Office of National Marine Sanctuaries
National Oceanic and Atmospheric Administration

Effects of Land-Based Anthropogenic Noise on Reproductive Success in Harbor Seals (*Phoca vitulina*) in Monterey Bay National Marine Sanctuary

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Monterey Bay National Marine Sanctuary

Technical Report

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Cover Photos:

Top Left: Road work on Ocean View Boulevard adjacent to Hopkins West Beach. Photo: Kim Akeman
Top Right: Harbor seal mother, named Talon, and her pup bonding "nose to nose." Photo: Kim Akeman
Bottom: Hopkins West Beach in 2021. Photo: Kim Akeman

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About the author: Denise Drachenberg graduated with a B.S. in Marine Science and a minor in Statistics from California State University Monterey Bay in 2021. She worked on a capstone with graduate students from Moss Landing Marine Lab and performed laboratory data collection and analysis in R. Denise has conducted field research and analysis in Costa Rica (as a teaching assistant) and collaborative research between UCSC and CSUMB determining urchin densities to further understand kelp-forest urchin barren dynamics. Currently, she is working as an instructor for Catalina Island Marine Institute.

Abstract

The objective of this report is to investigate the impact of land-based noise disturbance on harbor seals in Pacific Grove, California, which is located along the shoreline of Monterey Bay National Marine Sanctuary. The study was carried out using surveys and field observations from the 2021 and 2022 pupping seasons. The review examines the magnitude and frequency of noise sources that the seals are exposed to, including human and animal disturbance, vehicles, and construction. It also examines the behavioral responses to noise, including head alerts, flushing, and avoidance. Results indicate that increased land-based noises caused increased frequency of altered seal behaviors. In addition to this, unique altered behaviors, such as prolonged site abandonment, occurred when construction was present. Furthermore, a statistical model indicates that seals are six times more likely to miscarry when construction is present. In 2021, the pupping success rate was 94% compared to a 67% success rate in 2022. This study suggests that land-based noise disturbance is a possible mechanism contributing to changes in harbor seal behavior and reproductive success. The effects of land-based noise on marine mammals are often overlooked, as research to date has focused on marine-based noise such as sonar and vessels. This report clearly identifies a knowledge gap and recommends areas for future research. Overall, this review highlights the importance of considering the impacts of land-based anthropogenic noise on harbor seals and underscores the need for continued research and management efforts to mitigate the impacts to ensure the success of future harbor seal populations.

Introduction

Harbor seals (*Phoca vitulina)* are semi-aquatic mammals that depend upon the ocean for their food supply yet haul out on rocky shores or sandy beaches, where seals perform many of their most fundamental behaviors (Watts, 1996). This includes giving birth to their pups, and haul out numbers peak during pupping season spanning from February to June (Oxman, 1995; Wursig Bernd, 2017). Despite ecologically valuable areas such as national marine sanctuaries having designated protections, seals are vulnerable to high levels of noise due to their proximity to developed areas (Buxton et al., 2017). Increased anthropogenic disturbance may cause seals to avoid or completely abandon certain sites (Montgomery et al., 2007). The increased noise levels are also known to alter animal foraging behavior, community structure, and reproductive success (Barber et al., 2010).

Although the impacts of noise pollution on terrestrial animals have been well documented, research on marine life is more limited, with most studies focused only on determining the effects of underwater noise created by sonar and vessels (NOAA Fisheries, 2018; Kight & Swaddle, 2011; Kvadsheim et al., 2010). There is a significant gap in knowledge pertaining to the effects of land-based noise on marine mammals. Therefore, examining reproductive success of aquatic mammals due to land-based anthropogenic noise is needed.

Methods

Data Collection

Harbor seal counts, disturbances, and behavior were recorded daily in 2021 and 2022 at Hopkins West Beach (Figure 1). Moreover, during the pupping season spanning from February to June, the same surveys were conducted at two additional rookery beaches: the 5th Street rookery and Fisher Beach Cove. Parameters known to influence haul out behavior such as tide level, weather, and water temperature were also collected. Observers would do “rounds” conducting surveys for 20–30 minutes at each site. At least one survey per day at each site was conducted in the morning and afternoon between the timeframe of 6:30 a.m. and 3:00 p.m.

