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Short Note

Largest Mortality Event to Date of California Sea Lions in Mexico Might Be Linked to a Harmful Algal Bloom

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We report a California sea lion (CSL; *Zalophus californianus*) massive mortality event that occurred in the western region of the Baja California peninsula, Mexico, in late summer 2020 and analyze its relationship with a harmful algal bloom (HAB) through the use of satellite images. The assessment of this kind of event is of high importance given the lack of information at these latitudes. It represents a unique opportunity to increase our knowledge regarding the threats to which CSLs are exposed—especially in light of the decline in CSL abundance in different areas of its Mexican distribution (Elorriaga-Verplancken et al., 2016; Adame et al., 2020; Pelayo-González et al., 2021b).

The CSL is distributed throughout the northeastern Pacific and Gulf of California (GC; Aurioles-Gamboa & Zavala, 1994). In Mexico, the CSL population is estimated at 70,000 to 75,000 individuals, of which ~15,000 inhabit the GC (Adame et al., 2020) and ~60,000 inhabit the western coast of the Baja California peninsula (Milanés-Salinas, 2012). However, the CSL population has declined by ~65% in the GC from 1991 to 2019 due to increases in sea surface temperature that exerted effects on the trophic dynamics of the region (Adame et al., 2020; Pelayo-González et al., 2021b). Moreover, a recent decline in CSL abundance has been reported along the western coast of the Baja California peninsula, which has been associated with the presence of the anomalous warm water mass in the North Pacific (known as "The Blob") that was exacerbated by the 2015-2016 El Niño (Elorriaga-Verplancken et al., 2016; Pelayo-González et al., 2021a).

Other oceanographic and environmental phenomena also threaten CSL abundance. For example, HABs along the California coast have been found to cause strandings and unusual mortality events (UMEs) of CSLs (e.g., Scholin et al., 2000; Gulland et al., 2002). Other pinnipeds from that region, such as the harbor seal (*Phoca vitulina richardii*), have also been affected (McHuron et al., 2013). Environmental factors that could exacerbate these events include oceanographic regime changes, ballast waste discharge, pollution, reduced oxygen availability, increased riverine nutrient run-off, eutrophication, and climate change (Anderson, 1997; Landsberg, 2002; Chávez et al., 2003; Glober, 2020). During a HAB, marine algae produce domoic acid, a potent neurotoxin (Iverson & Truelove, 1994) that causes multiple disorders and signs of illness in CSLs, including epilepsy, seizures, ataxia, head weaving, decreased responsiveness to stimuli, and scratching behaviors (Gulland et al., 2002; Buckmaster et al., 2014).

The impact of HABs on the wildlife of the northeastern Pacific was first reported in 1991 following a high mortality of brown pelicans (*Pelecanus occidentalis*; Work et al., 1993). Similar effects on marine mammals were recorded in 1998 when a bloom of *Pseudonitzschia australis*, known to produce domoic acid, was deemed to have caused the deaths of 48 CSLs that had washed up on the

California coast (Scholin et al., 2000). A similar event was linked to the deaths of 81 CSLs in California in 2000 (Gulland et al., 2002).

Since then, HABs have become regular events, and their toxic effects have been recorded in California waters (Walz et al., 1994; McCabe et al., 2016). Moreover, the overall frequency of HABs has intensified in recent decades, in part because of climate change (Hinder et al., 2012; Glober, 2020). One driver of ocean warming is the accumulation of atmospheric CO_2, which enters the ocean and acidifies its surface (Doney et al., 2009). Dinoflagellates, which are responsible for the majority of HABs, have a greater affinity for conditions of elevated CO_2 compared to those of other algae (Reinfelder, 2011). The connection between anomalous oceanographic conditions and the presence of HABs was reported in spring 2015 when high concentrations of domoic acid were found along the western coast of the United States, causing several fisheries to cease operations, and resulting in multiple stranding events involving pinnipeds and cetaceans. From 2010 to 2013, only 64 ± 21 CSLs per year were reported to have been intoxicated by domoic acid in this region, while more than 200 CSLs were intoxicated yearly from 2014 to 2015 (McCabe et al., 2016).

