Spring 5-19-2023

Offshore Wind Energy and Seabird Collision Vulnerability in California

Whitney Grover
wlgrover@gmail.com

Recommended Citation

Grover, Whitney, "Offshore Wind Energy and Seabird Collision Vulnerability in California" (2023). *Master's Projects and Capstones*. 1508.
https://repository.usfca.edu/capstone/1508

This Master's Project

Offshore Wind Energy and Seabird Collision Vulnerability in California

by

Whitney Grover

is submitted in partial fulfillment of the requirements
for the degree of:

Master of Science
in
Environmental Management

at the

University of San Francisco

Submitted:

5/16/2023
………………………………………..
Whitney Grover Date

Received:

Aviva Rossi 5/16/2023
……………………………………….
Aviva Rossi PhD Date

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List of Acronyms

AOWFL	Aberdeen Offshore Wind Farm Limited
APWRA	Altamont Pass Wind Resource Area
BOEM	Bureau of Ocean Energy Management
CDFW	California Department of Fish and Wildlife
CEC	California Energy Commission
COP	Construction and Operations Plan
EEMS	Environmental Evaluation Modeling System
EEZ	Exclusive Economic Zone
GW	Gigawatt
IUCN	International Union for the Conservation of Nature
MW	Megawatt
NOAA	National Oceanic and Atmospheric Association
NREL	National Renewable Energy Laboratory
OCS	Outer Continental Shelf
SLC	State Lands Commission
TADS	Thermal Animal Detection System
WEA	Wind Energy Area

Abstract

California has ambitious clean energy goals designed to help mitigate the worst outcomes of climate change. Offshore wind is an important part of the solution to meet California's clean energy goals, but has potential negative impacts on the marine environment. As offshore wind energy is new to California, this paper reviews and synthesizes existing literature from other parts of the world, looking at the real and theoretical risk of seabird collision with offshore wind turbines. Learnings from existing offshore wind projects in the U.K. as well as theoretical and modeled risk assessments are applied to California's plans to determine the risk of seabird collision with turbines in the Humboldt and Morro Bay Wind Energy Areas. The species groups most vulnerable to collision are pelicans, terns, albatross, medium and large gulls, sea ducks, phalaropes, and jaegers/skuas. Generally, across real surveys of operating wind farms and models, collision risk is low. Seabirds tend to avoid wind energy areas completely, flying around the wind energy area at a distance. Those birds who enter the wind energy areas can most often avoid turbines by flying between them. Despite the overall low risk, several key factors impact a bird's ability to avoid turbines: placement of turbines and wind energy areas in relation to breeding or roosting grounds and foraging locations, visibility conditions, artificial lights, and attraction to the wind energy area through food availability and roosting opportunities. More information on region specific flight behavior, migration and commuting routes, and avoidance rates should be collected in the California wind energy areas before turbines are deployed to better anticipate and avoid risk.

1. Introduction

Climate change is the most formidable challenge we face as a species and it will have repercussions for all life on earth (Pörtner et al. 2022). Rising temperatures and changes in precipitation will have global impacts on food and water availability and changing habitat ranges for plants and animals (Rose et al. 2023). The consequences will include drought, famine, mass displacement, species extinction, and ultimately biodiversity loss (Butchart et al. 2010, McMichael 2012). This is not only an impending threat, the effects of climate change on ecosystems and wildlife are already happening (Parmesan and Yohe 2003).

To prevent the most devastating scenarios, we must stop burning fossil fuels for energy production to curb greenhouse gas emissions (Pörtner et al. 2022). Reducing reliance on fossil fuels through reduction of energy demand has been practically and politically infeasible in the U.S.; in fact, higher energy demand is forecasted in response to rising temperatures (Jacobson et al. 2015). Therefore, the supply of alternative sources of energy is critical to reduce greenhouse gas emissions. Growing human populations, paired with increased energy demand from the electrification of transportation and buildings, further increases the need for clean energy solutions (California Energy Commission 2023). According to the U.S. Department of Energy, clean energy sources include solar, wind, hydropower, geothermal, bioenergy (biomass energy), nuclear, and hydrogen (Department of Energy 2023).

Wind energy has the potential to supply a significant portion of our energy needs and can be perfectly paired with solar with respect to the time-of-day increase in power generation, supplying more energy generation at night when solar is not available (Jacobson et al. 2015, Wang et al. 2022). However, certain terrestrial (on land) wind farms have high collision mortality with bats and birds, particularly large raptors (Kuvlesky et al. 2007). In the Altamont Pass Wind Resource Area in California (APWRA), for example, species such as Golden Eagles (*Aquila chrysaetos*) and Burrowing Owls (*Athene cunicularia*), designated as fully protected or species of special concern by California Fish and Wildlife Service (Battistone 2023), have seen significant collision fatalities since the first wind turbines were constructed there in the 1980s (Smallwood and Thelander 2008). These bat and bird deaths could have been prevented or reduced with proper placement of the wind power project on the landscape, better planned micro-siting decisions of turbine locations within the project area, and improved turbine design (Kuvlesky et al. 2007).

Significant amounts of time and money have been spent on several lawsuits in the APWRA (Carter 2005, Howe 2021). Wildlife conservation organizations like the Center for Biological Diversity, local Audubon Chapters, and Audubon California claim the companies are not doing their part to mitigate impacts on local wildlife and that the government agencies did not fully perform their environmental review and enforcement duties (Carter 2005, Howe 2021). This political conflict, with local wildlife and climate change stuck in the middle, could have been prevented with more information, knowledge, and planning before the siting and construction of turbines.

Wind energy can be generated with terrestrial turbines, like in the APWRA, or offshore in the marine environment. Offshore wind is a promising source of renewable energy for the state of California in particular and has yet to be built here (California Energy Commission 2022). We now have the opportunity to learn from our previous mistakes with terrestrial wind generation projects, and adequately plan to minimize impacts before implementation of offshore wind projects. Careful planning, taking into consideration lessons learned in other parts of the world, can prevent the worst harm to our marine ecosystems.

Marine ecosystems are typically out of sight and therefore out of mind for the general public. But here on the California coast and further out to deep ocean waters, we have remarkable species richness and abundance of animals (Wooninck 2023). Strong winds, paired with the steep dropoff of the continental shelf close to the coast, creates upwelling: the process of deep nutrient rich waters rising to the surface (Webb 2021). When moved into surface waters those nutrients allow phytoplankton (photosynthesizing plankton) to thrive. Like plants in terrestrial ecosystems, the phytoplankton provide the foundation for an elaborate food web above and below the water (Webb 2021). In the Monterey Bay National Marine Sanctuary, off the coast of central California, there are 36 species of marine mammals, 525 species of fish, and 180 species of shorebirds and seabirds (Wooninck 2023).

Seabirds, also referred to as pelagic birds, are avian species dependent on the marine environment (Rajpar et al. 2018). Many seabirds spend the majority of their lives in the sky, scanning the sea surface for food, or perched on the water far off the coast, out of view from land. Some seabirds breed on offshore islands, never encountering the mainland in their entire lives (Rajpar et al. 2018). Because most people will never see a skua (*Stercorarius spp.*), shearwater (*Ardenna spp.*), storm-petrel (*Hydrobates spp.*), or albatross (*Phoebastria spp.*), for example, they are more difficult to protect and advocate for. Charismatic animal species, especially when connected to the public through experiences such as zoos, safaris, or natural experiences, are more effective at inspiring conservation efforts (Skibins et al. 2013). Despite their unfamiliarity and often drab plumage, these seabirds are no less important, and their ecological functions are no less critical than that of a Bald Eagle (*Haliaeetus leucocephalus*) or mountain lion (*Puma concolor*).

We need to act swiftly and at large scale to stop emitting greenhouse gases (Pörtner et al. 2022). However, we mustn't devastate ecosystems or harm sensitive species as we transition to clean energy. This analysis presents and synthesizes the current state of knowledge on offshore wind impacts and technologies, and provides recommendations to implement offshore wind energy projects in California, focusing on direct and impacts to seabirds. Impacts to marine environments (including seabird habitat) by offshore energy projects are typically considered in three phases: construction, operation, and decommission (Boehlert and Gill 2010). While construction and decommission impacts are important to consider, my analysis will only include operation phase impacts.

1.1 Background and Setting

California is located on the west coast of North America, with a coastline spanning 1,350 km along the Pacific Ocean (Beaver 2006). The state is the third largest in terms of land area in the U.S., and has the largest human population, with just over 39 million residents (U.S. Census Bureau 2022). California also has the largest economy of all the states, with a gross state product of $3.4 trillion in 2022 (Woodruff and von Kerczek 2022). To fuel California's economy and large human population, energy demand and generation in the state are substantial. In 2021 the California Energy Commission reported generating 277,764 gigawatt-hours (GWh) from all sources, and imported slightly more to meet the 280,738 GWh of energy consumed in 2021 (California Energy Commission 2023). Approximately 33% of the energy generated in 2021 was from renewable sources such as wind, solar, and geothermal (California Energy Commission 2023).

1.1.1 California Geography, Geology, and Climate

California’s unique geography and climate make the state rich with natural resources and biodiverse in terms of its natural ecology (Baldwin et al. 2017). The climate of California is mild: most of the state is categorized as Mediterranean by the Köppen-Geiger climate classification system (Peel et al. 2007). This temperate climate is caused by the California Current System in the Pacific Ocean which brings water south along the coast from colder northern oceans (Checkley and Barth 2009). This current system, paired with strong winds, moves surface waters; as warmer surface waters move, they are displaced by the movement of cold deep ocean waters in a process called upwelling (Checkley and Barth 2009) (Figure 1). Deep ocean waters are nutrient rich, and when they are introduced to surface waters where the sun’s energy can penetrate, known as the photic zone, the nutrients increase productivity of phytoplankton (Webb 2021). Phytoplankton are the base of the marine ecosystem, and support an abundance of life up through the food chain (Webb 2021).

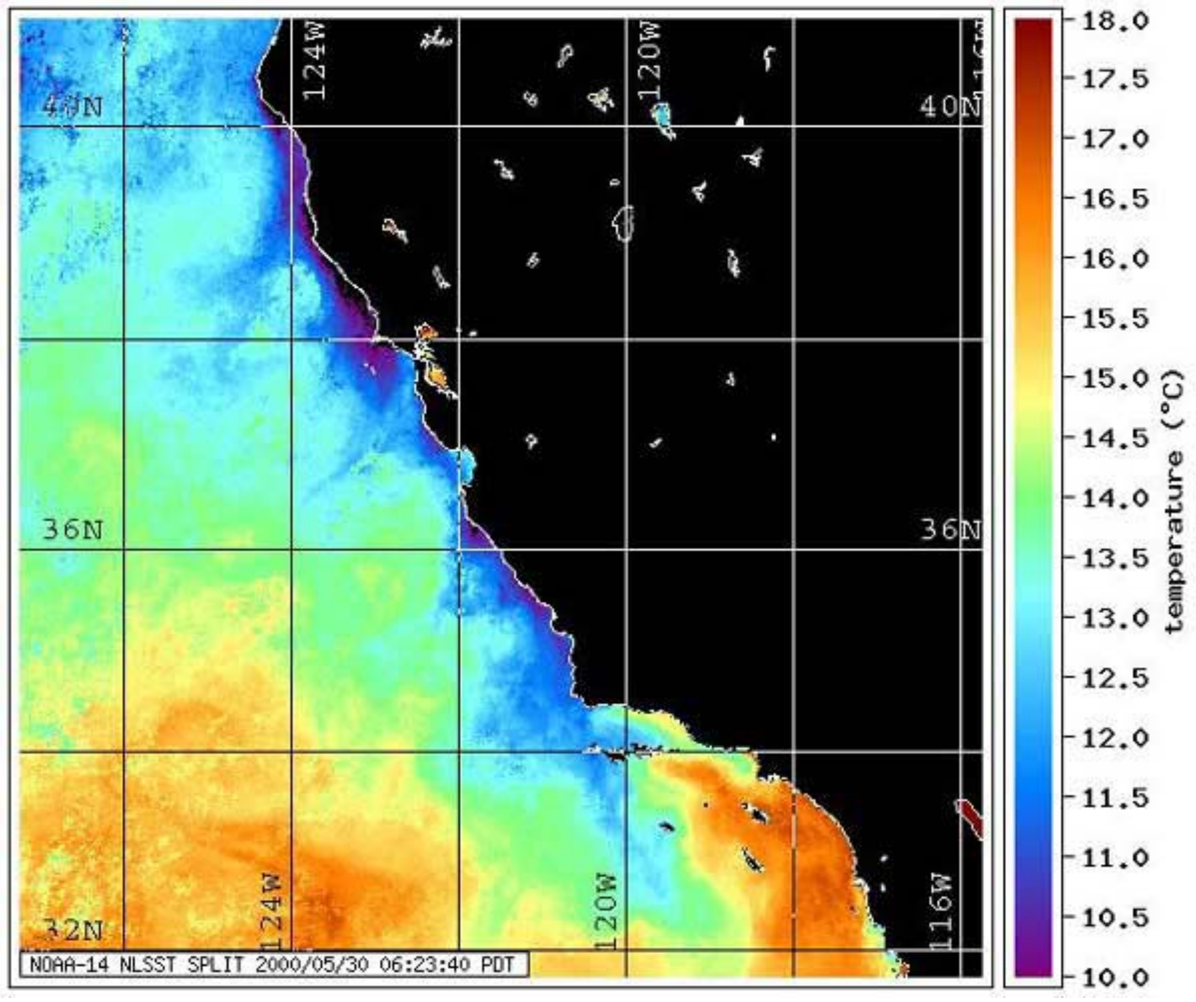


Figure 1: Visualization of Upwelling Through Surface Water Temperatures

California surface water temperatures measured in degrees Celsius. Colder temperatures are shown in purple, and occur close to shore where deep ocean waters are brought to the surface. Warmer temperatures are shown in orange and red. This map was created from data collected in 2000 by the National Oceanic and Atmospheric Association (NOAA) and produced by Sanctuary Quest and the NOAA Ocean Explorer Webmaster (NOAA Oceanic Explorer 2002).

California's offshore bathymetry (ocean floor topography), rapidly deepens off the coast. From sea level at the shoreline, 0 m deep, the continental shelf drops off to greater than 5,000 m deep only 30 miles or so from the coast, depending on the area (Tezak 2017). This unique bathymetry further aids in the upwelling process (Webb 2021). The oceanic area at the edge of the continental shelf is known as the Outer Continental Shelf (OCS) (Optis et al. 2020). While this unique bathymetry helps create California's significant biodiversity, the deep sea floor close to shore presents challenges for offshore wind infrastructure which will be discussed further in later sections of this analysis.

In the simplest terms, wind is created by pressure differentials in the air: cool air moving over coastal waters mixes with warmer air rising off the land, the cold and warm temperatures with different pressures move air horizontally over the earth (NOAA 2009). As a result of this and other phenomena, California has strong offshore winds (Optis et al. 2020). In Northern California in particular, average annual wind speeds are 11.1 to 12 meters per second (m/s) (Optis et al. 2020). For reference in imperial units, 12 m/s is approximately 26.8 miles per hour. While it would be more practical in terms of energy transmission to have turbines or other generation sources closer to where the energy is needed on shore, winds are strongest further off the coast (Figure 2) (Pendleton 2021a).

