Synergistic Data Source Approach to Studying Keystone Marine Predators

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November 23, 2022

Abstract

The synergistic use of large datasets from cabled array sensors and remote sensing satellites is vastly under used for studying marine mammals. An important element of assessing long standing shifts in biodiversity within marine environments is to understand the relationship between physical and biological oceanographic variables and the occurrence of these keystone predators. The study area for this project is the California Current Ecosystem, a dynamic and productive coastal and offshore marine ecosystem within the Pacific Northwest region of the United States. This complex environment is influenced by the southward flowing California Current, seasonal changes in wind intensity, and a narrow continental shelf paired with a steep continental slope. A series of long-term, continuous data are collected by the Ocean Observatories Initiative (OOI) and includes physical and biological sensors from fixed and mobile sensors, as well as passive acoustic data from broadband hydrophones. We analyzed recordings collected during 2017 from three recorders located on the shelf (~80 m), slope (~580 m), and from a 200 m platform located above the base of the slope. Detections of sperm whales, delphinid species, humpback whales and fin whales suggest the region is a productive habitat. We combined acoustic derived marine mammal observations with information from the OOI sensors and remotely sensed chlorophyll data to describe ecosystem characteristics and explore indirect measures of prey availability. Our findings provide insight into regional biodiversity and associated physical and biological characteristics in a dynamic region of the northwest Pacific Ocean.

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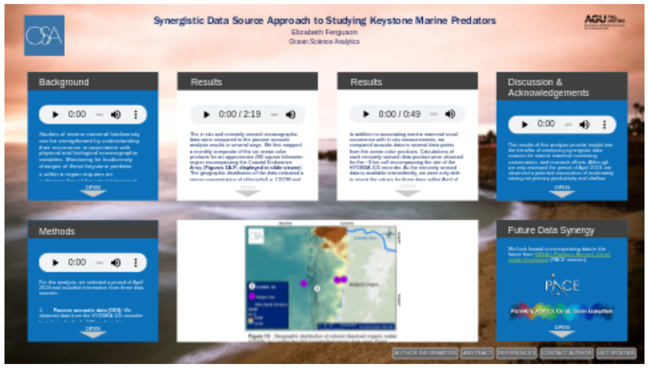

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Ocean Science Analytics

AGU FALL MEETING
New Orleans, LA & Online Everywhere
13–17 December 2021

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BACKGROUND

Studies of marine mammal biodiversity can be strengthened by understanding their occurrence in association with physical and biological oceanographic variables. Monitoring for biodiversity changes of these keystone predator

s within a region requires an understanding of the natural temporal and spatial distribution of these animals. Small and large-scale analyses and a combination of in situ and remotely sensed data is a logical approach to serve this informational need. We employ this strategy for the Coastal and Offshore Oregon Marine Mammal Ecological Study which is situated in the California Current Ecosystem. The Ocean Observatories Initiative (https://oceanobservatories.org/) (OOI) maintains the Coastal Endurance Array, a series of coastal and offshore monitoring platforms off Newport, Oregon that include cabled sensors and gliders (Trowbridge et al., 2019). This cross-platform study uses a combination of acoustic derived marine mammal observations from in situ hydrophones, physical oceanographic data from co-located OOI sensors, and remotely sensed data. Our findings provide insight into the regional marine mammal biodiversity and associated physical and biological characteristics of a dynamic region of the northwest Pacific Ocean.

RESULTS

The in situ and remotely sensed oceanographic data were compared to the passive acoustic analysis results in several ways. We first mapped a monthly composite of the six ocean color products for an approximate 200 square kilometer region encompassing the Coastal Endurance Array (**Figures 1A-F; displayed in slide viewer**). The geographic distribution of the data indicated a strong concentration of chlorophyll-a, CDOM and phytoplankton carbon biomass in the northern portion of the study area just off the Columbia River. Despite an immediate reduction in the chlorophyll-a and CDOM values beyond the Columbia River plume, net primary productivity persisted off the coast and in association with patches of moderately warmer waters. Sea surface temperatures were warmer in the southern region of the study area by several degrees which overlapped with the recorder location along the slope. The mixed later depth was much shallower off the Columbia River and following the slope as compared to values closer to shore and within offshore regions.

We detected several species of marine mammals regularly within the month of April 2018 including delphinid species that could not be classified to species, fin whales (*Balaenoptera physalus*), humpback whales (*Megaptera novaeangliae*) and sperm whales (*Physeter macrocephalus*)(**Figure 2**). The data were summarized as daily percent of vocalizations from each of the species in the four panels. Corresponding physical oceanographic data are found in the bottom portion of this figure. We see varying levels of each variable, with sea water temperature fluctuating within one degree Celsius during the month, partial pressure of CO_2 and dissolved oxygen increasing slightly towards the end of the month, and salinity displaying negligeable fluctuations (**Figure 2**).