In contrast to the ample amount of published information regarding CSL mortality linked to HABs for the California coast, little information is available for the Mexican coasts. In the GC and in the Mexican Pacific, *Pseudonitzschia* HABs have been documented (Gárate-Lizárraga et al., 2007; García-Mendoza et al., 2009) and found to be associated with mortality of seabirds in Cabo San Lucas (Sierra-Beltrán et al., 1997) and marine mammals, including more than 150 dolphins and nine CSLs in Sinaloa in 1997 (SEMARNAP-PROFEPA, 1997), and 112 dolphins and 195 CSLs in Sonora in 2004 (Gallo-Reynoso et al., 2005). In 2002, the stranding of 87 dead CSLs on the western coast of the Baja California peninsula between Tijuana and Ensenada was assumed to have been caused by a HAB (Hernández-Becerril et al., 2007), although this could not be tested conclusively.

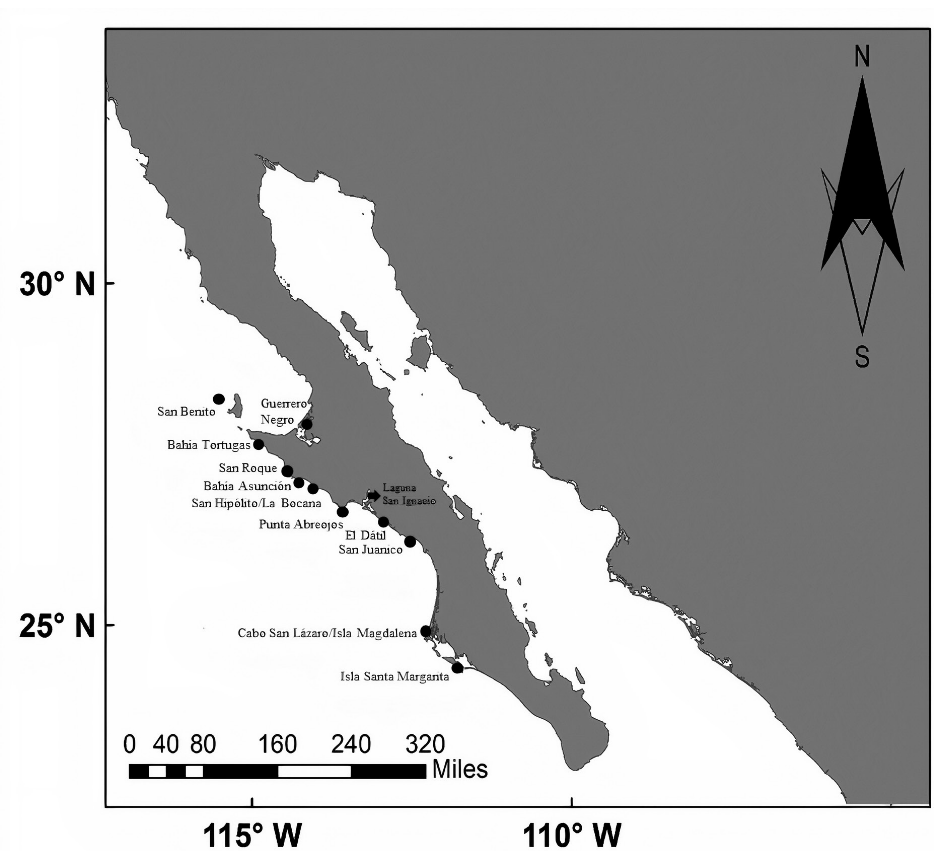

Figure 1. Sites throughout the western region of the Baja California peninsula in which stranded dead California sea lions (*Zalophus californianus*) were recorded