Not only are winds strong off the coast in California, they are also consistent (Optis et al. 2020). In 2020 the National Renewable Energy Laboratory (NREL) published a report assessing the potential for offshore wind energy in California. In the Humboldt Wind Energy Area, the north-most black polygon in Figure 2, the winds were considered stable between “weakly stable” and “strongly stable” 82% of the time (Optis et al. 2020). Stability was calculated mathematically using the bulk Richardson number which considers wind shear and temperature shear between two vertical atmospheric layers (Optis et al. 2020). NREL concluded that California can generate a total of 201.2 gigawatts (GW) of offshore wind energy from three investigated areas once built out (Optis et al. 2020). Two of the three areas analyzed were the Humboldt and Morro Bay Wind Energy Areas now being developed. The third area was eventually not considered for development, although other areas will be considered in the future. Multiple models analyzing winds over a 20-year period were considered when generating this conclusion (Optis et al. 2020).

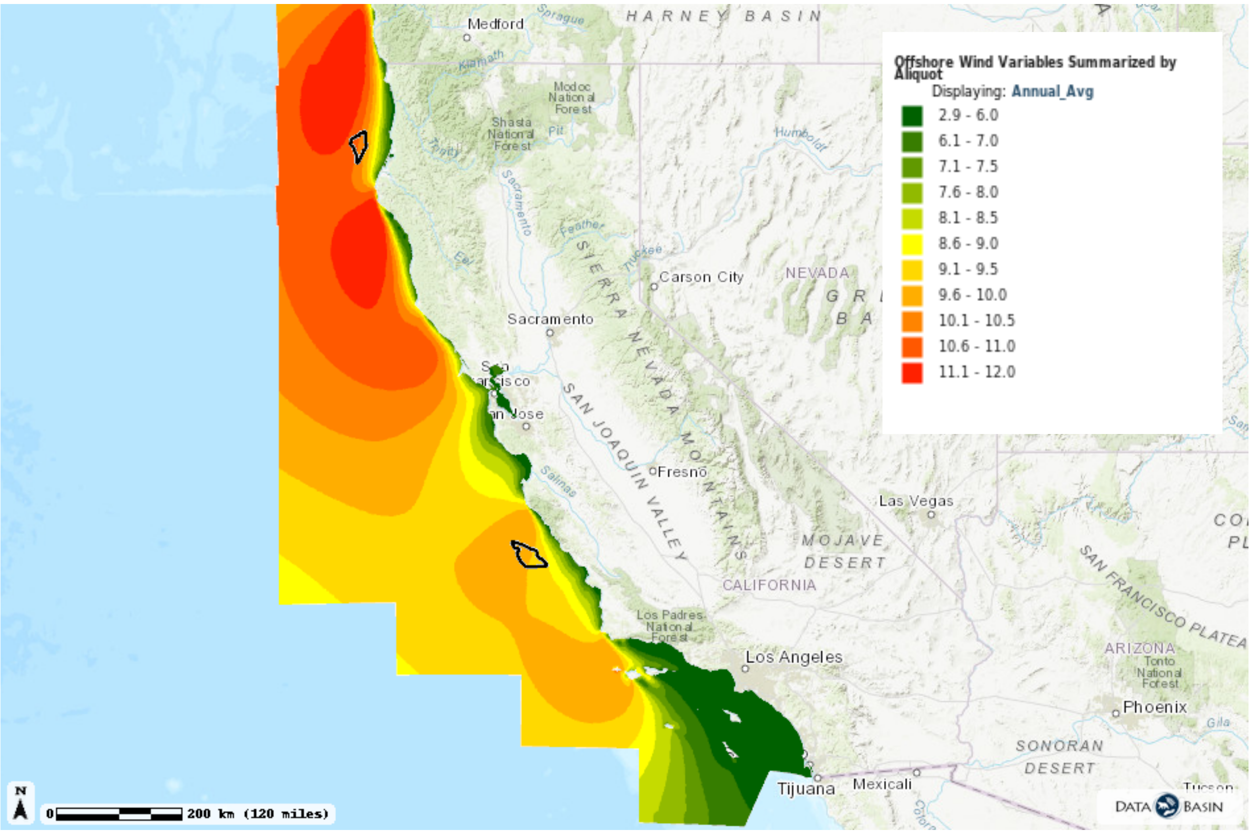


Figure 2: Average Annual Wind Speed Off the California Coast

Average annual wind speed in meters per second (m/s) off the coast of California. Red indicates the windiest areas with average speeds of 11.1 to 12 m/s, and forest green indicates the least windy at average speeds of 2.9 to 6 m/s. The Humboldt and Morro Bay Wind Energy Areas are outlined in black. Wind speed data was provided by California State University Northridge, the Bureau of Ocean Energy Management, and the National Renewable Energy Lab. The map was generated using the Conservation Biology Network's "California Offshore Wind Energy Gateway" powered by Data Basin (Conservation Biology Institute 2023).

1.1.2 Offshore Wind Technology

Offshore wind turbines work like their onshore counterparts: wind moves across turbine blades that are designed like airplane wings; when air moves over the blade it causes lift, making the blade spin (Wind Energy Technologies Office 2023). Inside the turbine, a rotor attached to a generator harnesses the wind power and converts it to energy. At the base of each turbine is a transformer, and all the energy generated by a project runs to a substation. The substations slow the electricity flow and deliver the energy through transmission lines, run between transmission towers, to the end consumers (Wind Energy Technologies Office 2023).

The distance from the ground to the center of the turbine blades, or hub, is called the hub height, and larger hub heights can support larger blades or rotors, resulting in a greater rotor-swept zone (the area where the rotors spin in the air) (Hartman 2022). More energy is generated by larger rotor-swept zones, and more free-flowing wind is available at higher altitudes, further increasing the energy generation power of larger and taller turbines (Hartman 2022). Offshore wind turbines are generally larger than those on land and as technologies advance, hub heights and blades have become even larger, with 2035 projections of hub heights of nearly 500 feet, generating a potential 17 megawatts (MW) of energy per turbine (Figure 3) (Musial et al. 2022).

Wind turbines are designed to have particular energy generated outputs, known as a nameplate rating (Musial et al. 2022). The turbine capacity is limited by cut-in and cut-out wind speeds (Wang et al. 2022). The cut-in speed is the lowest wind speed that will cause the blades to turn enough to generate the full energy capacity, or nameplate rating. The cut-out speed is the highest wind speed at which the turbine can operate before potential damage to the blades and hubs. For a 15 MW turbine (hub height of 149 m), an emerging standard size for the newest developing offshore technology (Figure 4), the cut-in speed is 11 m/s and the cut-out speed is 25 m/s (Wang et al. 2022).

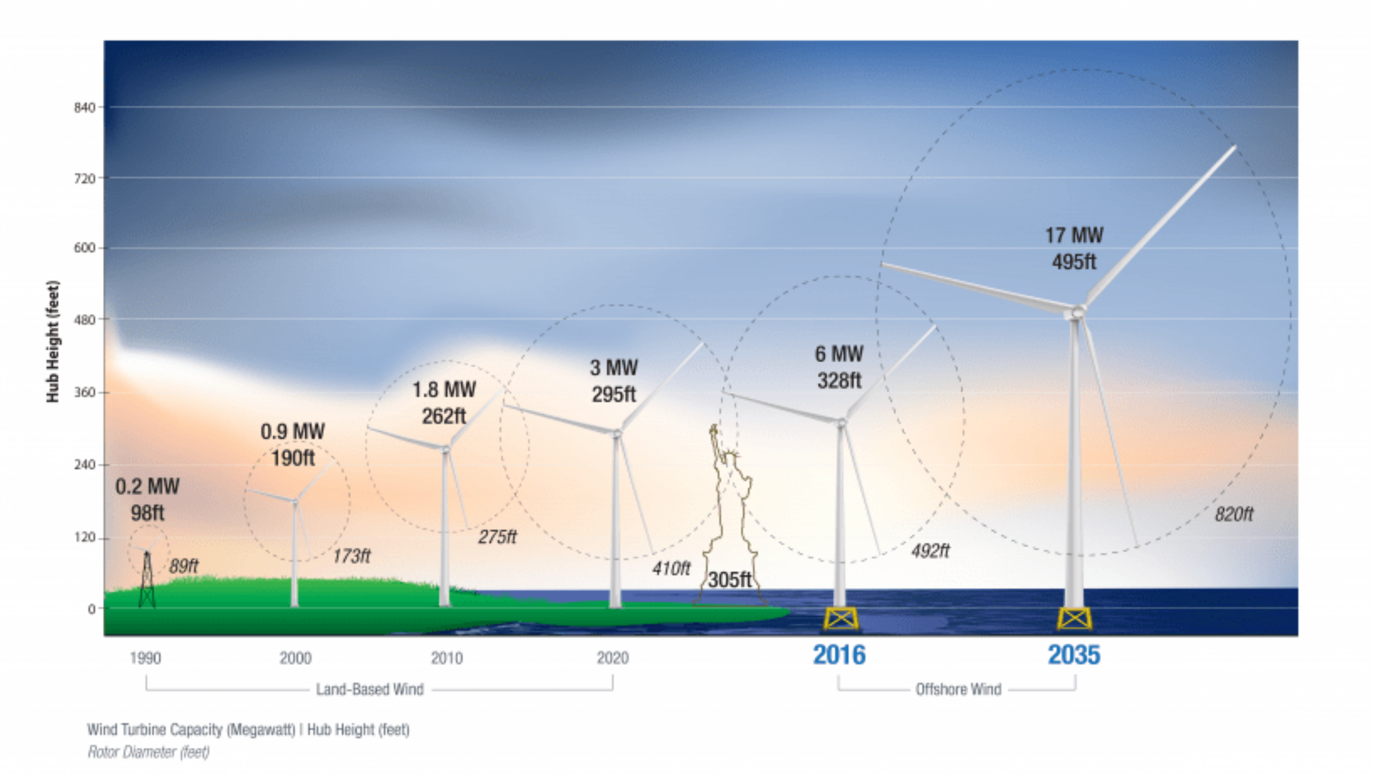


Figure 3: Wind Turbine Capacity Based on Hub Height

Office of Energy Efficiency and Renewable Energy illustration comparing the wind turbine hub heights, in feet, and rotor-swept diameters of terrestrial and offshore wind turbines from 1990 through projected dimensions in 2035. Also included is energy generation per turbine in megawatts (MW), showing that as turbine sizes increase, so too does energy generation (Hartman 2022).

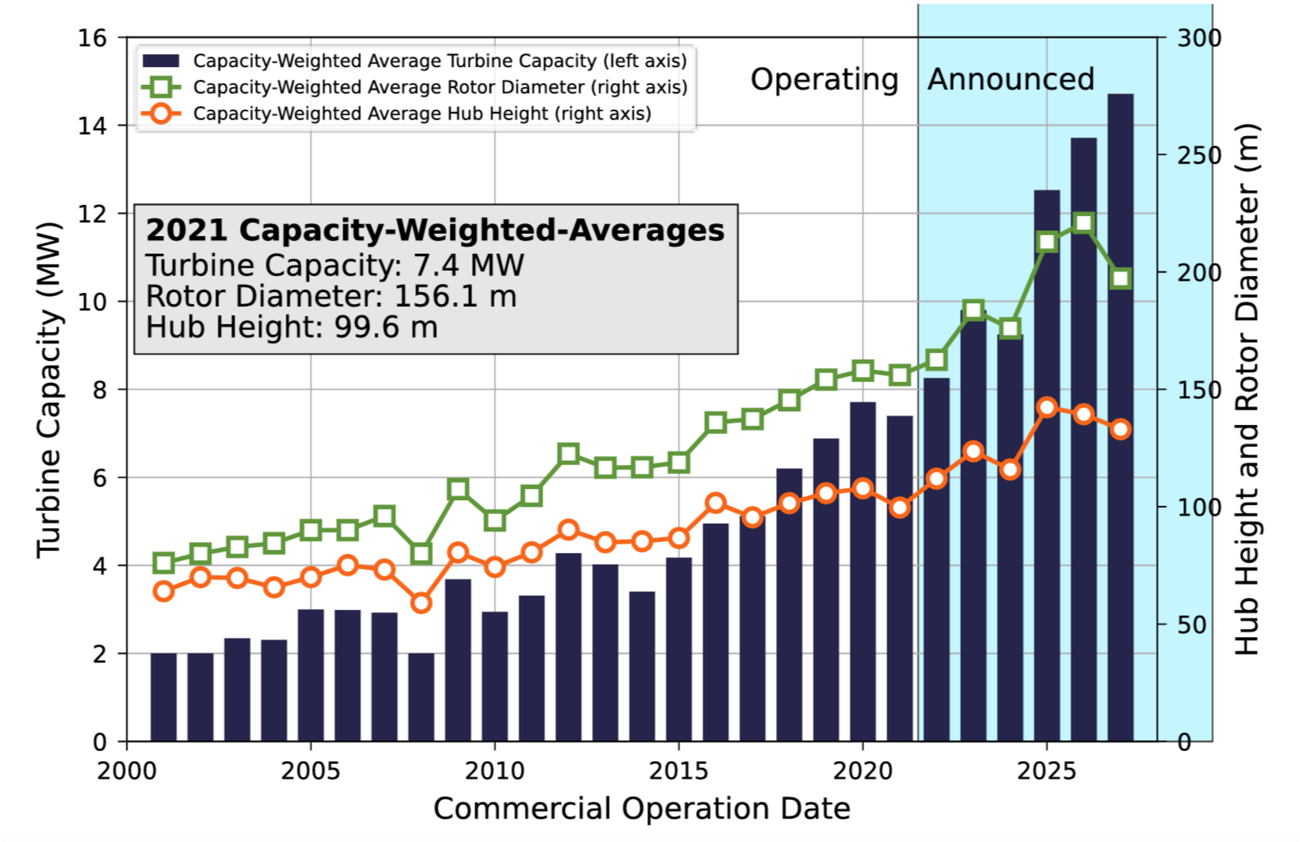


Figure 4: Operating and Announced Offshore Turbine Sizes and Capacity

Increase over time in turbine capacity in megawatts (MW) and hub height and rotor diameter in meters. From the 2022 Offshore Wind Market Report, published by the U.S. Department of Energy. In 2021 the average turbine capacity in commercial operation was 7.4 MW with a rotor diameter of 156 m and hub height of just under 100 m (Musial et al. 2022).

Offshore wind turbines are mounted on platforms that can either be fixed to the sea floor or floating and tethered to the seafloor (Wind Energy Technologies Office 2023). Current technologies limit fixed-bottom platforms to 60 m in depth: any ocean floor areas greater than 60m in depth require floating platforms. The maximum depth for technologies with tethered floating platforms is currently 1,300 m (Lopez et al. 2022). All currently operating offshore wind farms in the U.S. are fixed bottom systems. Worldwide, 80% of current offshore wind projects use fixed-bottom, monopile platform foundations (Hartman 2017), although there are various foundation types (Figure 5).

The California Wind Energy Areas in Humboldt and Morro Bay will be the first in the U.S. to use floating platform technologies (Musial et al. 2022). Although these floating technologies are new to the application of wind turbines, they have been used in the oil and gas industry's offshore activities (Kaplowitz and Seaman 2023). Globally, only 123 MW of energy is currently generated from floating offshore wind projects, the majority of that being in the UK. Norway has 88 MW in offshore energy projects with floating platforms under construction, but the technology development is escalating with over 60,000 MW (60 GW) of floating platform offshore wind projects in permitting and planning phases across 16 countries (Musial et al. 2022). 4,554 MW of the global total of pipeline projects will be in the U.S. (Musial et al. 2022). Of the small number of existing projects with floating platforms, the semi-submersible foundation type is most common (Musial et al. 2022).