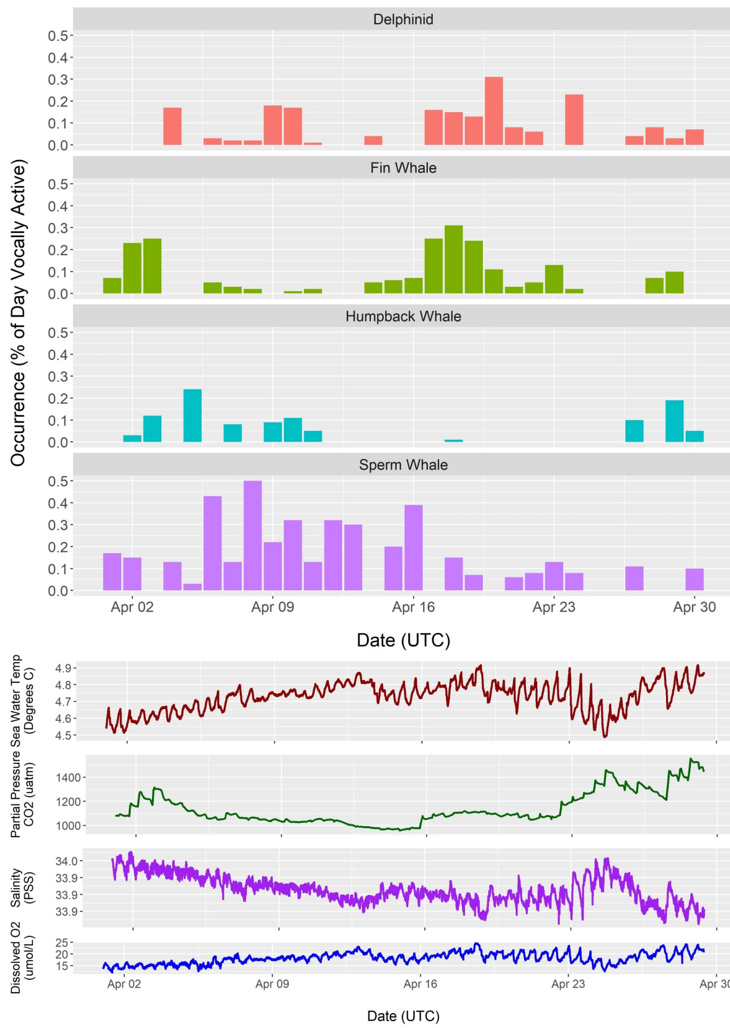
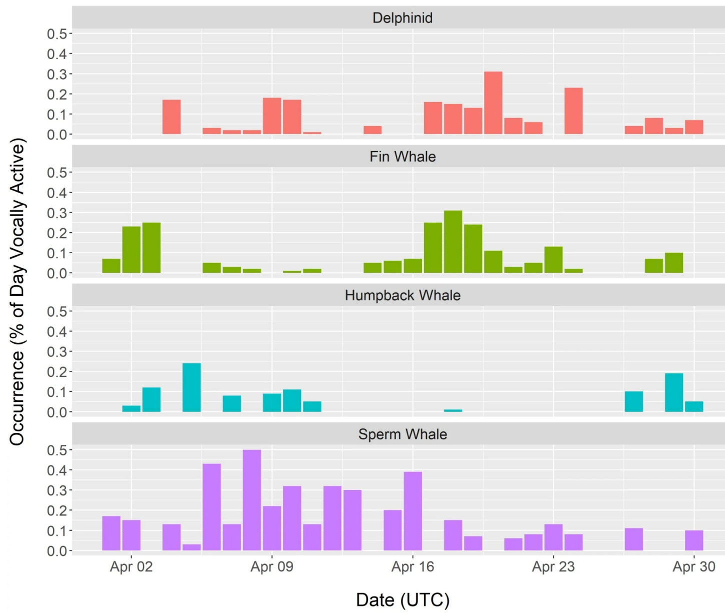


Figure 2: Distribution of marine mammal vocalizations pared with in situ oceanographic data co-located with the hydrophone from the month of April 2018. The top panels indicate the percentage of data containing vocal activity from each of four species/species group: delphinid species we could not classify to species (top panel), fin whales (*Balaenoptera physalus;* second panel), humpback whales (*Megaptera novaeangliae*; third panel) and sperm whales (*Physeter macrocephalus*; fourth panel). The bottom portion of this figure represents the time series for oceanographic data collected by in-situ OOI sensors.