Behaviors

Behavior was summarized in the following six categories: “head alert,” “beach flush,” “water flush,” “active avoidance,” and “passive avoidance.” No indication of behavioral change was recorded as “none.” A head alert is a behavior that is evident as seals quickly turn in the direction of the sound source. This jerking motion often occurs when resting seals are woken up from loud, abrupt sounds. Flushing on the beach occurs when a noise is startling enough for seals to rapidly move down the beach. Typically the seals flush to the edge of the water moving a total of approximately 15 meters. Distance may vary depending on where the seal is originally positioned. If this noise is constant, the seals may flush into water. Avoidance is a behavior that is documented when the seals are actively in the water, but not coming onto the beach. During periods of disturbance, seals might come onto the far side of the beach, choosing to avoid the areas closest to the sound source. This led to seals being crammed together at the edge of a site near rocks—a clear deviation from regular behavior, which was therefore included as active avoidance. Passive avoidance indicates that seals do not return to a site. This occurred during

intermittent noise emitted during construction events ranging from two to eight hours. It is important to distinguish between disturbance behaviors because they vary in severity and energy use by the seals.

Disturbance

Disturbance sources were binned into four categories: human, animal, vehicle, and construction. Human disturbances were recorded when they caused disturbance-associated behaviors. Human disturbance includes people speaking loudly, laughing, or clapping at the fence line close to the recreation trail in Pacific Grove. People have also been recorded jumping the fence, or coming close to the seals when scuba diving, boating, kayaking, or paddle boarding, which are also included under "human" disturbance. "Animal" disturbances include deer, birds, and rodents that come onto the beach. Dogs barking at the fence may also cause disturbance behaviors such as flushing. Vehicle disturbance includes cars and motorcycles revving their engines, in addition to planes, drones, blimps, and helicopters flying low over the rookeries. Other vehicle disturbances documented include noise from trucks, sirens, and boats. Lastly, "construction" includes the noise emitted from nailing, jackhammering, and bulldozers. These noises were documented during rooftop construction work and road maintenance work along Ocean View Boulevard, and construction activities taking place at the Monterey Bay Aquarium. Constant construction noise was documented as one observation. However, most of the construction noise documented was intermittent, resulting in multiple behavioral observations per day.

Miscarriages

Miscarriages were documented when obvious indicators such as placentas or fetuses were observed. In special cases where it was uncertain what happened to a pup, the "disappearance" was not counted as a miscarriage. Some non-miscarriage population losses may occur in rare instances where pups are still born or when pups are abandoned by their mothers. Births were not deemed successful until the pups reached the weaning stage.

Study Sites

The city of Pacific Grove within the Monterey Bay offers several beaches that harbor seals inhabit. Fisher Beach and 5th Street rookery are both pupping beaches for breeding harbor seals. Hopkins West Beach is a year-round haul out site in addition to being a rookery. Hopkins West, Fisher, and 5th Street beaches are referred to as HPW, F, and 5, respectively. They are close to each other, with the distance of Fisher Beach to 5th Street being 0.3 miles. Due to the varying geography of the three sites, each is subjected to unique disturbances that alter harbor seal behavior. For instance, Fisher Beach is not visible from the road and therefore is less impacted by human intrusion, whereas Hopkins West Beach is visible from the recreation trail, and is more accessible despite the chain link fence. Most of the documented construction occurred on Ocean View Boulevard (Figure 1).

Figure 1. Map of harbor seal pupping beaches in Pacific Grove, California. Fisher Beach, Hopkins West Beach, and 5th Street rookery. Most of the documented construction occurred on Ocean View Boulevard which is highlighted in blue.

Results

During pupping season in 2022, 29 miscarriages were observed, compared to three miscarriages in the prior year. In 2021, the birthing success rate was 94% compared to a 67% success rate in 2022 (Figure 2).

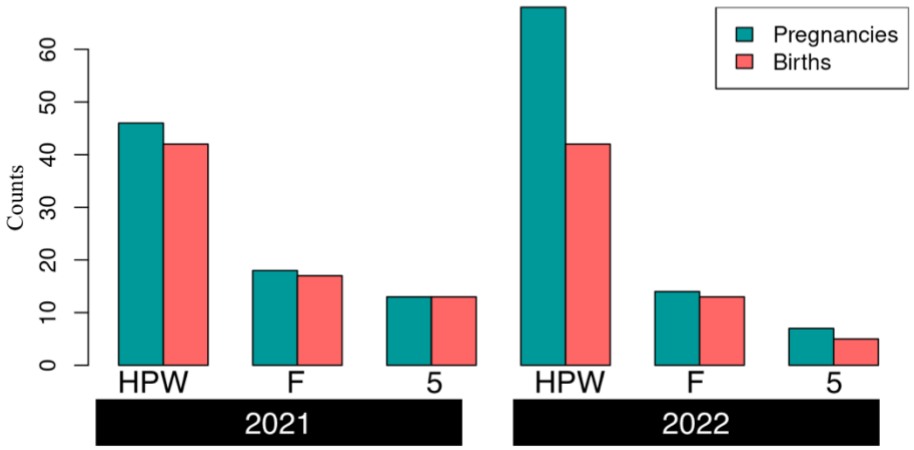

Figure 2. Number of pregnancies and successful births by site and year. Hopkins West Beach, Fisher Beach, and 5th Street rookery are referred to as HPW, F, and 5 respectively.