Figure 5: Illustration of Offshore Wind Turbine Platforms

Various turbine platform foundations. From left to right: monopile, jacket, twisted jacket, tension-leg floating platform, semi-submersible platform, and spar-buoy. Illustration by Josh Bauer of the National Renewable Energy Laboratory (NREL 2016).

Wind turbines are arranged in configurations within the project areas called arrays. The National Renewable Energy Laboratory, a national laboratory of the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy, is currently conducting an extensive offshore wind energy array design project to be concluded in 2025. The results of the project will use advanced modeling to aid in the array design process for future offshore wind projects in the U.S. (Hall 2022).

1.1.3 California Policy and Plans

In 2018 California passed Senate Bill 100 (De León 2018), The 100 Percent Clean Energy Act. The bill set ambitious goals for the state, requiring a renewable energy portfolio of 60% eligible renewable sources by 2030. Additionally, the bill requires all energy procured by all state agencies, both California-generated and imported, to be 100% carbon free by 2045 (Flint et al. 2022). To achieve these goals, power plant and transmission infrastructure will also need to be developed to facilitate delivery of energy from generation to the end users (Flint et al. 2022).

In 2020 the California Ocean Protection Council published their 2020-2025 Strategic Plan to Protect California's Coast and Ocean. In it, they set a goal of producing a statewide policy by 2024 to establish criteria for implementing offshore wind energy while minimizing impacts to marine ecosystems and commercial fisheries. By 2026, they hope to implement offshore wind projects. In September 2021, California Assembly Bill 525 (AB525) was passed and signed by Governor Gavin Newsom (Chiu 2021). AB525 tasked the California Energy Commission (CEC) to work with stakeholders to investigate potential opportunities, identify priority areas for offshore wind, and create a permitting process with the agencies (Chiu 2021). Through the bill, the CEC set offshore wind goals of 2-5 GW by 2030 and 25 GW by 2045 (Ocean Protection Council 2023).

In addition to the CEC, many government agencies are involved in the planning, permitting, and implementation of offshore wind in California; the California Independent System Operator, the Bureau of Ocean Energy Management (BOEM), the California Department of Fish and Wildlife, the California Ocean Protection Council, the California State Lands Commission, the California Coastal Commission, the California Public Utilities Commission, and the Governor's Office of Planning and Research all have a role to play (Flint et al. 2022).

California state jurisdiction in coastal waters extends 3 nautical miles (5.56 km) from tidal areas (Gaffney 2023). Between three nautical miles and the edge of the Exclusive Economic Zone (EEZ) (200 nautical miles, or 370.4 km, from the territorial sea baseline) is federal jurisdiction (NOAA 2023, Gaffney 2023). Any offshore wind infrastructure placed outside state coastal areas and within the EEZ are under the jurisdiction of BOEM, a department of the U.S. Department of the Interior (Gaffney 2023). Any offshore wind infrastructure within 3 nautical miles of California's tidal zone will be overseen by the State Lands Commission (SLC) (Gaffney 2023).

Beginning in 2016, BOEM began examining potential locations for offshore wind implementation, engaging with stakeholders and partner agencies. They identified and analyzed five sites as potential offshore wind locations, and concluded that the Humboldt county and Morro Bay Wind Energy Areas (WEAs) should be recommended for approval. Mandated by the Coastal Zone Management Act, the California Coastal Commission must review and approve any projects inside or beyond the coastal zone that can impact California's coastal resources. In April and June of 2022 the California Coastal Commission reviewed and concurred with the BOEM's recommendations for those two sites, issuing consistency determinations which approved moving forward with offshore wind development there (Flint et al. 2022).

In May 2022, BOEM produced a final Environmental Assessment for the Humboldt County WEA, in accordance with the National Environmental Policy Act (NEPA) (U.S. Department of the Interior 2022a). In October 2022, BOEM produced the final Environmental Assessment for the Morro Bay WEA. In both cases a finding of *no significant impact* was determined, allowing the lease issuance and easement of the sites to proceed. These initial issuances only pertained to the site characterization activities for planning and surveying of the lease areas. Once wind energy companies submit a Construction and Operations Plan (COP), a new environmental review process will be required (U.S. Department of the Interior 2022b), including Endangered Species Act and the Marine Mammal Protection Act consultations (Miller 2023). Until the COP is produced, specific details about the turbine numbers, sizes, platform foundation types, transmission infrastructure design, and locations will be unknown.

On December 7, 2022 the U.S. Department of the Interior and BOEM issued a press release announcing the final sale of offshore wind lease areas in the Morro Bay WEA and Humboldt WEA to energy companies. The Humboldt WEA was subdivided into two parcels, and the Morro Bay WEA into three parcels for a total of five parcels. Once built out, these two first lease areas and their five parcels are anticipated to generate at least 4.6 GW of energy, which will meet the 25-GW-by-2030 goal (U.S. Department of the Interior 2022c). This sale marks the beginning planning stages of offshore wind implementation in California, and the west coast of the U.S. more broadly. Once site assessment activities begin, the energy companies will have 5 years to produce a COP, then agency review of the COP could take 2 years, including public comment periods (Gaffney 2023).

Because California's geography and climate offer unique challenges, new technologies will need to be developed, and to that end a 20% credit was offered to lease bidders who contributed to developments in workforce training or domestic supply chain solutions in floating platform technology (U.S. Department of the Interior 2022c). Additionally, in September 2022, the CEC announced a grant solicitation for advancements in mooring line and floating platform technology, with the explicit goals of reducing costs and mitigating impacts to wildlife and their habitats (California Energy Commission 2022).

1.1.4 Specifications Needed to Meet California's Clean Energy Goals

Although the specifications of the offshore wind infrastructure will be unknown until the COPs are published, government agencies and researchers have done work extrapolating dimensions and density of turbines based on estimated energy output, especially as it relates to meeting California's clean renewable energy goals. It's likely that the energy companies will opt for specifications with optimal energy generation and lowest construction and operations costs.

In 2022 NREL produced a report assessing multiple scenarios for delineation of the two WEAs (Cooperman et al. 2022). In addition to their internal technical knowledge, five industry representatives agreed to provide information on the specifications in their upcoming plans. This report informed the final BOEM delineation of the five lease areas within the WEAs. Their technical assessment considered turbine spacing, mooring equipment footprints, wake (the blocking of wind to a turbine by another turbine) and other system losses (Cooperman et al. 2022). The primary focus was maximum energy production, environmental considerations were outside the scope of their assessment.

Because floating platforms require mooring lines to tether the platform to the seafloor, the minimum distance needed between turbines is dependent on the mooring line footprints, rather than blade lengths (Cooperman et al. 2022). Different platforms and mooring styles will have different mooring line footprints. Only 15 MW turbines were assessed by NREL, in two different mooring line configurations, and two different turbine spacing scenarios. In the mooring line types assessed in this report, tension-leg platforms (Figure 5) had the smaller mooring footprint compared to catenary moorings.

The first spacing scenario investigated was a simple 1 nautical mile by 1 nautical mile grid (1 nautical mile is 1.1 miles or 1.9 km) (Cooperman et al. 2022). In both offshore and onshore wind projects, spacing is typically considered in terms of the rotor diameters. The other spacing scenario assessed was a 4Dx10D (4 rotor diameters by 10 rotor diameters, or 1 km by 2.4 km) (Cooperman et al. 2022). In each of their delineation assessments and in both WEAs, 4Dx10D spacing with tension-leg platform mooring generated the most energy, despite slightly higher wake loss (Cooperman et al. 2022).

Other turbine nameplate ratings and spacing configurations in California have been reviewed, taking into consideration our regional wind patterns (Wang et al. 2022). One review compared 12 MW turbines to 15 MW turbines and concluded that they would generate similar amounts of energy for the total wind energy area because although 15 MW turbines generate more per turbine, they would need to be spaced further apart (Wang et al. 2022). The same analysis compared 7Dx7D spacing to 8Dx10D and found, not surprisingly, the 7Dx7D spacing to be more productive. However, these researchers did not consider wake in their assessments as the NREL report had (Wang et al. 2022).

15 MW turbines with 248 m rotor diameters and 149 m hub heights are likely to be deployed in the California WEAs (Musial et al. 2022, Wang et al. 2022, Cooperman et al. 2022). This means the rotor-swept zone will extend 25 m off the seafloor, not taking into consideration the height of the platform. In the modeled assessments outlined in Sections 2.3 and 3.3 of this analysis, 10 m, 30 m, and 20-150 m altitude rotor-swept zones were used (Furness et al. 2013, Ainley et al. 2015, Kelsey et al. 2018). The likely 25-30 m rotor-swept zone in California is within the range considered for the modeled vulnerability assessments. While additional calculations should be performed with region specific seabird flight heights and the actual rotor-swept zone specifications, their calculations are likely similar to what we can assume for California WEAs.

1.1.5 Avian Impacts

The term *seabird* refers to bird species that depend on the marine environment and extends to at least five taxonomic orders: Sphenisciformes (penguins), Procellariiformes (albatrosses, petrels, storm-petrels, fulmars, and shearwaters), Ciconiiformes (herons, egrets, storks, ibises, and spoonbills), Pelecaniformes (pelicans, frigatebirds, gannets, boobies, cormorants, and anhingas), and Charadriiformes (shorebirds, skuas, jaegers, skimmers, auks, guillemots, and puffins) (Rajpar et al. 2018). Additionally, some species of Anseriformes (ducks and geese), Gaviiformes (loons), and Podicipediformes (grebes), rely on marine–as opposed to freshwater–systems, and can therefore be considered "seabirds" (Croxall et al. 2012).

Worldwide, 346 bird species are classified as seabirds (Croxall et al. 2012). Seabirds are the most threatened group of bird species, with 28% of species globally threatened and 47% of the 346 species experiencing population declines (Croxall et al. 2012). The U.S. is number one in terms of seabird diversity, with over 150 species (Croxall et al. 2012). The primary threats to seabirds are invasive species, being caught as fishing bycatch (accidentally caught in nets during fishing operations), climate change and severe weather, and pollution (Croxall et al. 2012). Seabirds generally have slow reproductive rates, maturing at late ages and only raising one or two chicks a year (Croll et al. 2022). Because this group of birds is already facing significant threats, we should ensure new offshore wind developments do not add to their vulnerability.

Offshore wind infrastructure in its operation phase poses both direct and indirect impacts to birds (Croll et al. 2022). Offshore wind's primary direct impact to seabirds is mortality or injury due to collisions with turbines, transmission lines, or increased air traffic from energy companies, such as helicopters (Reid et al. 2023). Other direct impacts include deterring and displacing birds from suitable habitat and foraging grounds, and creating barriers blocking migratory or forage routes. Potential indirect impacts include attracting birds to WEAs through the reef effect, noise disturbance, light pollution, electromagnetic impacts, seabed disruptions impacting benthic organism composition, and pollution from increased human traffic and corrosion of materials in the water (Langhamer 2012, Kirchgeorg et al. 2018, U.S. Department of the Interior 2022a, Croll et al. 2022). As yet unidentified additional impacts, especially indirect impacts, will certainly emerge as more plan details are published and implementation proceeds.

Because collision with turbines causes direct mortality, turbine collision will be the focus of this analysis. Before investigating collision risk, collision avoidance should be discussed.

Collision avoidance can be broken down into three spatial scales: meta-avoidance where a bird flies around the entire WEA, avoiding the project area completely; meso-avoidance is when a bird enters the WEA but avoids individual turbines; and micro-avoidance is the sudden change in direction, avoiding turbine blades or maneuvering through blades at close range (May 2015, Kelsey et al. 2018).

While avoidance is clearly a positive outcome compared to collision, there are potential negative impacts of avoidance and deterrence (May 2015, Kelsey et al. 2018). When birds avoid a WEA, they are losing access to potential foraging habitat and expending energy to take longer routes on their journeys (May 2015). It is not within the scope of this analysis to include these additional direct and indirect impacts, but it is important to understand that avoidance is not without cost to the individual birds, putting pressure on bird populations.

The Pacific Ocean is vast, and seabirds travel large distances, some on long migration routes and others simply on their normal foraging patterns (Rajpar et al. 2018). Biodiversity hotspots–or concentrations of abundance and species richness–emerge around the ocean based on oceanic conditions and the marine food sources they support, such as phytoplankton (Sydeman et al. 2006). Rather than the open ocean being a homogenous mix of all its abiotic conditions and creatures, life and the biodiversity of the open ocean is in fact patchy (Reese and Brodeur 2006). Seabirds concentrate in areas where their food sources are abundant (Santora and Sydeman 2015). To better understand how new human infrastructure like offshore wind in the open ocean will impact seabirds, we need to understand, however challenging, where birds and their food sources are on the seascape.

Different species have different diets, but the majority of seabirds eat fish and/or invertebrates such as squid, crustaceans, mollusks, krill, and zooplankton; therefore, these prey species can be used to understand where critical bird habitat may be (Rajpar et al. 2018). Despite location changes of salinity, temperature, density of surface waters, and seasons, hotspots of biodiversity and abundance remain fixed at least over two-year periods (Reese and Brodeur 2006). While the size of hotspots grow and contract with the factors listed above, the location remains stable (Reese and Brodeur 2006). This conclusion is important for understanding impacts of offshore wind on marine ecosystems because it dispels potential misconceived notions that marine ecosystems can readily move and simply shift out of WEAs. In turn, this also means current biodiversity hotspots can be avoided in advance of planning and construction.

That said, new biodiversity hotspots can be created when hard infrastructure is introduced into the marine environment (Inger et al. 2009). The turbine platforms and foundations have the potential to produce a reef effect, where fixed marine invertebrates are able to colonize and underwater animals like fish are able to find refuge (Langhamer 2012). This effect has the potential to be beneficial for many species, but as with any change to an ecosystem, it will surely result in potential negative impacts for others (Inger et al. 2009). For example, invasive species may take hold in these "artificial reefs" (Langhamer 2012). While the reef effect may improve fish populations, it could also have an indirect negative impact on seabirds by attracting them to WEAs where they are at greater risk of turbine collision.

1.2 Research Topic and Questions

The primary question of this analysis on offshore wind in California is: How can California operate offshore wind to meet its clean energy goals while minimizing collision risk to seabirds? To answer this question and frame my analysis, the question was broken down into the following three subquestions:

1. What seabird species are currently present in the planned wind energy areas?
2. Based on the scientific literature including case studies and models, what is the real and theoretical risk of seabird collision with offshore wind turbines?
3. How do the impacts found elsewhere apply to the planned CA projects?

1.3 Methods

This analysis will only be considering collision risk from wind turbines in the marine environment within the WEAs (30-34 km from shore) during operation of the turbines for energy production. There are other potentially impactful offshore wind energy infrastructure such as ships, helicopters, transmission lines, transformers, substations, and towers but they are not investigated in this analysis. Offshore wind energy infrastructure will run from the turbines all the way to the shore, and then continue onshore to the substations and end consumers. However, because transmission lines in the marine environment are often run under water along the seafloor, they are unlikely to be a major concern for seabirds. Construction impacts for this infrastructure will not be reviewed in this analysis. The lease terms and lifespan of a wind turbine is typically 25-30 years, after which the infrastructure will be decommissioned (Gaffney 2023). Later, down the road decommission impacts will also be excluded from this analysis.