In this study, we address the relationship between a HAB and a CSL massive mortality event that occurred in the western region of the Baja California peninsula (Figure 1). Taking place from approximately 28 August to 4 September 2020, this mortality event included 447 CSLs spanning the western region of the Baja California peninsula. Counts of dead animals were made by the authors of this work or local authorities. Where possible, size (length between nose and tail), sex, and age class were recorded. The highest concentration of stranded dead CSLs was recorded in Cabo San Lázaro (Isla Magdalena) and Bahía Asunción (Table 1). At least 15 dead CSLs were recorded in the San Benito Archipelago during November 2020; however, due to their advanced degree of decomposition, it was assumed that they were part of the massive mortality event of September 2020.

We obtained normalized fluorescence line height (nFLH) data from the MODIS-Aqua platform with a temporal and spatial resolution of 1 mo (i.e., August and September 2020) and 4 × 4 km, respectively, to define if a HAB occurred in the area during the study period (Hu et al., 2015; Hu & Feng, 2016). These data were obtained from the National Aeronautics and Space Administration (NASA) website (https://oceancolor.gsfc.nasa.gov/l3) and were used to draw a polygon that included the western region of the Baja California peninsula.

From the image of the monthly average for August 2020, nFLH values greater than 0.25 W m^{-2} μm^{-1} sr^{-1} were observed from Punta Eugenia to Laguna San Ignacio, evidencing high primary productivity in the region. In contrast, the image of the monthly average for September 2020 indicated that lower primary productivity was present compared to that of August 2020, with values below 0.25 W m^{-2} μm^{-1} sr^{-1} (Figure 2). Since no phytoplankton samples were taken in the area during these 2 mo, it was not possible to corroborate toxicity linked to these algal blooms. It was only possible to assume that these events took place. However, the average monthly conditions in September 2020 differed from those in the previous month. The notable conditions for August 2020 must have had an effect towards the end of this month and early September.

The sex and age class of the CSLs stranded were similar among sites. In Cabo San Lázaro, the age-class structure was determined with greater precision compared to those of the other sites where only overall counts and photographs were provided by local authorities. Most individuals stranded in Cabo San Lázaro were subadult males (~91%), followed by adult males (~7%) and juveniles (~2%). Subadult and adult male CSLs were identified based on their developed sagittal crests and large necks (although these are less developed in subadult males), their darker pelage, and their larger size (2.0 to 2.5 m for male subadults and 2.4 to 2.6 m for male adults) than adult females or juveniles (Lluch-Belda, 1969; Orr et al., 1970; Elorriaga-Verplancken et al., 2018). No evidence of poor body condition or traces from fishing nets or from any other anthropic interactions were observed that could be related to the UME.

Table 1. Number of dead California sea lions (*Zalophus californianus*) recorded along the western coast of the Baja California peninsula from the end of August to the beginning of September 2020

Site	Number of California sea lions
San Benito	15
Guerrero Negro	2
Bahía Tortugas	2
San Roque-Bahía Asunción	80
Bahía Asunción	123
San Hipólito	5
La Bocana	2
La Bocana-Punta Abreojos	14
Punta Abreojos	7
El Dátil	2
San Juanico	21
Cabo San Lázaro/Isla Magdalena	137
Isla Santa Margarita	37
Total	447

Cabo San Lázaro was the area where most CSLs stranded (137 individuals; Table 1). This site is recognized as one of the areas where more strandings of marine mammals occur throughout the year, both in Mexico and in the U.S. (Mercuri, 2007). Cabo San Lázaro on Isla Magdalena is located within a highly productive temperate-tropical transition zone, which supports a high abundance and diversity of temperate and tropical species (Lluch-Belda, 2000; Lluch-Belda et al., 2003). The coastline of the Gulf of Ulloa and especially of Isla Magdalena promotes the deposition of dead marine animals, particularly CSLs, due to the area's currents and circulation patterns (Mercuri, 2007). It is not known where these animals come from, although they are believed to belong to the closest colony on Santa Margarita Island (~75 km south of Cabo San Lázaro) (Ascencio, 2010). This colony presents an abundance of 1,000 to 1,300 individuals (Pelayo-González et al., 2021a). The unusual stranding of CSLs in 2020 was considered to be an anomaly when compared to the magnitude of previous stranding events in the same location