Considering the contrast miscarriage by year, the author chose to summarize miscarriages by total monthly averages to gain a better overview of the pupping season. The ANOVA (Table 1) reveals that monthly miscarriages differed significantly by site (p-value < 0.05). The interaction was also significant, meaning that the variation in monthly miscarriages is a combination between sites and years.

Table 1. Analysis of Variance Table: Total monthly miscarriages by year and site are statistically significant.

Response: Monthly Miscarriages	**Df**	**Sum sq**	**Mean sq**	**F value**	**Pr(>F)**
Year	1	20.19	20.118	4.082	0.0557
Site	2	46.19	23.093	4.670	**0.0204**
Year*Site	2	34.25	17.127	3.463	**0.0492**
Residuals	22	108.80	4.945		

Differences in true mean monthly miscarriages by year and site were detected. To find which year and sites were significant, a Post Hoc analysis was conducted. Hopkins West Beach had more miscarriages than the other sites (Figure 3). Table 2 shows which of the sites and year produced monthly miscarriages that were significantly different from the rest.

```
  Tukey multiple comparisons of means
    95% family-wise confidence level

Fit: aov(formula = total ~ Year * Site, data = misc_month_tot)

$Year
              diff         lwr      upr     p adj
2022-2021 1.702564 -0.04505571 3.450184 0.0556805

$Site
           diff        lwr      upr     p adj
F-5   0.1628205 -2.4870516 2.812693 0.9869590
HPW-5 2.7628205  0.1129484 5.412693 0.0399557
HPW-F 2.6000000  0.1016766 5.098323 0.0403666

$`Year:Site`
                          diff        lwr       upr     p adj
2022:5-2021:5      4.000000e-01 -4.6591742  5.459174 0.9998569
2021:F-2021:5      2.000000e-01 -4.8591742  5.259174 0.9999954
2022:F-2021:5      2.000000e-01 -4.8591742  5.259174 0.9999954
2021:HPW-2021:5    4.000000e-01 -4.6591742  5.459174 0.9998569
2022:HPW-2021:5    5.200000e+00  0.1408258 10.259174 0.0416088
2021:F-2022:5     -2.000000e-01 -4.5813734  4.181373 0.9999906
2022:F-2022:5     -2.000000e-01 -4.5813734  4.181373 0.9999906
2021:HPW-2022:5   -1.776357e-15 -4.3813734  4.381373 1.0000000
2022:HPW-2022:5    4.800000e+00  0.4186266  9.181373 0.0263363
2022:F-2021:F      1.526557e-15 -4.3813734  4.381373 1.0000000
2021:HPW-2021:F    2.000000e-01 -4.1813734  4.581373 0.9999906
2022:HPW-2021:F    5.000000e+00  0.6186266  9.381373 0.0192100
2021:HPW-2022:F    2.000000e-01 -4.1813734  4.581373 0.9999906
2022:HPW-2022:F    5.000000e+00  0.6186266  9.381373 0.0192100
2022:HPW-2021:HPW  4.800000e+00  0.4186266  9.181373 0.0263363
```

Table 2. Tukey multiple comparisons of means: 95% family-wise confidence level. Statistically significant at P<(0.05). Table 2 is visualized as a box plot in Figure 3.

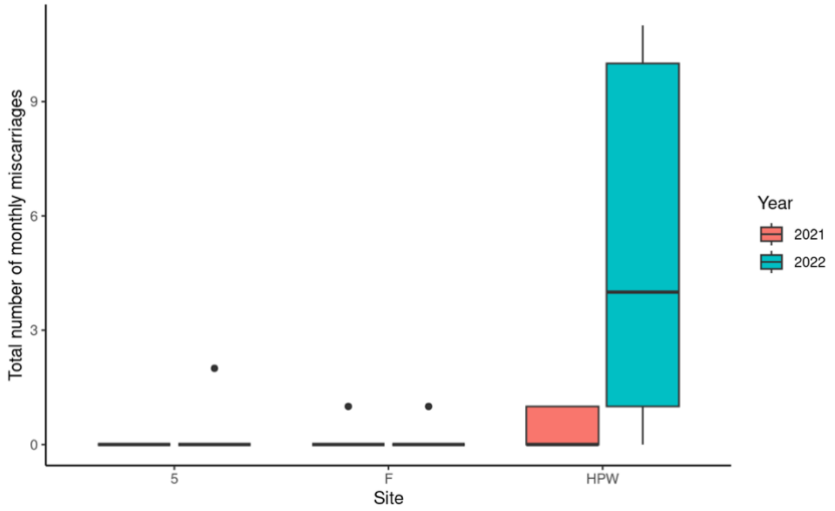

Figure 3. Box plot of monthly miscarriages by sites: 5th Street, Fisher, and Hopkins in 2021 and 2022.