Only seabirds were investigated in this analysis due to the distance from shore of the Humboldt and Morro Bay WEAs. Migratory passerines (songbirds), raptors, and shorebirds are all present along the California coast, but not found as far offshore as 30 km, with the exception of occasional vagrants. If future wind projects will be placed closer to shore, the list of impacted species should be expanded.

1.3.1 Literature Review

I performed a literature review using peer-reviewed scholarly sources found on the FUSION, SCOPUS, and Google Scholar databases. The search terms used were “offshore wind,” “birds,” “impacts,” “collision,” “turbine collision,” and “wind farm,” in various combinations. Additional search terms were added when relevant: “California,” “seabirds,” “reef effect,” and “marine ecosystem”, for example. All search results were reviewed for relevance to the main question and subquestions outlined in the previous section. Any results related to terrestrial wind farms or literature which did not directly address collision impacts to birds were not included. Additionally, I investigated sources cited in articles found from the general search process and used the SCOPUS database for access to the articles. Case studies of real impacts found in operating offshore wind farms were reviewed, outlined and analyzed for relevance to California’s plans. Additionally, I reviewed the literature on theoretical collision impacts, looking for modeled calculations of collision vulnerability. I synthesized the information from the literature review in Table 3 in Section 2.2.

Due to recent developments in offshore wind policy in California and the U.S. more broadly, I accessed government agency websites for general information, published strategic plans, and reports. The agency websites utilized were those of BOEM, CEC, California Department of Fish and Wildlife (CDFW), the California Ocean Protection Council, U.S. Department of the Interior, and the California Governor’s Office. On March 23, 2023 I attended a one-day virtual conference on West Coast offshore wind developments put on by The Seminar Group, a legal and professional education organization. Representatives from BOEM, American Clean Power Association, and other related industries presented on various topics relevant to the regulatory process in play. The information learned at the conference helped fill in the gaps of knowledge related to the state of the current plans.

1.3.2 Methods for Seabird Species Lists

A comprehensive offshore wind infrastructure collision and displacement vulnerability assessment was performed for the seabird species found in the California current system of the Pacific OCS (Kelsey et al. 2018). Researchers from the U.S. Geological Survey, Western Ecological Research Center and BOEM collaborated to analyze and assess the species most vulnerable to collision and displacement. More information about their methodology and conclusions are detailed in Sections 2.3 and 3.3. They selected species based on aerial at-sea surveys conducted from 1981-2014, with several additional species added that are known to be in the area but not counted in the aerial surveys (Kelsey et al. 2018). Their species list was used as the basis for Table 1 in Section 2.1. I cross-referenced the species list with bird field guides for validation and additional context (Dunn and Alderfer 2011, Sibley 2014, Howell and Sullivan 2015). Conservation status, primary diet, resident or migrator, and time of year information was compiled from field guides and the Cornell Lab of Ornithology's Birds of the World database (Dunn and Alderfer 2011, Sibley 2014, Howell and Sullivan 2015, The Cornell Lab of Ornithology 2023).

The "Conservation Status" column refers to the International Union for the Conservation of Nature (IUCN) Red List. This conservation status is reflective of the full global population of the species, not necessarily the vulnerability of local California populations. Local population information is included in vulnerability calculations explained in Section 3.3. Diet is listed with the most specific information available in the scientific literature (The Cornell Lab of Ornithology 2023). Some species' diets change from breeding to non-breeding parts of their lifecycles and ranges. When there is sufficient information available on diet in the time of year in the California OCS, that will be listed, and it may not reflect the species' primary diet in the other parts of their life cycles.

If the species is only within the Pacific OCS area on its migration journey, simply moving through the area on the way to breeding or overwintering grounds, the "Resident or Migrant" column will be marked "Migrant." If the species can be found throughout the breeding season, winter season, or year round the column will be marked “Resident.” Species with verified sightings in the OCS but the OCS is not considered its normal range are marked “rare.” If the species can only be found in the OCS during certain months or seasons they are listed in the far right column. “Non-breeding” in the final column means the bird can be found in the OCS during migration seasons as well as the fall and winter season, but does not breed offshore in the OCS. When there is no distinction between northern and southern California pointed out, the Resident/Migrant status and time of year are the same along the full coast of California.

1.3.3 Methods for Combining Risk Models

In Table 4 I combined the results of three modeled collision risk analyses found in the literature by applying a simple score to each species’ calculated score in each review and combining the simple scores. Each of the three modeled collision vulnerability assessments investigated in Section 3.3 of this analysis produced a quantitative calculation of collision vulnerability for each species or species group (Furness et al. 2013, Ainley et al. 2015, Kelsey et al. 2018). To consider each of these models together to generate a single score of combined collision vulnerability a simple score based on even quartiles was applied to each number: 1-4. The simple scores were then added together to synthesize collision vulnerability across assessments.

Kelsey et al. created a collision vulnerability score, ranging from 3 to 13 with 3 being the least vulnerable to collision and 13 being the most vulnerable (2018). I broke their scores into even quartiles and assigned a simple score: 3-5.5 scored 1; 5.5-8 scored 2; 8-10.5 scored 3; and 10.5-13 scored 4. The Ainley analysis used a flight style and wind speed linear mixed model analysis to assess collision vulnerability (2015). They used slope as a quantitative measure of collision vulnerability with a range of -0.06581 to 0.142368. The simple score assignment in even quartiles were: -0.06581 to -0.0137655, 1; -0.0137655 to 0.038279, 2; 0.038279 to 0.0903235, 3; and 0.0903235 to 0.142368, 4. Finally, Furness et al. produced a collision risk score ranging from 0 for the least vulnerable to 288 at the most vulnerable (2013). The simple score assignments in even quartiles were: 0-72, 1; 72-144, 2; 144-216, 3; and 216-288, 4.

2. Results

Below are the main results of the review and synthesis of the current literature. First, a collection of information from multiple sources outlines which seabird species are found in the Pacific OCS and likely present in the Humboldt and Morro Bay WEAs. Subsequently, lessons learned from case studies performed on operating wind farms in Europe are investigated for their relevance to the California WEAs and the general risk of seabird collision with wind turbines. Thirdly, results from modeled risk assessments are combined to understand the vulnerability of species groups relative to each other. Modeled risk assessments were also considered for understanding the infrastructure specifications and factors which increase risk of collision. This analysis on seabird collision risk has informed the conclusions and management recommendations outlined in Section 4.

2.1 Seabirds Found in the Pacific OCS in California

The first step in assessing impacts of offshore wind on seabirds is assessing the vulnerability of species or populations (Croll et al. 2022). In this and other environmental contexts, vulnerability can be defined as the combined influence of sensitivity, presence or exposure to a given threat, and the state of the population relative to the threshold of potential damage (Luers 2005). In other words, one should consider which species are present in and around the WEAs, what the current state of their conservation status is, and finally, what will be the species-specific impacts from offshore wind infrastructure. Table 1 below outlines the seabird species present in the Pacific OCS area off the coast of California, and therefore likely present in the Humboldt and Morro Bay WEAs. Also included is the species' global conservation status, their primary diet during the period of their life cycle spent in the OCS, whether they are migrants or residents of the OCS area, and what time of year they can be found in the OCS.

For migratory animals, including birds, all parts of their migration journey should be considered critical habitat, as they are critically important for maintaining their population health and resiliency (Kirby et al. 2008). One important takeaway from the collection of information in Table 1 is 67 out of the 81 species are residents, meaning they spend some significant part of their lives in the marine environment here in California. Only 14 species are rare or only present passing through on their migratory route. In fact, the majority of seabird species using the California coast and the Pacific OCS are here during their winter and non-breeding seasons

(Table 1). Of the total 81 species, 24 species have global populations that are designated by the IUCN as near threatened, vulnerable, or endangered, making the California populations critical for the continuing health of the species.

There are 19 species who breed in or around the OCS (Table 2). Seabirds nest, often in large colonies, on offshore islands, rocky coastlines, or marshes and estuaries along the coast (The Cornell Lab of Ornithology 2023). Marbled Murrelet (*Brachyramphus marmoratus*) and Ashy Storm-Petrel (*Hydrobates homochroa*) are resident breeding species which are endangered. Scripp's Murrelet (*Synthliboramphus hypoleucus*), Leach's Storm-Petrel (*Hydrobates leucorhous*), and Cassin's Auklet (*Ptychoramphus aleuticus*) are resident breeding species listed as vulnerable or near threatened by the IUCN (Table 2).

Table 1: Seabird Species found in the Pacific Outer Continental Shelf

These seabird species are found in the Pacific Outer Continental Shelf and are therefore likely in or around the California WEAs, making them potentially vulnerable to collision with offshore wind turbines (Kelsey et al. 2018). Status column refers to IUCN Red List Conservation Status, LC=Least Concern, NT=Near Threatened, V=Vulnerable, E=Endangered. HB=Humboldt Bay, sCA=Southern California, nCA=Northern California, cCA=Central California. YR=Year round, NB=Non-breeding, NP=Not present.

Group	Common Name	Scientific Name	Status	Primary Diet	Resident or Migrant	Period in CA OCS
Sea Ducks	Brant	*Branta bernicla*	LC	Eelgrass	Migrant	Spring and fall, stages in HB
	Common Merganser	*Mergus merganser*	LC	Fish	Resident	NB
	Red-breasted Merganser	*Mergus serrator*	LC	Fish, crustaceans	Resident	NB
	Harlequin Duck	*Histrioicus histrionicus*	LC	Invertebrates	Resident	NB
	Surf Scoter	*Melanitta perspicillata*	LC	Invertebrates	Resident	Winter
	White-winged Scoter	*Melanitta deglandi*	LC	Mollusks	Resident	Winter
	Black Scoter	*Melanitta americana*	NT	Mollusks	Resident	NB
	Long-tailed Duck	*Clangula hyemalis*	V	Invertebrates, fish	Resident	Winter, rare
Loons	Red-throated Loon	*Gavia stellata*	LC	Invertebrates, fish	Resident	NB
	Pacific Loon	*Gavia pacifica*	LC	Fish, squid	Resident	Winter
	Common Loon	*Gavia immer*	LC	Fish	Resident	NB
	Yellow-billed Loon	*Gavia adamsii*	NT	Invertebrates, fish	Resident	Winter, rare
Grebes	Horned Grebe	*Podiceps auritus*	V	Fish, crustaceans	Resident	NB
	Red-necked Grebe	*Podiceps grisegena*	LC	Invertebrates, fish	Resident	NB
	Eared Grebe	*Podiceps nigricollis*	LC	Insects, crustaceans	Resident	NB
	Western Grebe	*Aechmophorus occidentalis*	LC	Fish	Resident	NB
	Clark's Grebe	*Aechmophorus clarkii*	LC	Fish	Resident	NB
Procellariids	Laysan Albatross	*Phoebastria immutabilis*	NT	Squid	Resident	Fall-Feb
	Black-footed Albatross	*Phoebastria nigripes*	NT	Squid, fish eggs	Resident	NB
	Short-tailed Albatross	*Phoebastria albatrus*	V	Squid, fish eggs	Resident	NB
	Northern Fulmar	*Fulmarus glacialis rodgersii*	LC	Fish, some cephalopods	Resident	nCA:NB; sCA: rare

	Murphy's Petrel	*Pterodroma ultina*	LC	Squid, fish, crustaceans, insects	Resident	NB
	Mottled Petrel	*Pterodroma inexpectata*	NT	Squid, fish, crustaceans	Resident	NB
	Hawaiian Petrel	*Pterodroma sandwichensis*	E	Squid, fish, crustaceans	Very Rare	NB
	Cook's Petrel	*Pterodroma cookii*	V	Squid, crustaceans, fish, carrion	Resident	nCA: rare; sCA: Apr-Nov
	Pink-footed Shearwater	*Ardenna creatopus*	V	Squid, fish	Resident	NB
	Flesh-footed Shearwater	*Ardenna carneipes*	NT	Squid, fish, invertebrates	Resident	NB
	Buller's Shearwater	*Adrenna bulleri*	V	Fish, squid, crustaceans	Resident	NB
	Sooty Shearwater	*Adrenna grisea*	NT	Fish, cephalopods, crustaceans	Resident	Apr-Oct
	Short-tailed Shearwater	*Ardenna tenuirostris*	LC	Fish, crustaceans, cephalopods	Resident	Late fall-winter
	Manx Shearwater	*Puffinus puffinus*	LC	Fish, squid, crustaceans	Rare	NB
	Black-vented Shearwater	*Puffinus opisthomelas*	NT	Fish, squid	Resident	nCA: rare; sCA: Fall-winter
	Wilson's Storm-Petrel	*Oceanites oceanicus*	LC	Krill, fish, small squid	Rare	Aug-Oct
	Fork-tailed Storm-Petrel	*Hydrobates furcatus*	LC	Amphipods, fish	Resident	nCA: YR, breeds HB; sCA: winter
	Leach's Storm-Petrel	*Hydrobates leucorhous*	V	Fish, crustaceans, cephalopods, jellyfish	Resident	YR, breeds on islands
	Ashy Storm-Petrel	*Hydrobates homochroa*	E	Small fish, young fish, crustaceans	Resident	YR, breeds on islands
	Black Storm-Petrel	*Hydrobates melania*	LC	Krill, fish	Resident	nCA: rare; sCA: YR, breeds on islands
	Least Storm-Petrel	*Hydrobates microsoma*	LC	Plankton	Resident	nCA: NP; sCA: NB
Cormorants	Brandt's Cormorant	*Phalacrocorax penicillatus*	LC	Fish	Resident	YR, breeds on islands and coast
	Double-crested Cormorant	*Phalacrocorax auritus*	LC	Fish	Resident	NB
	Pelagic Cormorant	*Phalacrocorax pelagicus*	LC	Fish, invertebrates	Resident	YR, breeds on islands and coast
Pelicans	American White Pelican	*Pelecanus erythrorhynchos*	LC	Fish, crustaceans, amphibians	Resident	nCA: NP; sCA: NB
	Brown Pelican	*Pelecanus occidentalis*	LC	Fish	Resident	YR, breeds on islands
Phalaropes	Red-necked Phalarope	*Phalaropus lobatus*	LC	Copepods	Migrant	Apr-May, Jul-Oct
	Red Phalarope	*Phalaropus fulicarius*	LC	Copepods, amphipods	nCA: Migrant sCA: Resident	nCA: winter; sCA: NB
Jaegers and Skuas	South Polar Skua	*Stercorarius maccormicki*	LC	Fish	Migrant	Aug-Oct