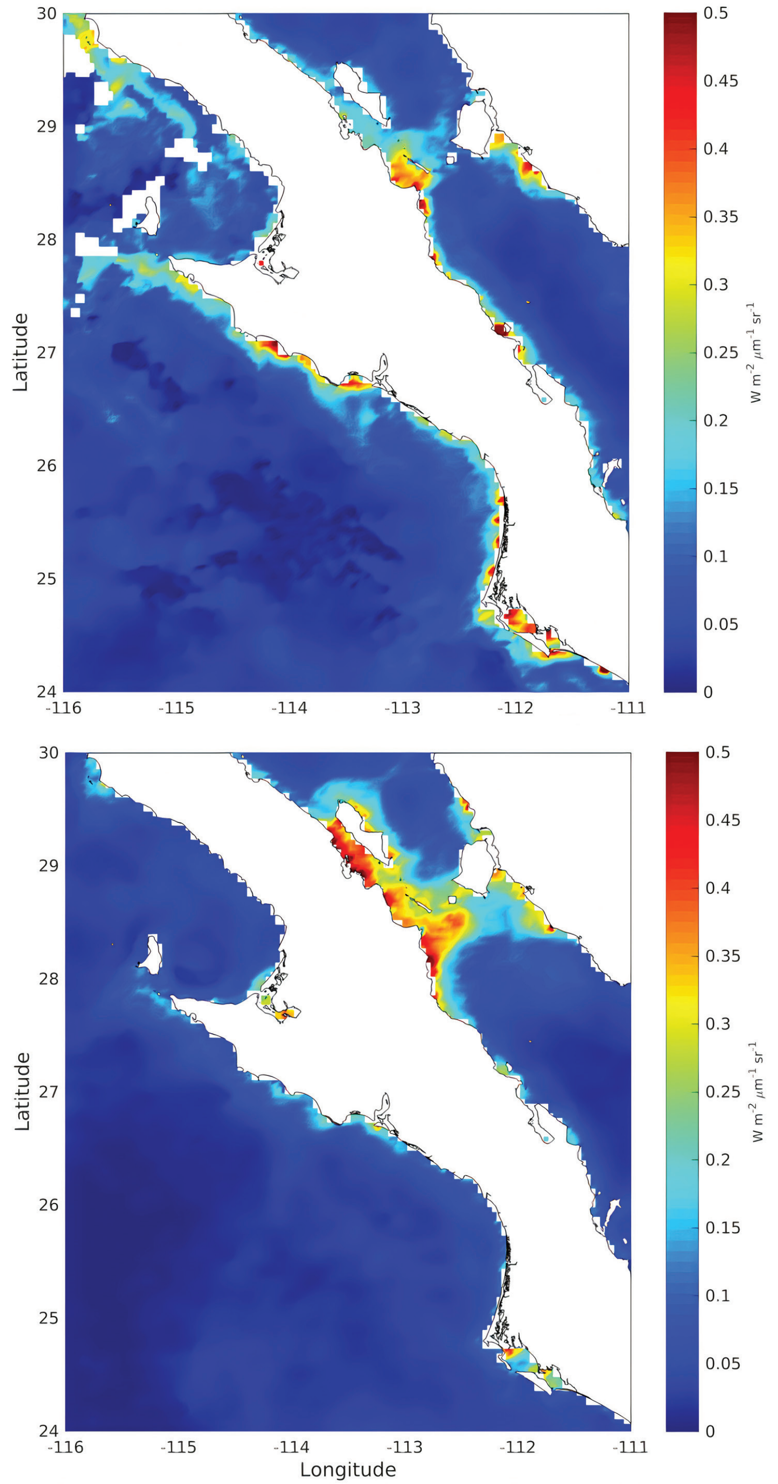

Figure 2. Average monthly values (W m^{-2} µm^{-1} sr^{-1}) for August (upper map) and September (lower map) 2020 (normalized fluorescence line height [nFLH])