RESULTS

In addition to associating marine mammal vocal occurrence with in situ measurements, we compared acoustic data to several data points from the ocean color products. Calculations of each remotely sensed data product were obtained for the ~9 km cell encompassing the site of the HYDBBA 105 recorder. As the remotely sensed data is available intermittently, we were only able to report the values for three days within April of 2018. **Figure 3** indicates the same distribution of marine mammal vocal occurrence as in Figure 2, with the bottom portion representing measures of chlorophyll-a, mixed layer depth and net primary productivity from ocean color data.



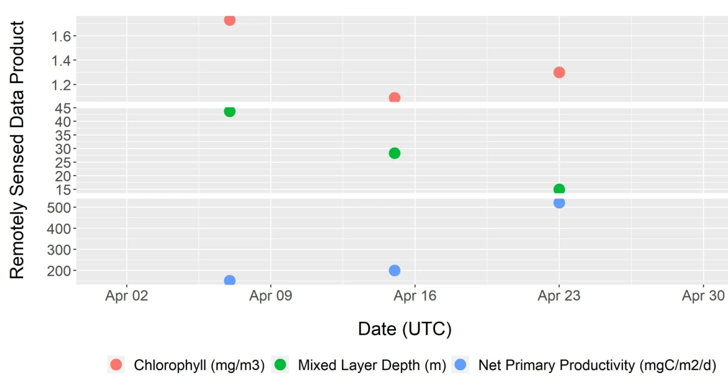


Figure 3: Distribution of marine mammal vocalizations pared with in situ oceanographic data co-located with the hydrophone from the month of April 2018. The top panels indicate the percentage of data containing vocal activity from each of four species/species group: delphinid species we could not classify to species (top panel), fin whales (*Balaenoptera physalus;* second panel), humpback whales (*Megaptera novaeangliae*; third panel) and sperm whales (*Physeter macrocephalus*; fourth panel). The bottom portion of this figure represents the time series for several 8-day remotely calculated values within the 10 km cell overlapping the HYDBBA 105 recorder. Plotted values include chlorophyll-a, mixed layer depth and net primary productivity.

DISCUSSION & ACKNOWLEDGEMENTS

The results of this analysis provide insight into the benefits of combining synergistic data sources for marine mammal monitoring, conservation, and research efforts. Although we only reviewed the period of April 2018, we observed a potential association of moderately strong net primary productivity and shallow mixed layer depth with a diverse assemblage of marine mammals. Comparatively, preliminary results from other recorders indicate delphinids are the most prevalent marine mammal at the shelf recorder site, and there is dramatically less vocal activity, but comparable diversity at the base of the slope. We did not observe any obvious trends in the association of marine mammal vocal activity and in situ data, but this is likely due to the small dataset and short temporal resolution. Analysis of a larger temporal scale are expected to elucidate patterns in these data. We plan to apply this approach to the remainder of the 2018 dataset, and statistically evaluate both seasonal and spatial (shelf/slope) variability.

As keystone predators, marine mammals serve as an indicator of ecosystem health. Monitoring changes in their regional biodiversity is an essential component to assessing large scale ecosystem changes. We argue that a comprehensive analysis of the biological and physical variables combined with continuous collection of marine mammal acoustic observations is a beneficial method of long-term monitoring of this region of the California Current Ecosystem.

We would like to acknowledge Dr. Toby Westberry for sharing his expertise in ocean color data and the contribution of remotely sensed data products to this analysis. We would also like to thank the many individuals involved in the NSF Funded Ocean Observatories Initiative (https://oceanobservatories.org/) for not only collecting this long-term data but supporting our requests for information and assistance. We are also grateful for NASA's Ocean Biology Processing Group (https://oceancolor.gsfc.nasa.gov/about/) for curating ocean color products. Finally, we are grateful for our Early Adopter partnership (https://pace.oceansciences.org/app_adopters.htm#:~:text=PACE%20Early%20Adopters%20are%20groups,aerosol%2C%20cloud%20or%20polarimetry%20data%3B&text with NASA's PACE mission and the associated mentorship with Dr. Westberry.