	Pomarine Jaeger	*Stercorarius pomarinus*	LC	Fish, stolen from kittiwakes	nCA: Migrant sCA: Resident	nCA: winter; sCA: NB
	Parasitic Jaeger	*Stercorarius parasiticus*	LC	Unknown, likely stolen fish	Migrant	Spring, fall
	Long-tailed Jaeger	*Stercorarius longicaudus*	LC	Unknown, likely fish, invertebrates	Migrant	Fall
Alcids	Common Murre	*Uria aalge*	LC	Fish, cephalopods, krill	Resident	nCA: YR, breeds; sCA: NB
	Pigeon Guillemot	*Cepphus columba*	LC	Fish, invertebrates	Resident	YR, breeds on islands and coast
	Marbled Murrelet	*Brachyramphus marmoratus*	E	Krill, fish	Resident	nCA: YR, breeds on coast; sCA: NB
	Scripp's Murrelet	*Synthliboramphus hypoleucus*	V	Larval fish	Resident	nCA: NB; sCA: YR, breeds
	Craveri's Murrelet	*Synthliboramphus craveri*	V	Larval fish	Resident	nCA: NP; sCA: NB
	Ancient Murrelet	*Synthliboramphus antiquus*	LC	Krill, fish	Resident	Oct-Mar
	Cassin's Auklet	*Ptychoramphus aleuticus*	NT	Krill, larval fish	Resident	YR, breeds on islands
	Parakeet Auklet	*Aethia psittacula*	LC	Zooplankton	Resident	nCA: NB; sCA: NP
	Rhinoceros Auklet	*Cerorhinca monocerata*	LC	Fish	Resident	YR, breeds on islands
	Horned Puffin	*Fratercula corniculata*	LC	Fish	Rare	Winter
	Tufted Puffin	*Fratercula cirrhata*	LC	Fish, invertebrates	Resident	YR, breeds on islands and coast
Gulls	Black-legged Kittiwake	*Rissa tridactyla*	V	Squid, fish, krill	Resident	Oct-Apr
	Sabine's Gull	*Xema sabini*	LC	Amphipods, insects, krill	Migrant	Jul-Oct
	Bonaparte's Gull	*Chroicocephalus philadelphia*	LC	Krill, insects, crustacean parts	Resident	NB
	Heermann's Gull	*Larus heermanni*	NT	Fish	Resident	NB
	Short-billed Gull	*Larus brachyrhynchus*	LC	Fish, crustaceans, krill, plankton, rodents, birds	Resident	NB
	Ring-billed Gull	*Larus delawarensis*	LC	Fish, arthropods, rodents, grains, insects, earthworms	Resident	NB
	Western Gull	*Larus occidentalis*	LC	Fish, invertebrates, refuse	Resident	YR, breeds on islands and coast
	California Gull	*Larus californicus*	LC	Fish, squid, invertebrates, refuse including plants	Resident	NB
	Herring Gull	*Larus smithsonianus*	LC	Fish, invertebrates, refuse	Resident	NB
	Iceland Gull (Thayer's)	*Larus glaucoides thayeri*	LC	Fish, invertebrates, plants, algae, carrion	Resident	Winter

	Glaucous-winged Gull	*Larus glaucescens*	LC	Fish, invertebrates, refuse, carrion	Resident	NB
Terns	Least Tern	*Sternula antillarum*	LC	Fish	Resident	nCA: NP; sCA: YR, breeds on coast
	Gull-billed Tern	*Sterna nilotica*	LC	Insects, terrestrial animals, chicks	Resident	nCA: NP; sCA: YR, breeds
	Caspian Tern	*Hydroprogne caspia*	LC	Fish	Resident	YR, breeds on island or coast
	Black Tern	*Chlidonias niger*	LC	Fish, plankton, insects	Resident	Summer
	Common Tern	*Sterna hirundo*	LC	Fish, invertebrates	Migrant	Apr-May, Jul-Oct
	Arctic Tern	*Sterna paradisaea*	LC	Fish, invertebrates, amphipods	Migrant	May, Aug-Sep
	Forster's Tern	*Sterna forsteri*	LC	Small fish	Resident	YR, breeds in marshes
	Royal Tern	*Thalasseus maximus*	LC	Sardines	Resident	nCA: NP; sCA: winter
	Elegant Tern	*Thalasseus elegans*	NT	Fish	Resident	NB
	Black Skimmer	*Rynchops niger*	LC	Fish	Resident	nCA: YR; sCA: NB

This species list was created by Kelsey et al. (2018) and additional information on conservation status, diet, and time of year in the OCS was aggregated from several sources (Dunn and Alderfer 2011, Ainley et al. 2015, Howell and Sullivan 2015, The Cornell Lab of Ornithology 2023).

Table 2: Breeding Seabird Species in the Pacific OCS

These 19 species breed in California, along the coast or offshore (The Cornell Lab of Ornithology 2023).

Breeding Range	**Species Common Name**	**Conservation Status**
Species Breeding in Northern and Southern CA	Leach's Storm-Petrel	Vulnerable
	Ashy Storm-Petrel	Endangered
	Brandt's Cormorant	Least Concern
	Pelagic Cormorant	Least Concern
	Brown Pelican	Least Concern
	Pigeon Guillemot	Least Concern
	Cassin's Auklet	Near Threatened
	Rhinoceros Auklet	Least Concern
	Tufted Puffin	Least Concern
	Western Gull	Least Concern
	Caspian Tern	Least Concern
	Forster's Tern	Least Concern
Southern CA Only	Black Storm-Petrel	Least Concern
	Scripp's Murrelet	Vulnerable
	Least Tern	Least Concern
	Gull-billed Tern	Least Concern
Northern CA Only	Fork-tailed Storm-Petrel	Least Concern
	Common Murre	Least Concern
	Marbled Murrelet	Endangered

2.2 Collision Risk Based on Case Studies

Generally, across multiple studies performed by researchers, government agencies, and industry, collision rates are low. Seabirds tend to avoid WEAs entirely at significant distances, on the macro-avoidance scale. That said, several factors led to higher than average collision rates: proximity of WEAs to breeding and roosting colonies, placement of turbines in high traffic areas such as migration routes, and low visibility conditions, and artificial lighting. While collision rates are generally low across all species, there were species specific trends and avoidance rates based on region. This highlights the importance of region specific surveying in California which will be discussed further in Section 4.2.1. Turbine size, turbine numbers, and spacing varied greatly between studies but none come close to the approximately 150, 15 MW turbines, spaced 1 km x 2.4 km as predicted in the California WEAs.

Table 3: Synthesis of Collision Risk Based on Case Studies

This table synthesizes the key information found in eight European case studies. With the exception of the Zeebrugge, Belgium case, collision rates were very low or 0. More discussion of the Zeebrugge case can be found in Section 3.2.

Case Study Name	**Authors (Year)**	**Publication Type**	**Location**	**Species Focus**	**Number of Turbines**	**Turbine Size**	**Array Configuration**	**Turbine Distance From Shore**	**Survey Duration**	**Number of Collisions**	**Number of Total Birds Counted**	**Collision Rate**	**Main Findings**
The Environmental Impact from an Offshore Plant	Larsson (1994)	Peer Reviewed Journal	Norgersund, Sweden	Migratory Birds	1	220 kW	Single turbine	250 m	March-June for 2 years	0	24,515	**0**	Zero collisions but significant displacement. Bird abundance near the turbine fell by 50%. Only 3.9% of birds in 1990 and 0.7% in 1991 flew within 125 m of the turbine.
The Impact of Offshore Wind Farms on Bird Life in Southern Kalmar Sound, Sweden	Pettersson (2005)	Government Report by University Researchers	Kalmar Sound, Sweden	Any present, but majority were eiders	12	2 MW	2 areas, each with 1 row of turbines	3 km	3 weeks during Spring and Fall for 4 years	1	1,533,000	**1 bird per turbine per year**	Birds generally avoid the WEAs by 1-2 km. Collision rate calculation included any birds detected within 100 m of a turbine, in addition to the one actual collision.
Avian collision risk at an offshore wind farm	Desholm and Kahlert (2005)	Peer Reviewed Journal	Nysted, Denmark	Ducks and geese	72	2.3 MW	850 m x 480 m grid	10.5 km	Unknown	0	200,000-300,000 per year	**less than 1%**	Birds avoided the WEA. 0.9% of the night migrants and 0.6% of the day migrants flew close enough to the turbines to be at risk of colliding.
Final results of bird studies at the offshore wind farms at Nysted and Horns Rev, Denmark	Petersen et al. (2006)	Government Report commissioned by industry	Nysted and Horns Rev, Denmark	54 species	80 (Horns Rev, Nysted above)	2 MW (Horns Rev, Nysted above)	560 m x 560 m grid (Horns Rev, Nysted above)	14 km (Horns Rev, Nysted above)	6 years	0	Over 1,000,000	**0.018-0.020%**	Zero collisions were detected but predictive modeling for collision rate percentage was performed on eiders. Birds generally avoid the WEAs, but rates are species specific. Horns Rev 71-86% of bird flocks avoided entering into the wind farm, 78% at Nysted.
Bird migration studies and potential collision risk with offshore wind turbines	Hüppop et al. (2006)	Peer Reviewed Journal	German Bight	217 species, including passerines	Unknown	-	grid	45 km (but between land formations)	Various by location	442 (but only 6 non-passerine)	13,037	**0.03%**	Most collision deaths were migrating passerines as opposed to waterfowl and seabirds. 50% of the collision deaths occurred on 2 nights of low visibility conditions.

Impact of wind turbines on birds in Zeebrugge (Belgium)	Everaert and Stienen (2006)	Peer Reviewed Journal	Zeebrugge, Belgium	Terns and gulls	25	200-600 kW	1 row	adjacent to shore	2 years during breeding season	329 (523 corrected)	-	**19.1-20.9 birds per turbine per year**	Placement of turbines between breeding and foraging grounds results in significant mortality.
Resolving Key Uncertainties of Seabird Flight and Avoidance Behaviours at Offshore Wind Farms	Cox and Larsen (2023)	Industry Report	North Sea, Scotland	Gannets, gulls, other seabirds	11	8.6 MW	Approx. 1.3 km x 0.65 km grid	3-4.9 km	April-October for 2 years	0	Over 10,000	**0**	Avoidance rates vary by species but generally seabirds have high macro-avoidance rates. Zero collisions were detected in this survey, however they only looked at day time movement.

2.3 Species Group Collision Risk Based on Models

Table 4 below combines three modeled collision vulnerability assessments using methodology outlined above in Section 1.3.3 to get an overall sense of the collision vulnerability of species groups. More discussion on each assessment and their application to the California WEAs can be found in Section 3.3. Based on the combined models, the species groups most vulnerable to collision are pelicans, terns, albatross, medium and large gulls, sea ducks, phalaropes, and jaegers/skuas. Medium risk groups are shearwaters, grebes, petrels, and small gulls. The least vulnerable groups are loons, storm-petrels, cormorants, and alcids.

Table 4: Synthesis of Three Collision Risk Models

The table below takes the seabird species list from Table 1 and combines the modeled collision analyses of Kelsey et al., Ainley, and Furness et al. to determine the most vulnerable species. The species are ranked by combined vulnerability. The Furness et al. collision risk scores in bold were species investigated by Furness et al. Non-bolded scores in column 6 were extrapolated based on shared genus or family and size. Kelsey et al.'s population vulnerability score was also included in the last column for context. Population vulnerability scores ranged from 6 to 27, 27 being the most vulnerable.

Common Name	Collision Vulnerability Score Best Estimate (Kelsey et al.)	Kelsey et al. Simple Score	Linear Mixed Model Analysis of Flight Style and Wind Speed: Slope (Ainley et al.)	Ainley et al. Simple Score	Collision Risk Score (Furness et al.)	Furness et al. Simple Score	Combined Score	Population Vulnerability Score Best Estimate (Kelsey et al.)
American White Pelican	12	4	0.00166	2	1306	4	10	18
Brown Pelican	12	4	0.00166	2	1306	4	10	22.5
Gull-billed Tern	11	4	0.09448	4	245	1	9	12.5
Caspian Tern	11	4	0.09448	4	245	1	9	16
Common Tern	11	4	0.09448	4	**229**	1	9	9.5
Arctic Tern	11	4	0.09448	4	**198**	1	9	10
Forster's Tern	11	4	0.09448	4	229	1	9	15
Black-footed Albatross	8	2	-0.00796	2	1306	4	8	16.5
Short-tailed Albatross	7.5	2	-0.00796	2	1306	4	8	19
Western Gull	9	3	-0.06581	1	1306	4	8	19
Herring Gull	9.5	3	-0.06581	1	**1306**	4	8	9
Glaucous-winged Gull	9	3	-0.06581	1	1306	4	8	12.5
Least Tern	9	3	0.09448	4	212	1	8	21
Black Tern	9	3	0.09448	4	212	1	8	9

Royal Tern	10	3	0.09448	4	245	1	8	13
Elegant Tern	10.5	3	0.09448	4	245	1	8	17.5
Black Skimmer	9	3	0.09448	4	245	1	8	17
Brant	7	2	0.142368	4	117	1	7	13
Common Merganser	8	2	0.142368	4	88	1	7	6
Red-breasted Merganser	8	2	0.142368	4	88	1	7	8
Harlequin Duck	7	2	0.142368	4	64	1	7	14
Surf Scoter	7	2	0.142368	4	96	1	7	12
White-winged Scoter	7	2	0.142368	4	88	1	7	8
Black Scoter	7	2	0.142368	4	96	1	7	10
Red-necked Phalarope	6.5	2	-0.05618	1	1306	4	7	9
Red Phalarope	7	2	-0.05618	1	1306	4	7	12
Pomarine Jaeger	12	4	-0.06148	1	327	2	7	9
Parasitic Jaeger	13	4	-0.06148	1	**327**	2	7	7.5
Long-tailed Jaeger	13	4	-0.06148	1	327	2	7	7.5
Heermann's Gull	9.5	3	-0.06572	1	960	3	7	14
California Gull	9.5	3	-0.0427	1	960	3	7	14.5
Iceland Gull (Thayer's)	9.5	3	-0.06581	1	960	3	7	13
Long-tailed Duck	5.5	1	0.142368	4	**64**	1	6	6.5
Pink-footed Shearwater	5	1	0.142368	4	0	1	6	20
Flesh-footed Shearwater	5.5	1	0.142368	4	0	1	6	12.5
Buller's Shearwater	5	1	0.142368	4	0	1	6	12
Sooty Shearwater	5	1	0.142368	4	**0**	1	6	14
Black-vented Shearwater	5	1	0.142368	4	0	1	6	17
South Polar Skua	12.5	4	-0.06148	1	320	1	6	14
Black-legged Kittiwake	9	3	-0.06572	1	**523**	2	6	9
Short-billed Gull	9.5	3	-0.06572	1	598	2	6	7
Ring-billed Gull	10	3	-0.0427	1	598	2	6	11.5
Horned Grebe	6.5	2	0.007822	2	**139**	1	5	9
Red-necked Grebe	6	2	0.007822	2	84	1	5	10
Eared Grebe	6	2	0.007822	2	139	1	5	7
Western Grebe	6	2	0.007822	2	84	1	5	16.5
Clark's Grebe	6	2	0.007822	2	84	1	5	15.5
Laysan Albatross	8	2	-0.00796	2	240	1	5	12
Northern Fulmar	5	1	0.060311	3	**48**	1	5	11
Murphy's Petrel	7	2	-0.00711	2	0	1	5	13
Mottled Petrel	6	2	-0.00711	2	0	1	5	12

Hawaiian Petrel	6	2	-0.00711	2	0	1	5	16.5
Cook's Petrel	6.5	2	0.018574	2	0	1	5	15.5
Double-crested Cormorant	9	3	-0.03735	1	150	1	5	15
Common Murre	3.5	1	0.087591	3	**37**	1	5	16
Sabine's Gull	9.5	3	-0.06572	1	288	1	5	10
Bonaparte's Gull	9.5	3	-0.06572	1	288	1	5	16
Red-throated Loon	5.5	1	0.007822	2	**213**	1	4	13
Pacific Loon	4	1	0.007822	2	213	1	4	11.5
Common Loon	3.5	1	0.007822	2	**240**	1	4	15.5
Yellow-billed Loon	3.5	1	0.007822	2	240	1	4	16
Short-tailed Shearwater	5	1	0.036555	2	0	1	4	8.5
Manx Shearwater	5	1	0.000922	2	**0**	1	4	11
Fork-tailed Storm-Petrel	5.5	1	0.018574	2	85	1	4	11
Leach's Storm-Petrel	5.5	1	0.018574	2	**85**	1	4	12
Ashy Storm-Petrel	5.5	1	0.018574	2	85	1	4	27
Black Storm-Petrel	5.5	1	0.018574	2	85	1	4	13.5
Least Storm-Petrel	5.5	1	0.018574	2	91	1	4	12.5
Brandt's Cormorant	8	2	-0.03735	1	150	1	4	21
Pelagic Cormorant	8	2	-0.03735	1	150	1	4	15
Pigeon Guillemot	3	1	-0.00168	2	30	1	4	17
Parakeet Auklet	3	1	-0.00168	2	30	1	4	8.5
Rhinoceros Auklet	3.5	1	-0.00168	2	27	1	4	17
Horned Puffin	3	1	-0.00168	2	27	1	4	10.5
Tufted Puffin	3	1	-0.00168	2	27	1	4	19
Wilson's Storm-Petrel	5.5	1	-0.04602	1	85	1	3	7.5
Marbled Murrelet	3.5	1	-0.01516	1	15	1	3	20
Scripp's Murrelet	3.5	1	-0.01516	1	15	1	3	19
Craveri's Murrelet	3.5	1	-0.01516	1	15	1	3	15
Ancient Murrelet	3.5	1	-0.01516	1	15	1	3	10
Cassin's Auklet	3.5	1	-0.01516	1	15	1	3	14

3. Discussion

Generally, across real surveys of operating wind farms and modeled vulnerability, collision risk is low. Seabirds tend to avoid wind energy areas completely, flying around the turbine area at distance. Those birds who enter the wind energy areas can most often avoid turbines by flying between them. The significant distance from shore of the Humboldt and Morro Bay WEAs improves collision risk vulnerability generally (Farr et al. 2021), and excludes terrestrial bird species such as passerines or raptors from offshore wind turbine collision.