There were more miscarriages in 2022 compared in 2021 on Hopkins West Beach. For both years, Hopkins had more monthly miscarriages than both Fisher and 5th Street, which were not significantly different from each other. The high number of miscarriages at Hopkins West Beach can be attributed to its large population, as seen in Figure 4. The low rates of miscarriage at 5th Street beaches are understandable due to seals abandoning the site (see Discussion for details). Notably, Fisher Beach has a low miscarriage rate despite its sizable population. Given the low miscarriage rate and sizable population at Fisher Beach, which is farthest from disturbances, and the high miscarriage rate at Hopkins West Beach, which is closest to disturbances, it is likely that disturbance played a significant role. Therefore, investigating disturbance as a possible mechanism is warranted.

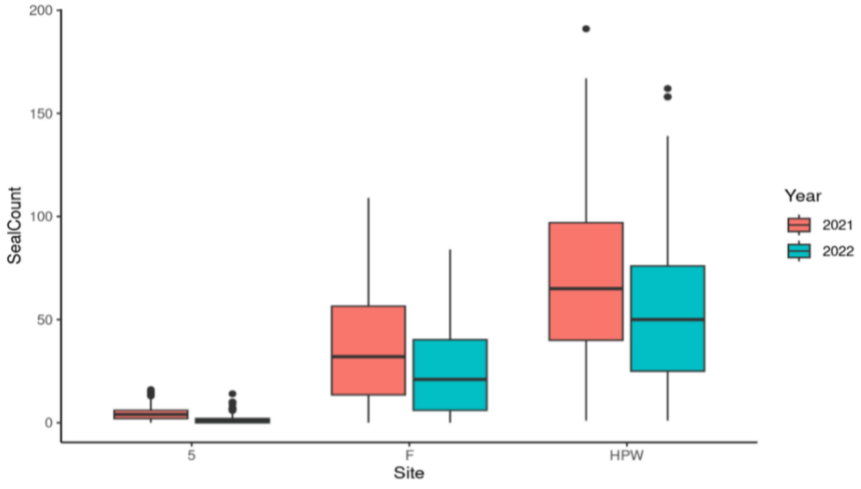

Figure 4. Box plot of harbor seal count by sites: 5th Street, Fisher, and Hopkins in 2021 and 2022.

An analysis of disturbance and disturbance related behaviors is crucial, as these incidents can drive changes in behavior, which increases stress levels and have profound effects on reproductive success (Ditchkoff et al., 2006). Overall disturbance counts increased in 2022, particularly construction related disturbances which are associated with altered behaviors (Figure 5).

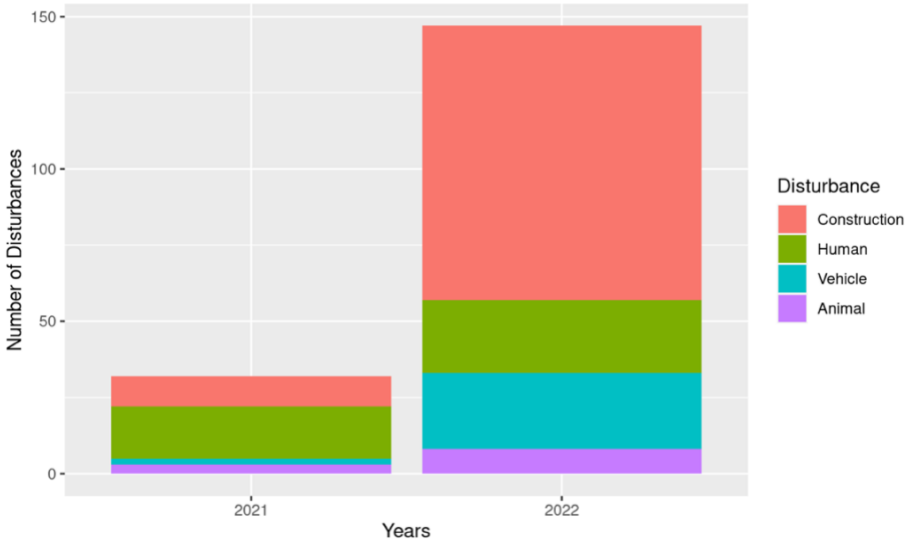

Figure 5. Number of construction, human, vehicle, and animal disturbances in 2021 and 2022.