METHODS

For this analysis, we selected a period of April 2018 and included information from three data sources:

1. **Passive acoustic data (OOI):** We obtained data from the HYDBBA 105 recorder found at a depth of ~580 m along the continental slope from the OOI raw server (NSF Ocean Observatories Initiative Data Portal, 2019). After extracting compressed audio (.wav) files we processed data using a combination of parameterized auto-detectors in the program PAMGuard (version 2.01.05; Gillespie et al., 2009). Data were collected at a sampling rate of 64 kHz which provided 32 kHz of monitoring bandwidth. This allowed for detection of several species of baleen whales and odontocetes. Subsequently, an expert bioacoustician review detections and annotated acoustic events (periods of single species bouts), identifying vocalization to the species or species group level. Data were summarized into percent vocal activity per day to compare to oceanographic variables.

2. **In situ physical oceanographic data (OOI):** We downloaded physical oceanographic data from the OOI Data Explorer by querying the period of April 2018 for the Oregon Offshore Cabled Benthic Experiment Package (NSF Ocean Observatories Initiative Data Portal, 2021). Physical data included sea water temperature (°C), partial pressure of carbon dioxide (μatm), salinity (PSS), and dissolved oxygen (μmol/L). We qualitatively compared data at the source of the received signal (not necessarily the position of the animals as they could be within 0-20 kilometer (km) distance from the fixed sensor).

3. **Remotely sensed data**: Six data products were used to explore the geographic distribution of oceanographic data within region. Data from MODIS Level 3 and consisted of a ~9 km spatial resolution and a weekly (8-day) temporal resolution (NASA Goddard Space Flight Center, Ocean Ecology Laboratory, Ocean Biology Processing Group; 2014). We qualitatively compared data to the occurrence of vocally active marine mammals. The following ocean color and related properties were incorporated in this analysis:

· Phytoplankton carbon biomass (mgC/m^3) as calculated from the particulate backscattering coefficient obtainable from ocean color sensors (Graff et al., 2015)

· Chlorophyll-a concentration (mg/m^3) measured using the default MODIS-Aqua algorithm.

· Color dissolved organic matter (CDOM; m^{-1}; 443 nm) as estimated by Werdell et al. (2013).

· Mixed layer depth (m)

· Sea Surface Temperature (SST; °C)

· Net primary productivity (mgC/m^2/d) calculated using the Carbon, Absorption, and Fluorescence Euphotic-resolving (CAFÉ) model. This productivity model estimates phytoplankton growth rates (μ) and net phytoplankton production as calculated from ocean color measurements (Silsbe et al., 2016).

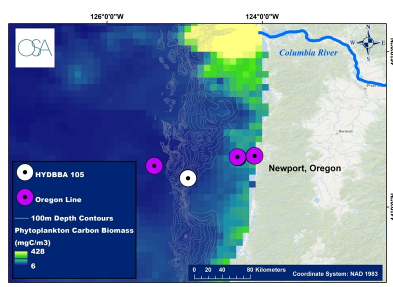


Figure 1A: Geographic distribution of phytoplankton carbon biomass (mgC/m^3) within the OOI Coastal Endurance study area. Fixed platform sensors along the array (purple) and the site-specific data used in this analysis (white) are indicated. The HYDBBA 105 hydrophone is located at a depth of ~580 m along the slope.

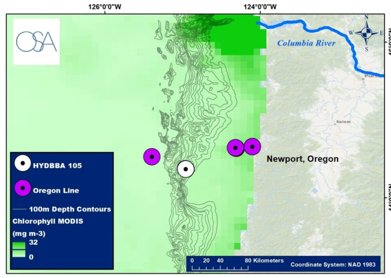


Figure 1E: Geographic distribution of MODIS-Aqua derived chlorophyll-a (mg/m^3) within the OOI Coastal Endurance study area. Fixed platform sensors along the array (purple) and the site-specific data used in this analysis (white) are indicated. The HYDBBA 105 hydrophone is located at a depth of ~580 m along the slope.

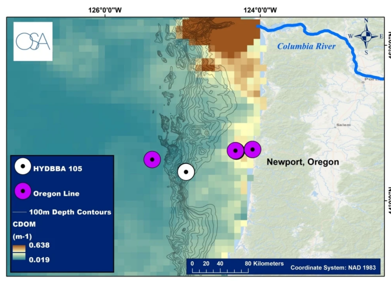


Figure 1C: Geographic distribution of colored dissolved organic matter (CDOM; m^{-1}) within the OOI Coastal Endurance study area. Fixed platform sensors along the array (purple) and the site-specific data used in this analysis (white) are indicated. The HYDBBA 105 hydrophone is located at a depth of ~580 m along the slope.