3.1 Seabird Presence and Distribution

In addition to the possible species lists (Table 1), where birds are on the seascape is critical to understanding how they will be impacted by offshore wind infrastructure. Seabirds and their prey species have been surveyed along the Pacific coast for several decades. Visualizing this information using maps and applying predictive modeling can better inform environmental impact assessments. Real survey information has been aggregated, collected, and displayed visually using maps in the Data Basin mapping tool (Conservation Biology Institute 2023). The survey data comes from many sources including CDFW, U.S. Fish and Wildlife, NOAA, United States Geological Survey, researchers at academic institutions, and private consulting firms. The purpose of the Data Basin tool, and visual mapping of seabird survey data more generally, is to compile and visualize data to aid environmental education and conservation efforts (Leirness et al. 2021, Conservation Biology Institute 2023). In addition to the datasets and mapping tool, Conservation Biology Institute operates the Environmental Evaluation Modeling System (EEMS). While EEMS is a powerful tool that should be utilized in the environmental assessment of offshore wind, it has not been explored in this analysis.

Some of the maps related to the marine environment were created for BOEM specifically for investigation into offshore wind impacts in the marine environment (Leirness et al. 2021). The Data Basin datasets and maps have species specific survey data as well as compilations of multiple species visualized together. Some maps include visualization of actual survey collected data, and other datasets show predicted values based on various environmental variables using spatial predictive modeling. Datasets and maps can be uploaded or built by any user, however when they have been used in, or vetted by, peer-reviewed literature they are marked as such. In August of 2021 BOEM produced a report of 33 species maps from survey data including predictive modeling which included a range of environmental conditions including satellite imagery of phytoplankton presence (as indicated by Chlorophyll-a), bathymetry, water turbidity, wind conditions, and temperature (Leirness et al. 2021). Their datasets and maps are available for viewing and modification in the Data Basin program.

Below is a sample of maps from Data Basin demonstrating their utility for understanding the distribution of seabirds on the seascape at various times of year. It should be noted that the predictions and real survey datasets are only as good as the underlying data. Colony locations, for example, were sampled from 1985 to 2003 (Figure 6). New surveys should be performed to make the location information more up-to-date (Conservation Biology Institute 2023). Despite these limitations, the mapping tools are critical to understanding the presence and distribution of seabirds in the WEAs.

Figures 7 and 8 compile multiple species data to show distribution of seabirds as a group, broken down by time of year: winter (Figure 7) and summer (Figure 8). Figure 9 is a species specific map showing the distribution of Black-footed Albatross (*Phoebastria nigripes*) on the seascape. Figures 10 and 11 show distributions of common seabird prey species: krill (Figure 10) and sardines (Figure 11).

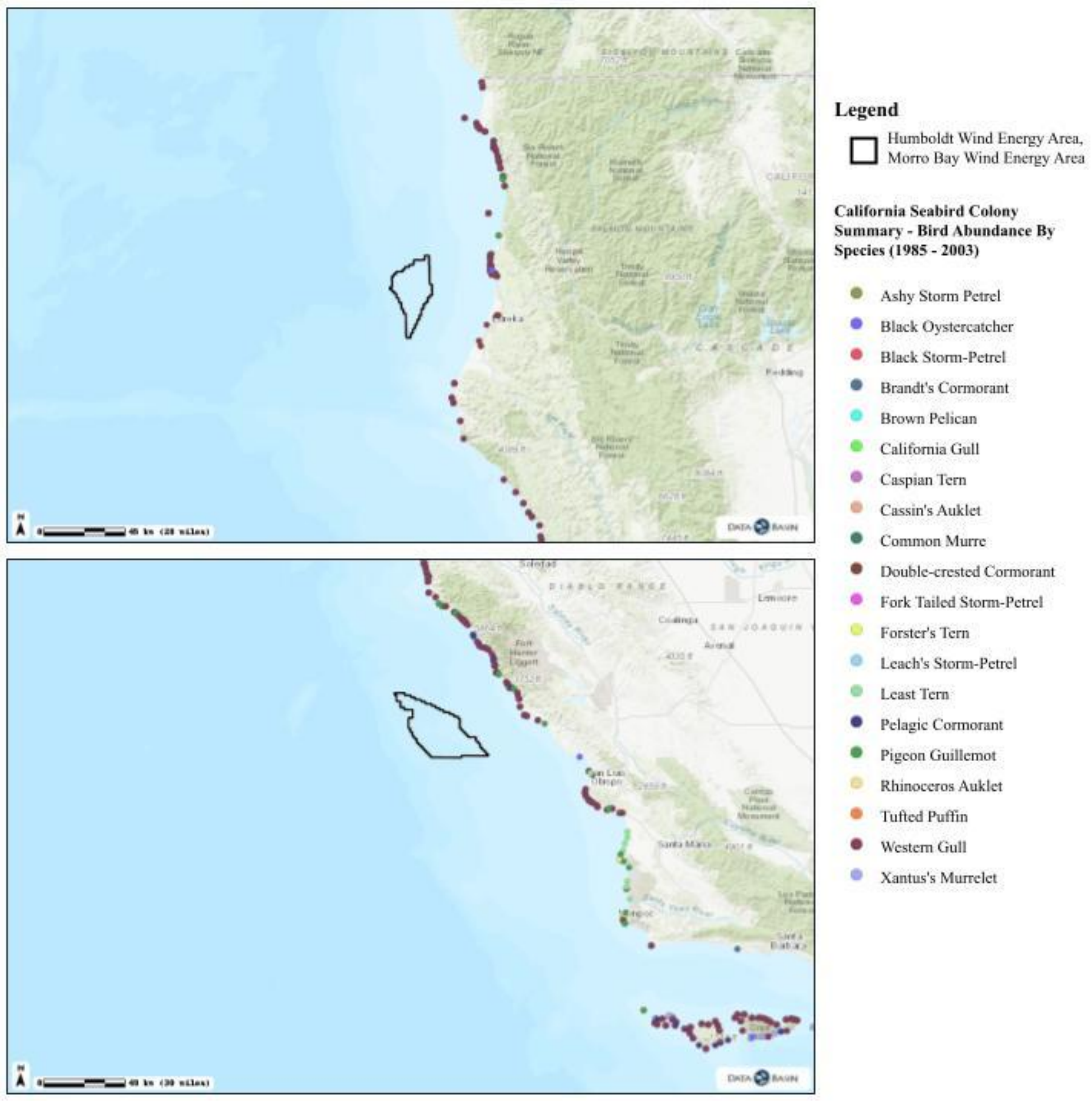


Figure 6: California Seabird Colonies and Spring Species Presence

Seabird colonies mapped from surveys performed 1985-2003. The top map shows the Humboldt WEA outlined in black and the bottom map shows the Morro Bay WEA outlined in black. Data provided by the U.S. Fish and Wildlife Service. Map created using Data Basin (Carter et al. 1992, 2000, Capitolo et al. 2004, Pendleton 2021b, 2021c).

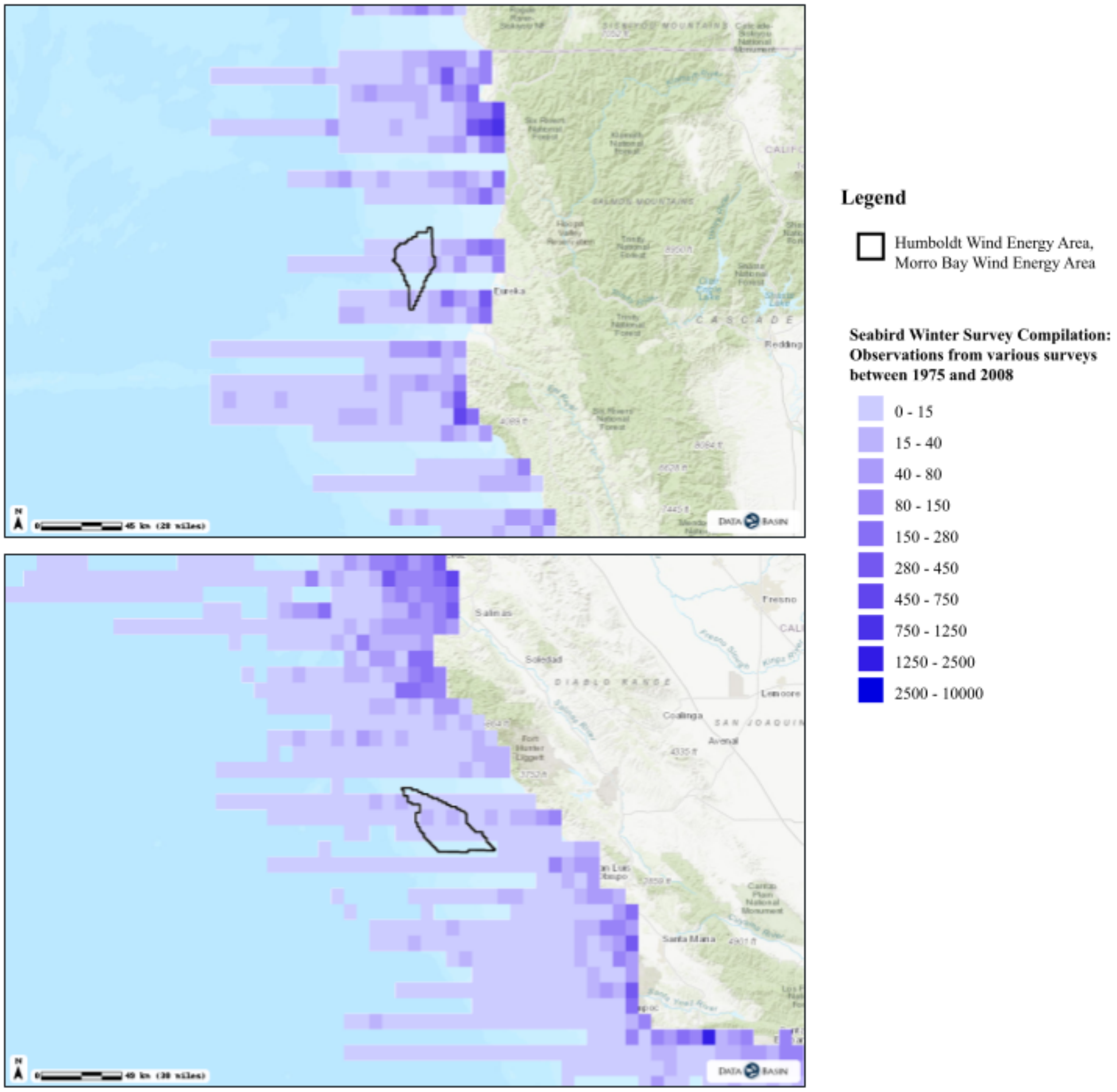


Figure 7: Seabird Survey Compilation: Winter

Compilation of all species for the winter season, years 1975-2008. The top map shows the Humboldt WEA outlined in black, the bottom map shows the Morro Bay WEA outlined in black. Lighter shades of purple represent fewer birds surveyed across all species and all years in winter. Darker purple shows higher abundance. Seabird distribution data are from CDAS, a compilation of at-sea survey data maintained by RG Ford Consulting Company under contract to California Department of Fish and Wildlife. This map was created using Data Basin (Briggs et al. 1987, Pendleton 2021b, 2021c).

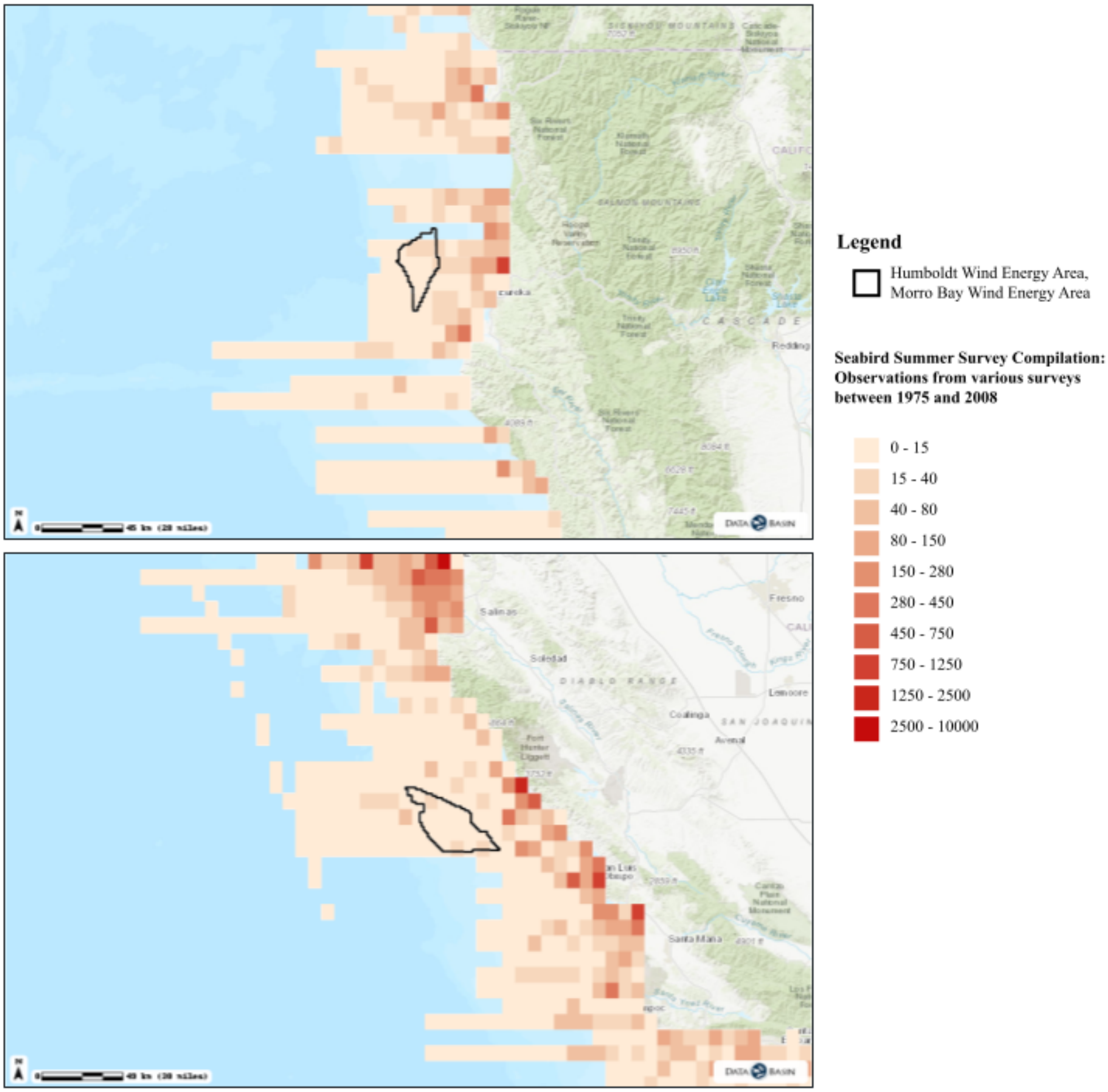


Figure 8: Seabird Survey Compilation: Summer

Compilation of all species for the summer season, years 1975-2008. The top map shows the Humboldt WEA outlined in black, the bottom map shows the Morro Bay WEA outlined in black. Lighter shades of orange represent fewer birds surveyed across all species and all years in summer. Darker orange shows higher abundance. Seabird distribution data are from CDAS, a compilation of at-sea survey data maintained by RG Ford Consulting Company under contract to California Department of Fish and Wildlife. This map was created using Data Basin (Briggs et al. 1987, Pendleton 2021b, 2021c).