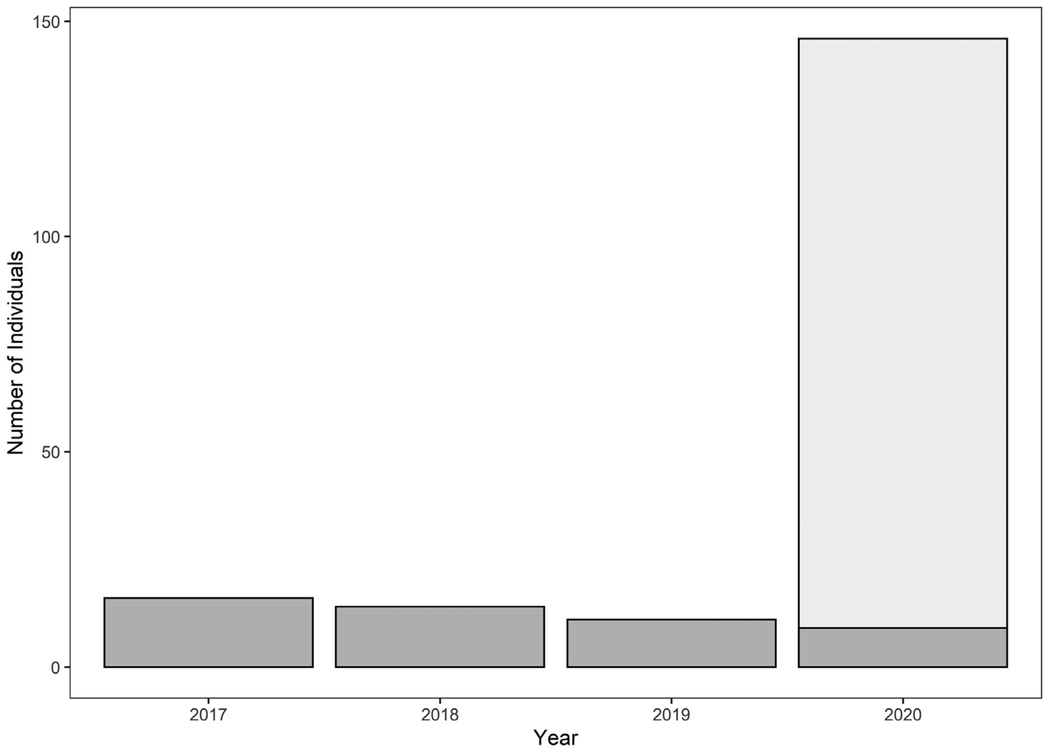

Figure 3. Number of California sea lions stranded per year at Cabo San Lázaro (Isla Magdalena). The column for 2020 is divided between the massive mortality event registered between the end of August and the beginning of September (light gray area) and the total number of strandings before the massive event (gray area).

(Cabo San Lázaro; Figure 3), which has been surveyed annually by one of the co-authors (CJH-C) of this short note.

Although CSLs were the most common species found in the UME, other species were also affected in the region. For instance, based on information provided by local authorities, a high number of dead clams was observed along 10 km of the coast of Cabo San Lázaro, and multiple dead fish and ray species were recorded in Bahía Asunción and in sites to the north of this area around the same dates. In addition, at least ten dead harbor seals were recorded in Bahía Asunción.

