal populations like the La Jolla sea lions in the face of escalating environmental challenges.

V.2 Further Research

Addressing the challenges posed by MHWs and climate change requires concerted efforts to reduce CO2 emissions and mitigate their impacts on marine ecosystems. Integrating observations, modeling, and interdisciplinary research can help inform effective policy and management strategies aimed at preserving marine biodiversity and ecosystem resilience in the face of ongoing environmental changes. There is a call for more research on marine heat waves in the SCB and their impacts on coastal marine ecosystems, such as sea lions. Additionally, further studies using the shifting baseline approach are needed to gain a more accurate understanding of MHWs and their impacts on nutrient availability.

V.3 Sea Lion Protection Policy

The Seal Society of San Diego's advocacy efforts, including calls for protection from NOAA and collaborative research initiatives, present the critical role of government agencies in safeguarding these vulnerable populations. However, despite their efforts, limited support from NOAA staff for enforcement and the inefficacy of signage in altering behavior pose significant challenges. Therefore, this study urges NOAA to allocate resources and support to bolster protection measures and gather essential data for this population. Given their smaller size compared to offshore populations and their susceptibility to MHW-related strandings, La Jolla sea lions could serve as a valuable study population for understanding the impacts of MHWs on marine mammals and informing conservation strategies. It is imperative that NOAA and other relevant authorities prioritize the conservation of La Jolla sea lions and allocate resources to ensure their long-term survival amidst increasing environmental pressures.

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