Most of the construction disturbance counts in 2022 can be attributed to an eight-week period of road work conducted on Ocean View Boulevard spanning from mid-February to mid-April (Figure 5). To determine if miscarriages were significantly different during that time, three eight-week periods—before, during, and after road work—were binned (Figure 6). An ANOVA and post hoc analysis (Table 3) reveals that miscarriages were significantly higher during the period in which road work took place (p-value < 0.05). Also note, the before and after periods are not significantly different from each other.

Table 3. Tukey multiple comparisons of means: 95% family-wise confidence level.

Event	Diff	Lwr	Upr	P adj
Before - After	-0.00478	-0.0529	0.04338	0.97052
During - After	0.04366	0.01177	0.07556	**0.00387**
During - Before	0.04844	0.0009	0.09608	**0.04462**

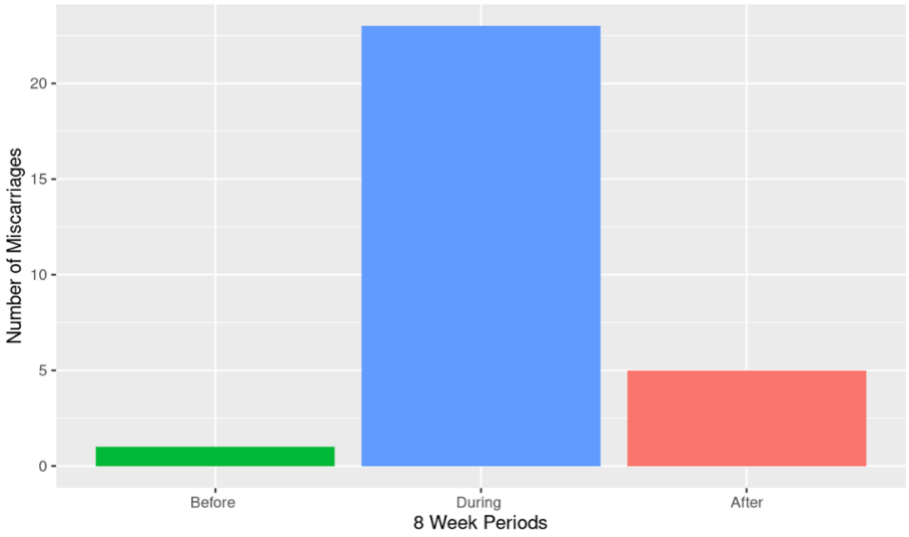

Figure 6. Miscarriage counts during each 8-week period before, during, and after road work on Ocean View Boulevard, Pacific Grove, California.

During the 2022 pupping season, construction accounts for the highest amount of disturbance, also producing unique altered behaviors (Figure 7). Active avoidance, one of the most energy intensive behaviors, occurs more frequently during construction. Head alerts and water flushing occur across all disturbance types. However, passive avoidance was unique to construction, which indicates that seals did not return to a site due to prolonged periods of disturbance.