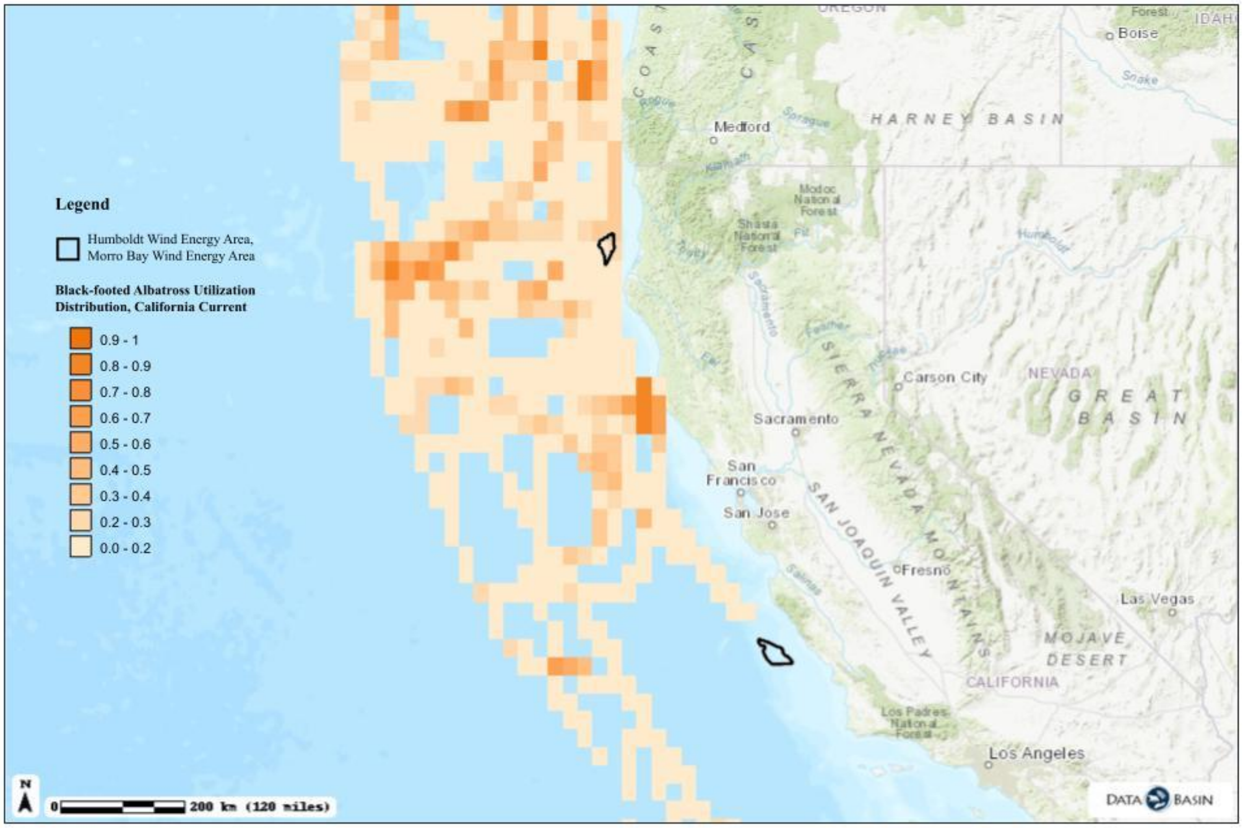


Figure 9: Black-footed Albatross Utilization Distribution

Utilization distribution of Black-footed Albatross (*Phoebastria nigripes*) within the California current system, clipped to the EEZ. Darker orange areas represent higher concentrations of albatross. The Humboldt and Morro Bay WEAs are outlined in black. Black-footed Albatross was chosen as one sample species due to their large foraging range and high collision risk. Data was provided by satellite and light-based geolocation tracking data from the Tagging of Pacific Predators project. This map was created using Data Basin (Maxwell et al. 2013, Pendleton 2021b, 2021c).

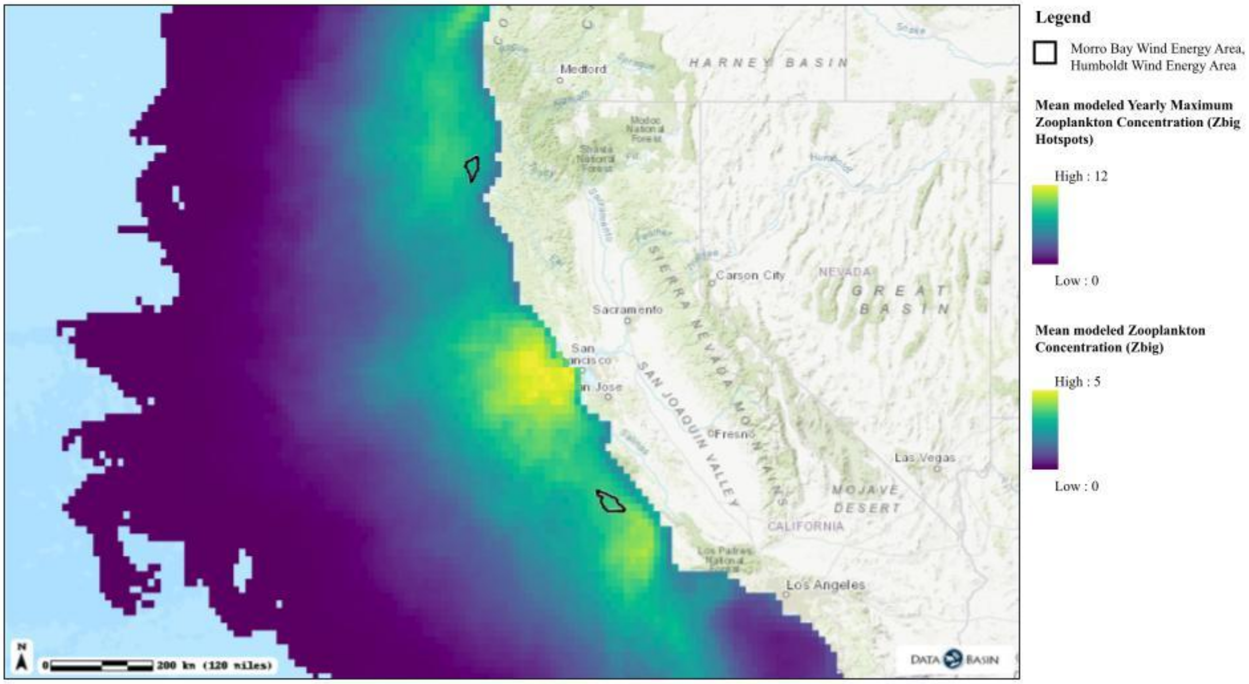


Figure 10: Modeled Yearly Krill Concentration

Mean modeled annual krill concentrations in the California current system. Lighter yellow areas illustrate high concentrations, darker blue areas lower concentrations. The Humboldt and Morro Bay WEAs are outlined in black. Krill data was provided by Monique Messié of the Monterey Bay Aquarium Research Institute. Map created using Data Basin (Pendleton 2021b, 2021c, Messié et al. 2022).

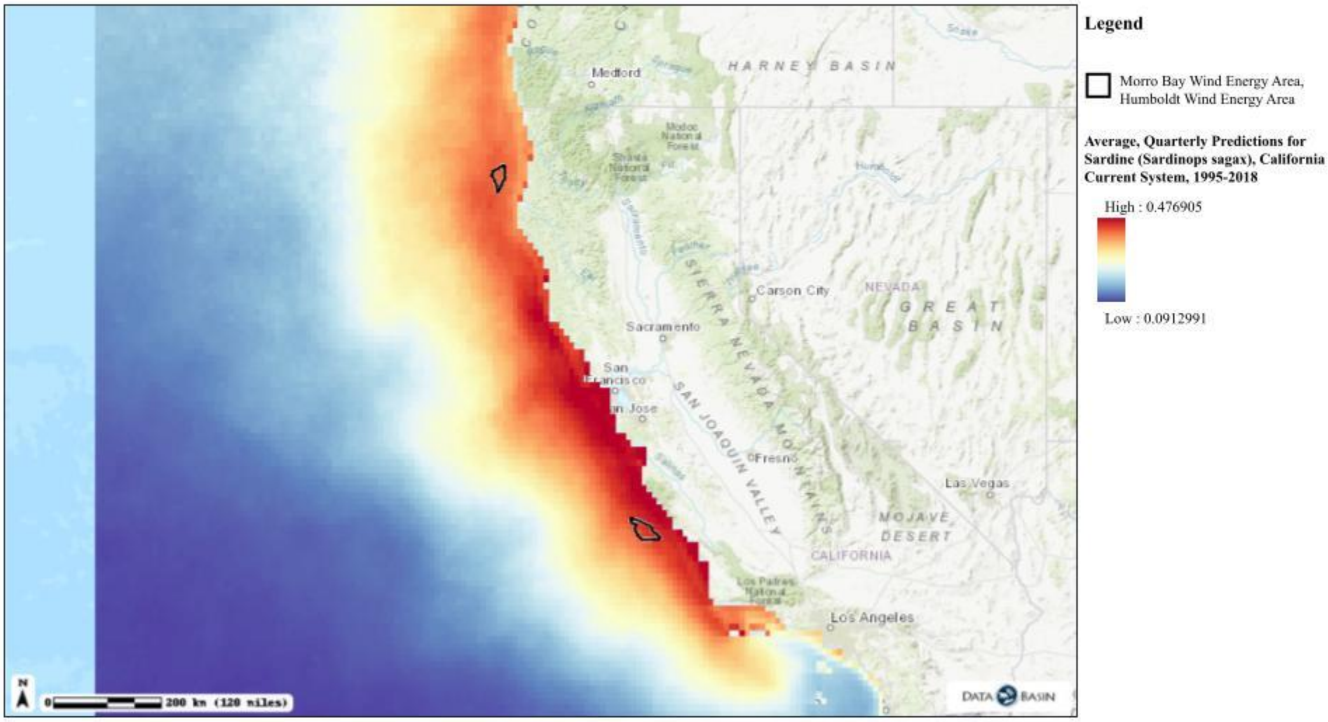


Figure 11: Average Quarterly Prediction for Sardines

Predicted sardine abundance in the California Current System for the 4th Quarter (October through December). Red areas signify high sardine concentrations, blue areas indicate lower sardine concentrations. The Humboldt and Morro Bay WEAs are outlined in black. Data provided by Barbara Muhling. Predicted probabilities of occurrence are from NOAA SWFSC trawl surveys. Map created using Data Basin (Muhling et al. 2019, Pendleton 2021b, 2021c).

3.2 Case Studies

Below are more details regarding the findings from surveys performed in Europe which monitored and reported on real bird collisions with offshore wind turbines. The methodology, offshore wind technology specifications, and bird species are outlined for each case. Additionally, main takeaways and relevance to the California WEAs are reviewed and outlined. These case studies were published in various forms, some peer-reviewed and published in the scientific literature and others are reports produced by or for energy companies. Despite not being peer-reviewed, the industry reports are valuable due to the small number of real studies performed on operating offshore wind projects and their collision impacts on birds. Criticism and limitations of methodology for each case is also outlined. These particular studies were selected for review due to their relevance to the species encountered in California, their findings for learnings to apply to California, or their similarity to array configuration predicted in the California projects.

The Humboldt and Morro Bay WEAs in California will be approximately 31-35 km (20-22 miles) from shore (Cooperman et al. 2022). In terms of collision risk, this distance from shore means passerines (songbirds), and other terrestrial species will not be migrating, foraging, nor commuting near the WEAs, with the exception of occasional vagrants. The species of concern for California, therefore, are only those marine reliant seabirds outlined above in Section 2.1 of this analysis.

Additional differences to be considered are the turbine specifications to be deployed in California. Specifications of the infrastructure will be unknown until the energy companies publish their COPs. The hub heights and blade lengths will define the rotor-swept zone, which may be different in practice than the dimensions used to calculate modeled risk. Due to technological advancements in wind turbine technology the dimensions and nameplate ratings will likely be larger than any deployed to date. Floating platforms and their mooring line technologies will be innovated for the California WEAs. And finally, turbine density and placement within the WEAs will need to be considered in their impact for collision risk.

Nogersund, Sweden 1994

The first offshore wind turbine was deployed in the south of Sweden near the fishing village of Nogersund in 1990 (Larsson 1994). Called “Svante 1,” this pilot project was created to test the environmental impacts of offshore wind turbines. The potential for offshore wind energy was newly emerging as a significant source of clean energy generation. Their study was designed to better understand impacts to birds, fisheries, shipping, public opinion, and the offshore wind infrastructure maintenance required by the harsh northern sea conditions.

The location for the turbine was specifically chosen on a bird migration route. Bird surveys were conducted for a two-year period during peak migration and looked at migratory birds, nearby breeding birds, and “resting” birds. Since the resting and breeding birds in the area were too few–and thus no impacts to these groups were found–they determined the data was insufficient to draw statistically significant conclusions. However, migratory bird routes were found to be impacted by the wind turbine, causing the birds to fly further out to sea. Fewer than

50% of the birds originally present remained within 500 m of the shore after deployment. Before the turbine was erected, 20% of migratory birds flew within 500 m of the shoreline, after which they reported only 9% of birds flying near the coast. While there were no collisions, this finding shows that wind turbines do displace birds and add distance to their migratory journeys.