Our documentation of the UME of CSLs during August and September 2020 highlighted similarities to previous mortality events that have been linked to domoic acid poisoning from HABs. These reports have also included an unusually high number of dead CSLs and a high degree of synchrony among strandings (e.g., Gulland et al., 2002; Gallo-Reynoso et al., 2005; McCabe et al., 2016). Additional patterns regarding the CSL stranding event of 2020 were also consistent with domoic acid poisoning. Practically all dead CSLs presented a similar degree of advanced decomposition (Figure 4), which may indicate that these individuals fed on similar domoic acid-contaminated items, possibly 10 to 15 d before the end of August and the beginning of September 2020 when they stranded. Additionally, almost all dead individuals were subadult males, which suggests that these animals fed in an area that was mostly used by this age class. In this regard, feeding niche segregation between CSL sex and age classes has been previously documented in Isla Santa Margarita in Bahía Magdalena (Elorriaga-Verplancken et al., 2013). Moreover, this type of segregation has been found between subadult males and adult females from the western region of the Baja California peninsula using stable isotopes, with subadult males showing both a higher trophic position and a wider isotopic niche compared to those of adult females, which suggests that males feed across a larger area (Elorriaga-Verplancken et al., 2018). Nonetheless, we recognize that the region in which the mortality of August and September 2020 was recorded was very wide, covering approximately 4° of latitude (nearly 500 km). Thus, it is possible that an

Figure 4. Stranded dead California sea lions recorded at Cabo San Lázaro (Isla Magdalena) (*Photo credit:* FRE-V)

unknown proportion of CSLs within this massive mortality event may have belonged to other sex and age classes.

Even though almost 450 CSLs were reported dead, this amount is likely underrepresenting the true number of dead animals as it includes only those animals that stranded and were documented. An unknown number of individuals may have died at sea and not reached land, while others may have stranded in inaccessible or uninhabited locations that are common in many areas of the peninsula.

We were unable to collect phytoplankton samples to determine the toxicity of the HAB nor did we manage to collect samples of the dead CSLs given the high degree of decomposition and empty stomachs; however, the timing of the HAB event in relation to the UME makes it likely that this was the cause. We were able to run histopathology analyses on two kidney samples collected from fresh CSL corpses. The kidneys showed degeneration of the renal tubules, moderate congestion, and no evidence of regeneration. While these lesions could be compatible with leptospirosis (Gulland et al., 1996), given that there has never been any reported outbreak of leptospirosis in the CSL populations in Mexican waters and that serological studies have shown significantly lower antibody titers as well as the presence of enzootic *Leptospira* serovars in these animals (Avalos-Téllez et al., 2016), it is unlikely that leptospirosis would be the cause of the UME. Furthermore, this event affected mostly adult and subadult males, and an outbreak of leptospirosis would be expected to affect other sex and age classes (Lloyd-Smith et al., 2007).

Final Remarks

To date, this is the largest CSL mass mortality event ever recorded in Mexico, highlighting the unprecedented impact that HABs could have along the western coast of the Baja California peninsula. The CSL population in this region is already known to be in decline due to warm oceanographic anomalies, such as El Niño events and the Blob, which have negatively impacted their feeding habits, as well as the body condition (Elorriaga-Verplancken et al., 2016) and immune competence of their offspring (Banuet-Martínez et al., 2017). Although it is not possible to determine the causes and intensity of this HAB, there is a connection between these blooms and warming/eutrophication events (Glober, 2020), the frequency of which have increased in recent decades in the Pacific Ocean (Gentemann et al., 2017; Freund et al., 2019). Thus, it is necessary to continue tracking HABs, the frequency with which they occur, their relationships with climate change, and their effects on ecosystems to properly describe potential threats to the CSL population throughout its distribution in the northeastern Pacific. Finally, we acknowledge the importance of collecting fresh samples or stomach contents from these events, when they are available, to form more solid conclusions regarding the causes of death of affected individuals.

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