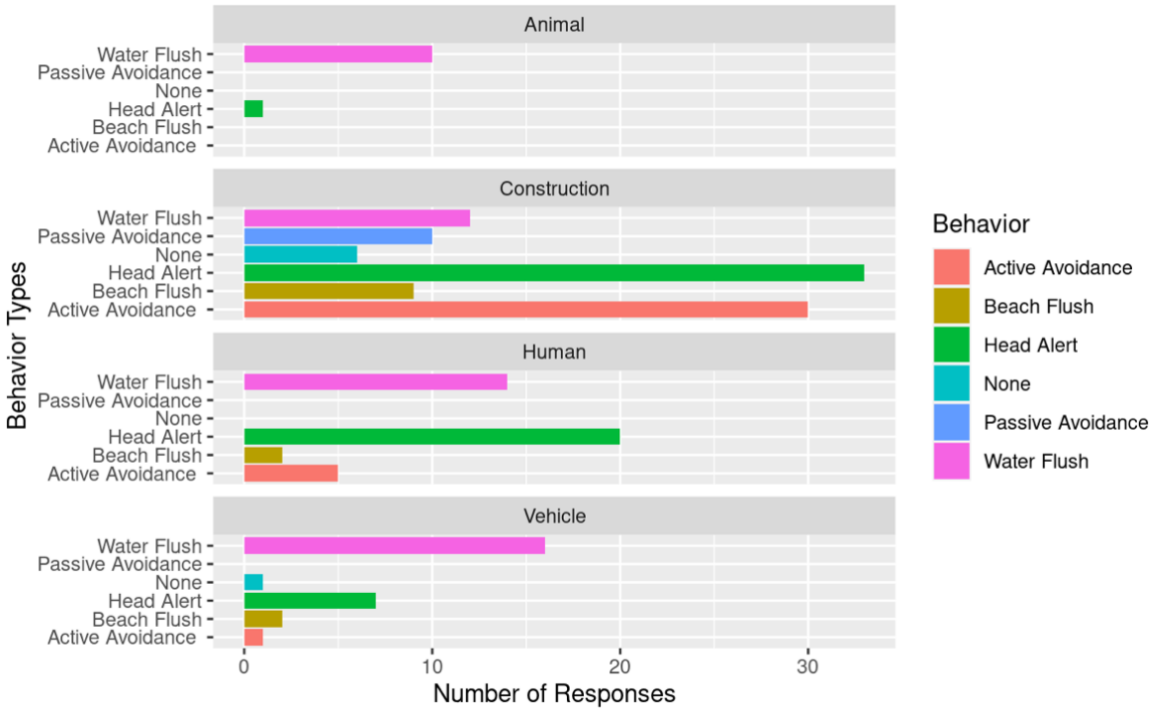

Figure 7. Behaviors resulting from each disturbance and how many times they occurred during 2021 and 2022 pupping seasons.

Disturbance is not the only variable that can affect miscarriage rates. Physical conditions and biological fitness can as well. Fitness was not tested statistically, but expert assessments and evaluations of nursing behaviors suggested comparable fitness in both years (see Discussion for details). To account for other factors that may alter behavior, such as tidal patterns, a statistical model was conducted. A Generalized Additive Model (GAM) was chosen because it is flexible, providing a good fit for linear and nonlinear relationships. The output will show an Akaike Information Criterion (AIC) and will evaluate how well a model fits the data it was generated from. The best-fit model according to AIC is the one that explains the greatest amount of variation is miscarriages using the fewest possible variables. The AIC weight (AICw) shows the amount of predictive power that model accounts for. The best-fitting model for these data (Table 4) includes disturbance, year, site, behavior, tide, and time–which account for 85% of variation in miscarriages (AICw= 8.5e-01).

	K <dbl>	AIC <dbl>	AICc <dbl>	delAIC <dbl>	AICw <dbl>
dysbtidetime.gam	15	262.5578	262.9493	0.000000	8.486562e-01
dysbtide.gam	14	266.0985	266.4408	3.491414	1.481088e-01
dystide.gam	9	274.0521	274.1982	11.248866	3.062469e-03
dysb.gam	13	281.5283	281.8247	18.875382	6.760747e-05
ysbtidetime.gam	11	281.6786	281.8932	18.943885	6.533103e-05
ystide.gam	5	284.3270	284.3755	21.426164	1.888424e-05
ysbtide.gam	10	285.5215	285.7002	22.750882	9.737347e-06
dystime.gam	9	286.4676	286.6137	23.664391	6.167008e-06
dytide.gam	7	288.1624	288.2532	25.303853	2.716876e-06
dys.gam	8	288.7059	288.8227	25.873335	2.043659e-06

Table 4. The top ten GAM models with the lowest AIC values.

Because disturbance was included in most of the models with the lowest AIC, another model was conducted containing only disturbance, revealing which disturbances were significant. According to this model, construction is a significant disturbance impacting miscarriages. The results indicate that harbor seals are six times more likely to miscarry when construction is introduced.

```
Formula:
Miscarriage ~ Disturbance

Parametric coefficients:
                         Estimate Std. Error z value Pr(>|z|)
(Intercept)               -3.8334     0.2085 -18.384  < 2e-16 ***
DisturbanceConstruction    1.7931     0.3470   5.168 2.37e-07 ***
DisturbanceHuman         -13.5884   574.8448  -0.024    0.981
DisturbanceVehicle       -13.5884   708.3708  -0.019    0.985
DisturbanceAnimal        -13.5884  1109.8038  -0.012    0.990
```

Table 5. R output for disturbance model indicate that construction is a significant disturbance impacting miscarriages.

Discussion and Conclusions

Factors Associated with Miscarriage Variability

Disturbance, year, site, behavior, tide, and time play a role in the variation in miscarriages. The number of miscarriages in 2022 (29) was significantly higher than the previous year (3), explaining the reason the best GAM model includes "year" as a factor. The inclusion of "disturbance" and "behavior" in the best model explains that not only the disturbance but also the resulting seal behaviors are important factors relating to an increased incidence of miscarriages. The frequency of altered behaviors rose during increased disturbance, suggesting that the seals did not become accustomed to the disturbance over time. Because these altered behaviors resulting from disturbance may be correlated, it is necessary to review the model inputs to ensure avoidance of multicollinearity.