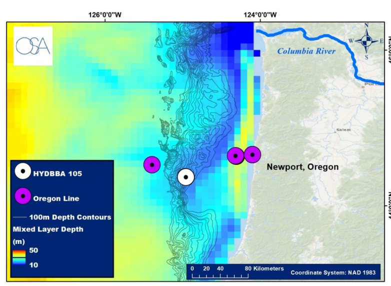


Figure 1D: Geographic distribution of mixed layer depth (m) within the OOI Coastal Endurance study area. Fixed platform sensors along the array (purple) and the site-specific data used in this analysis (white) are indicated. The HYDBBA 105 hydrophone is located at a depth of ~580 m along the slope.

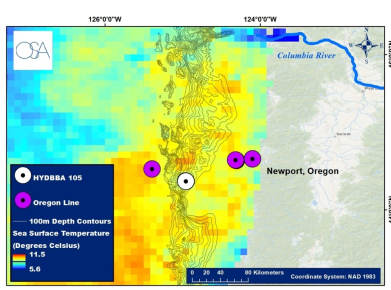


Figure 1F: Geographic distribution of MODIS-Aqua derived sea surface temperature (°C) within the OOI Coastal Endurance study area. Fixed platform sensors along the array (purple) and the site-specific data used in this analysis (white) are indicated. The HYDBBA 105 hydrophone is located at a depth of ~580 m along the slope.

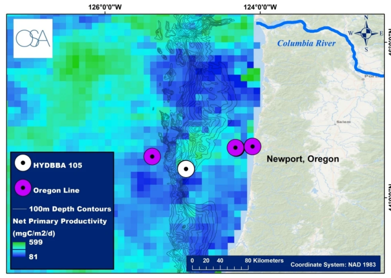


Figure 1B: Geographic distribution of net primary productivity (mgC/m^2/d) within the OOI Coastal Endurance study area. Fixed platform sensors along the array (purple) and the site-specific data used in this analysis (white) are indicated. The HYDBBA 105 hydrophone is located at a depth of ~580 m along the slope.

FUTURE DATA SYNERGY

We look foward to incorporating data in the future from NASA's Plankton, Aerosol, Cloud, ocean Ecosystem (https://pace.gsfc.nasa.gov/) (PACE mission)

The PACE mission will provide information on the diversity of planktonic species of ocean ecosystems, leading to finer resolution of the role of these organisms and their ecological impact.

AUTHOR INFORMATION

Liz Ferguson (eferguson@oceanscienceanalytics.com) is a Marine Ecologist and Educator with 18 years of experience in the education and research communities of San Diego. Through much of her career, she has specialized in marine mammal bioacoustic research, with expertise in passive acoustic monitoring and analytical software. More recently, her efforts involve exploring soundscape ecology use for large, long-term datasets and physical-biological impacts on marine mammal population dynamics. Prior to founding Ocean Science Analytics, Liz worked at the Southwest Fisheries Science Center (NOAA Fisheries) as a passive and active acoustic technician. In this role she gained extensive field experience in the Gulf of Mexico, the Eastern Tropical Pacific, and the Pacific Northwest regions. Liz later worked for Bio-Waves Inc., as their Chief Operating Officer (COO), with additional responsibilities in data analytics and project management. She is the CEO of Ocean Science Analytics, which is a marine science research and online technical training company that emphasizes the use of accessible analytical software and data.

ABSTRACT

The synergistic use of large datasets from cabled array sensors and remote sensing satellites is vastly under used for studying marine mammals. An important element of assessing long standing shifts in biodiversity within marine environments is to understand the relationship between physical and biological oceanographic variables and the occurrence of these keystone predators. The study area for this project is the California Current Ecosystem, a dynamic and productive coastal and offshore marine ecosystem within the Pacific Northwest region of the United States. This complex environment is influenced by the southward flowing California Current, seasonal changes in wind intensity, and a narrow continental shelf paired with a steep continental slope. A series of long-term, continuous data are collected by the Ocean Observatories Initiative (OOI) and includes physical and biological sensors from fixed and mobile sensors, as well as passive acoustic data from broadband hydrophones. We analyzed recordings collected during 2017 from three recorders located on the shelf (~80 m), slope (~580 m), and from a 200 m platform located above the base of the slope. Detections of sperm whales, delphinid species, humpback whales and fin whales suggest the region is a productive habitat. We combined acoustic derived marine mammal observations with information from the OOI sensors and remotely sensed chlorophyll data to describe ecosystem characteristics and explore indirect measures of prey availability. Our findings provide insight into regional biodiversity and associated physical and biological characteristics in a dynamic region of the northwest Pacific Ocean.

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