The identification of "site" as a significant factor in the model may be explained by most miscarriages occurring at Hopkins. Note that the majority also occurred during an eight-week period of high noise disturbance from road work. 5th Street rookery was closest to the noise, and therefore largely uninhabited during this eight-week period. The mothers that gave birth at 5th Street in 2022 had left the site shortly after birthing, in some cases within minutes. In one instance, a mother had come onto 5th Street and flushed into the water during a noise disturbance, giving birth in the open ocean, which is an unusual behavior (K. Akeman RVT, observation, March 2022). Despite the seemingly low seal population at 5th Street compared to the other sites in 2021, 13 births occurred with 100% success rate. In contrast, to the 13 births in 2021, there were only five births at 5th Street in 2022.

To help explain this further, the individual seals are recognized and tracked through a Photo Identification System started in 2011 (ref: Kim Akeman, 2022 Harbor Seals of the Pacific Grove Colony). Female harbor seals are beach specific for birthing. In 2020, 13 harbor seals were identified and gave birth at 5th Street beaches, all successfully. In 2021, the same 13 females returned to the 5th Street beaches, and again successfully gave birth. In 2022, seven of the 13 seals attempted to give birth in the 5th Street area. The first two attempted during the road construction and both miscarried. Five successful births all occurred after the construction, and subsequently, all of the females moved their pups to other beaches within their first few hours. Some of the other seals that typically use the 5th Street rookery were seen approaching the beach during construction and turning away to go elsewhere.

Harbor seals have a series of natural responses to disturbances. Flushing involves quickly retreating into the water, providing them with immediate relief, and they resume resting after the disturbance has passed. However, the frequent occurrence of head alerts suggest that the seals were in a constant state of alert, potentially resulting in heightened stress. Higher frequencies of active avoidance were also observed in 2022. This is one of the most energy-intensive behaviors as it involves flushing into the water and treading for extended periods of time to assess the disturbance on the beach. When disturbances persist, seals may abandon the site for prolonged periods ranging from days to the entire pupping season; this is classified as passive avoidance. This behavior was uniquely observed during construction activities. It is interesting to note that during periods of storm activity or intense wind, the noise was "drowned

out," rendering it inaudible to the seals (K. Akeman RVT, observation, April 2022). Periods of no altered behavior during construction shown on Figure 7 represented such conditions..

Other factors such as diet and nutrition play a role in reproductive success. Observations of harbor seals during both pupping seasons indicated that they were in good health, with noticeable weight gain (K. Akeman RVT, observation, February 2022). These observations suggest that the miscarriages in 2022 were unlikely to have been caused by food scarcity, as the seals were able to put on and maintain weight. Furthermore, it is important to note that the typical nursing period for harbor seals in this population ranges from three to six weeks (K. Akeman RVT, personal communication, March 25, 2023). In years when food is scarce, emaciated seals have been observed giving birth and nursing for only two weeks, suggesting poor maternal health and malnutrition. However, during the 2022 pupping season, harbor seal mothers were observed nursing for the full six weeks, indicating a healthy lactation period.

Recommendations for Continued Research

Due to the large seal population and proximity to anthropogenic disturbances, Hopkins West Beach yielded more data than both Fisher and 5th Street. To verify that altered behavior is caused by disturbance, synchronized, standardized (e.g., 20-minute) daily surveys at all three beaches over a specific period (e.g., two weeks) are recommended.

Collaborating with researchers from California State University, Monterey Bay, and Stanford University would enhance the study. Professors Alison Haupt and Ryan James O'Connor, respectively, could contribute statistical guidance and data on fish stock trends and climate anomalies, allowing a more holistic understanding of harbor seal population changes over time.

A marine heatwave known as the "blob" occurred from 2014 to 2017 off the West Coast marine ecosystem. It impacted forage species and food availability during this period, triggering malnutrition for many species, including harbor seals. Observers noted a 50% decline in adults at the seal colony (from Fisherman's Wharf to Pebble Beach; K. Akeman RVT, personal communication, April 3, 2023) during these years.

Figures 8 and 9 show an apparent correlation between fish stocks and harbor seal counts over the last two decades. Seal data are provided by Pearse et al. (2022), and fish stock data are derived from species distribution models of Muhling et al. (2019). This relationship should be further explored, in conjunction with disturbance data, to understand the combined effects of fitness changes and disturbance on harbor seal reproductive success.

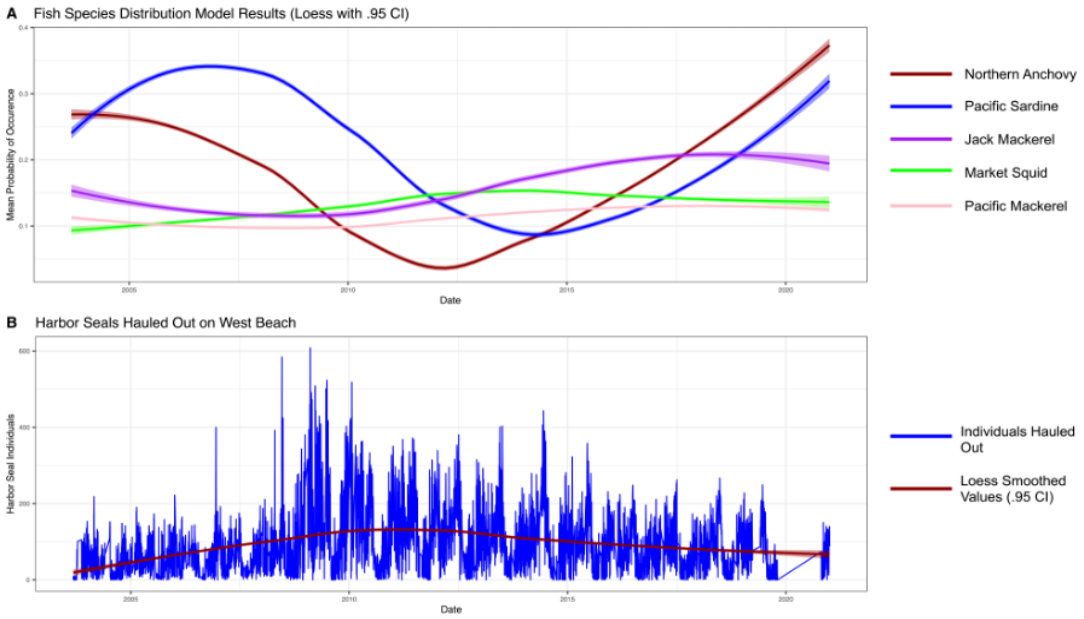

Figure 8. (A) Time series of forage fish probability of occurrence as calculated by boosted regression trees from Muhling et al. (2019) and the NOAA ERDDAP dataset for Northern Anchovy, Pacific Sardine, Market Squid, Jack Mackerel, and Pacific Mackerel. Time series are smoothed using the Loess method to accommodate day-to-day variability and to better visualize trends. Shaded areas around the respective lines indicate the 95% confidence interval of the Loess smoothing. (B) Time series of harbor seal individuals hauled out on Hopkins West Beach. The blue line represents counts of individuals. The red line represents a Loess smoothing of counts of individuals with a 95% confidence interval in shaded red.

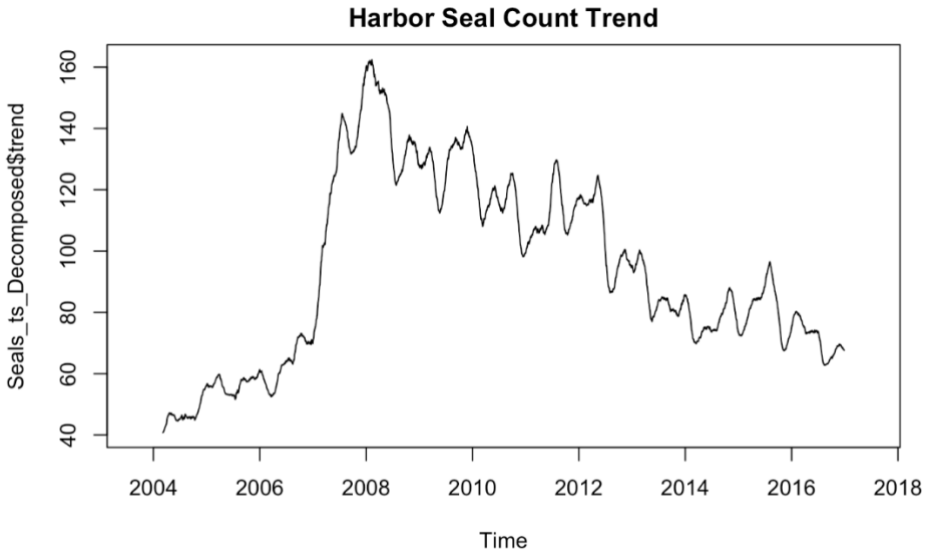

Figure 9. The trend of observed harbor seals at Hopkins West Beach. These values are generated by subtracting random and seasonal variability from observed values.

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