Several limitations of this initial study make it inapplicable to current plans, especially in California. First, it was one turbine with a maximum output of 220 kW and a hub height of only 37.5 m. The turbine was positioned 250 m offshore, at a depth of 6 m (Larsson 1994). The paper did not detail the methodology of the bird surveys but it is assumed they were conducted by visual observations made by human observers, therefore it is possible some collisions were not detected.

Kalmar Sound, Sweden 2005

The southern Kalmar Sound off Sweden's south east coast is a high traffic bird migration route (Pettersson 2005). In 2000 and 2001 two small offshore wind farms were constructed in the Sound with a total of twelve 1.5 MW turbines. The Swedish Energy Agency requested a study be conducted on the wind farm's impact on the migrating birds of the area. The researchers surveyed during peak bird migration for a 3-week period in the spring and fall from 1999-2003. They looked at changes in migratory paths, species composition, collision avoidance based on weather conditions, and visibility. During times of good visibility, expert observers visually surveyed from three triangulated spots using an optical rangefinder. When visibility was poor, radar films were used to track migratory routes.

The surveyors observed a total of 859,000 birds in spring and 674,000 in fall across the four years. The majority of the spring migrants–95%–were eiders. Other species included other ducks, geese, and cormorants. During the four-year study period only one collision incident was reported. Four eiders in the outer flank of a flying v-formation were struck by a rotor. They fell into the water, where one bird died and three were observed leaving the water and flying back into their migratory route. Additionally, the observers counted five near-miss scenarios where a flock swerved quickly very near the turbine to avoid collision. Based on these observations the study concluded that the risk of collision is one bird per turbine per year. Despite this single collision and few micro-avoidances, the majority of the birds avoided the wind farm area completely, maneuvering away 1-2 km before the turbines.

The survey found that low visibility conditions such as fog did not result in more collision risk, mainly because the birds mostly chose not to fly in these conditions. Only 5-6% of the general abundance of birds was found in the sound in foggy conditions. About 22-27% of the birds there migrate at night, and the flocks did get closer to the wind farm at night, but were still able to avoid the area at an average distance of 500-1000 m.

In addition to migrating birds, the surveyors looked at "staging" birds in the sound and near the wind farms. Staging birds are those who are not currently on a migratory route but they are in the sound foraging, and spending more time on the water than in flight. The prevalence of staging birds in the wind farm area was dependent on food sources. When mussels were abundant in the shallow sound near the turbines, Long-tailed Ducks (*Clangula hyemalis*) in particular were found around the wind farm area. No collisions were reported among the staging birds and the authors hypothesized that the bow shaped configuration of the turbines, one row of turbines in an arched line, allowed the ducks to come in and out of the wind farm area without colliding.

The authors of the report also discussed the potential impact to birds of the additional energy required to avoid the turbine area. In this case, they concluded there was a 0.2-0.5% added distance to their full migratory route, which would not be significantly energy intensive and would therefore have relatively low impact on migratory birds. This result is optimistic but the wind farm areas in the Kalmar Sound are significantly smaller than California WEAs. The turbines in California will also be much larger than the Kalmar Sound turbines, which may help birds see and therefore avoid the area, but their route around a fully built out WEA will be longer.

Nysted and Horns Rev, Denmark 2006

A comprehensive study of birds, specifically migrating and resting seabirds, was performed preconstruction through operation phase in two wind energy areas off the coast of Denmark in Nysted and Horns Rev (Petersen et al. 2006). The surveyors used visual observations, radar, and aerial surveys to track bird locations and movements. Additionally, they deployed a Thermal Animal Detection System (TADS) which used infrared video monitoring. Based on real data collected on avoidance during construction and operation, they were able to model collision risk and migratory route changes around the wind farm areas. Using this modeling, they predicted collision rates of 0.018-0.020% with 95% confidence in the fall migration season. With the known 235,000 passing birds there each fall, this could result in 41-48 individual birds killed or injured in collisions. In reality, during their seven-year survey period, across all technologies, only one small unidentified bird collided.

Across all bird species they found 71-86% avoided the wind farm area at a 1.5-2 km distance at Horns Rev. At Nysted 78% of birds avoided the wind farm area (Figure 12). Those birds and flocks which entered the wind farm area navigated between turbines. The avoidance distances of the most abundant species, Common Eider (*Somateria mollissima*), were calculated to increase the migratory route by 0.5-0.7%. The researcher's detection techniques found that eiders did come closer to the wind farm area at night, but avoidance was still high. Surveys were not performed during low visibility conditions, but migration generally slowed or ceased in those conditions as well.

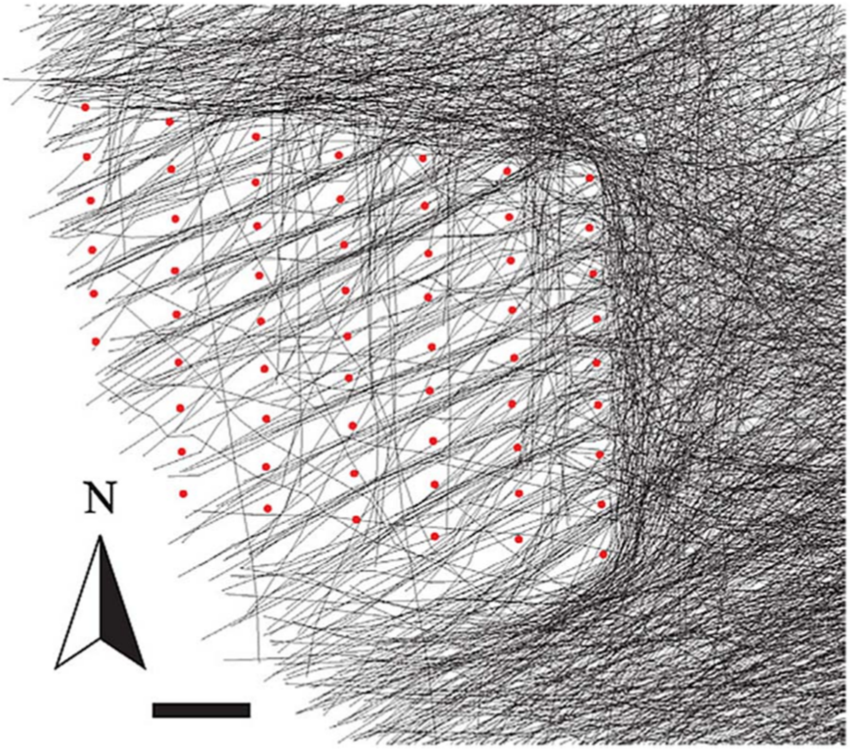


Figure 12: Visualization of Radar Tracked Bird Routes in Nysted

Black lines are radar tracked bird routes and the red dots are turbines in the Nysted offshore wind farm. This visualization shows the majority of birds avoiding the wind farm area entirely (Desholm and Kahlert 2005).

Certain species were actually found to be attracted to the wind energy area for foraging and roosting potential. Cormorants and gulls were specifically attracted to the turbine infrastructure for these purposes. However, these particular wind farm areas were close to natural sandbar formations where social roosting naturally occurred. Fortunately, California WEAs in Morro Bay and Humboldt do not have similar proximity to roosting areas of these social birds.

The wind farm areas studied here were larger and further from shore than the two studied areas outlined above. Nysted lies 10.5 km from the nearest shore and Horns Rev 14 km from land. The Nysted farm consisted of 72 turbines configured in a square with 69 m hub heights and 41 m blade radii, rated at 2.3 MW each. The Horns Rev farm consisted of 80 turbines with 70 m hub heights, 40 m blade radii with 2 MW ratings. While the individual turbines are smaller than the 12-15 MW turbines anticipated in California, the size and scope of the general area is more similar than other studies. The researchers also called out the need for additional future studies, particularly for the potential effect of habituation (Desholm and Kahlert 2005). The novelty of the turbines may be the leading cause for birds keeping their distance, and at some point they may become less fearful and approach closer, putting them at future risk of collision.

In 2009, a follow-up study was performed at the Nysted site (Masden et al. 2009). This second study focused on Common Eiders and the avoidance response impact on their migration distances. The authors determined that 500 m was added on to their migration journey to avoid the wind farm area. The additional 500 m was insignificant compared to their full 1400 km migration route, but the authors did caution that more offshore wind farms along their journey could have compound effects on their access to habitat, especially when compounded with other anthropogenic impacts. Their survey also concurred with the results of the 2006 report at the site previously described.

German Bight, Germany 2006

Beginning in 2004, surveys were conducted in the German Bight off Germany's north west coast (Hüppop et al. 2006). The researchers used radar taken from platforms, ship radar, thermal imaging cameras, audio recording, and human observers to track year round migration data of nocturnal and diurnal birds. Their results showed that roughly half of the birds observed were flying in the "dangerous altitudes" within the turbine rotor-swept zone. They tracked all birds, which in that particular area included terrestrial birds such as passerines (songbirds or perching birds). Terrestrial birds were more prone to attraction by lights on the turbines and were also more prone to collision.

The main purpose of their study was to document abundance and seasonality of bird movement in the German Bight, which is not transferable to different locations such as California's OCS. The birds migrating over the German Bight are different from the seabirds we have foraging and migrating further out at sea off California. They did, however, research collision. The platform created for the radar equipment collected carcasses of collided birds. Each carcass was examined for cause of death. Of the 442 collected carcasses determined to be killed by collision, only 6 were non-passerines (Hüppop et al. 2006). Remarkably, over 50% of the collision deaths occurred on just 2 nights with misty, low-visibility conditions. The authors hypothesize the illuminated platform attracted more birds in those low visibility conditions, increasing their chances of collision.

Zeebrugge, Belgium 2006

In November 2006 a sobering article was published reporting collisions of tern species with offshore wind turbines placed along a breakwater in Zeebrugge, Belgium (Everaert and Stienen 2007). The 25 small turbines lined a dam along the port; 14 turbines faced the sea and 11 faced the land. The wind farm was adjacent to a tern colony with nesting Sandwich Terns (*Thalasseus sandvicensis*), Common Terns (*Sterna hirundo*), and Little Terns (*Sternula albifrons*). Surveys were conducted for two years during the breeding season and collision calculations were estimated at 168 terns in 2004 and 161 terns in 2005. The row of turbines between the tern's breeding and foraging areas created a barrier, forcing terns to cross through the rotor-swept zone regularly.

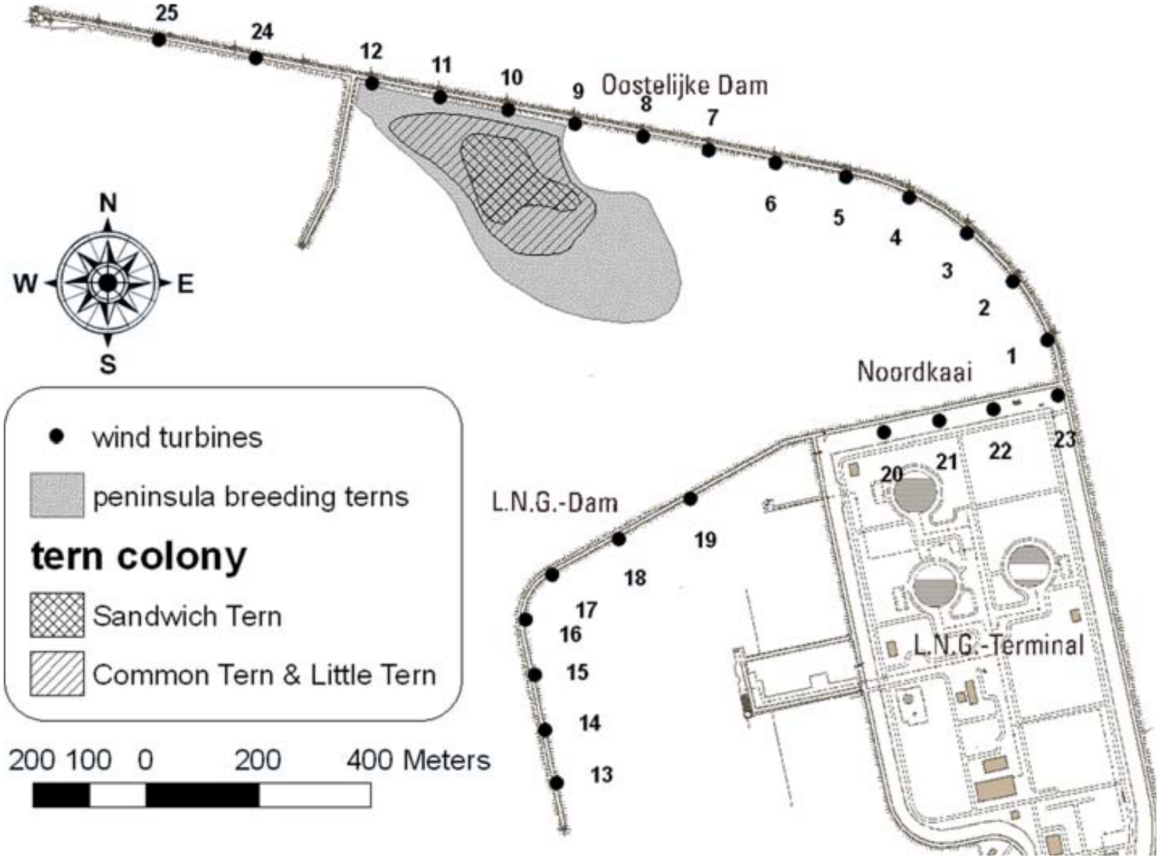


Figure 13: Map of the Zeebrugge Wind Farm Area

Turbines positioned on the Oostelijke Dam created a barrier between the tern breeding colony and the tern's foraging habitat at sea, resulting in collision mortality (Everaert and Stienen 2007).

While the location and configuration of these turbines are unlike anticipated California plans, it is an important reminder to keep WEAs far from breeding grounds. Commute from breeding or roosting areas to foraging grounds results in high traffic zones and even a single row of small turbines can become barriers, resulting in high collision rates (Everaert and Stienen 2007).

North Sea, Scotland 2023

In February 2023 Aberdeen Offshore Wind Farm Limited (AOWFL) produced a final report for a study conducted from 2020-2021 on seabird avoidance in Scotland's North Sea (Cox and Larsen 2023). The study was produced for Vattenfall, a Swedish state-owned energy company with energy projects all around Europe (Vaughan 2017). The study looked at four focus species, and their groupings, with breeding grounds near the WEA: Northern Gannet (*Morus bassanus*), Great Black-backed Gull (*Larus marinus*), Herring Gull (*Larus argentatus*), and Black-legged Kittiwake (*Rissa tridactyla*). The researchers collected information on day-time movement of birds during the breeding season and post-breeding dispersal, April through October, over a two year period. They surveyed bird avoidance on a meso and micro scale using radar-camera monitoring units able to produce 3-dimensional flight tracks. The study and its findings were produced in a report by Vattenfall; it should be noted that it was not peer-reviewed nor published in the scientific literature.

The radar detection system picked up approaching birds, triggering an automated response for orienting the cameras on the approaching bird. Camera tracking was aided by an AI-based tracking algorithm, orienting the cameras to the bird or flock as it approached turbines. The automated radar detection system did not work in rough sea conditions with high wakes, typically over 15 m/s winds, so a static camera system was used as a backup, with a fixed camera position, rotating between cameras at one-hour intervals. Additionally, due to their method of training the cameras, the authors admitted a bias against low flying birds. Fog was not discussed as a potential factor for both the technology to detect birds, and birds to see and avoid turbines. Their technology was able to detect over 10,000 birds inside the wind energy area and their results showed no collisions during the study periods.

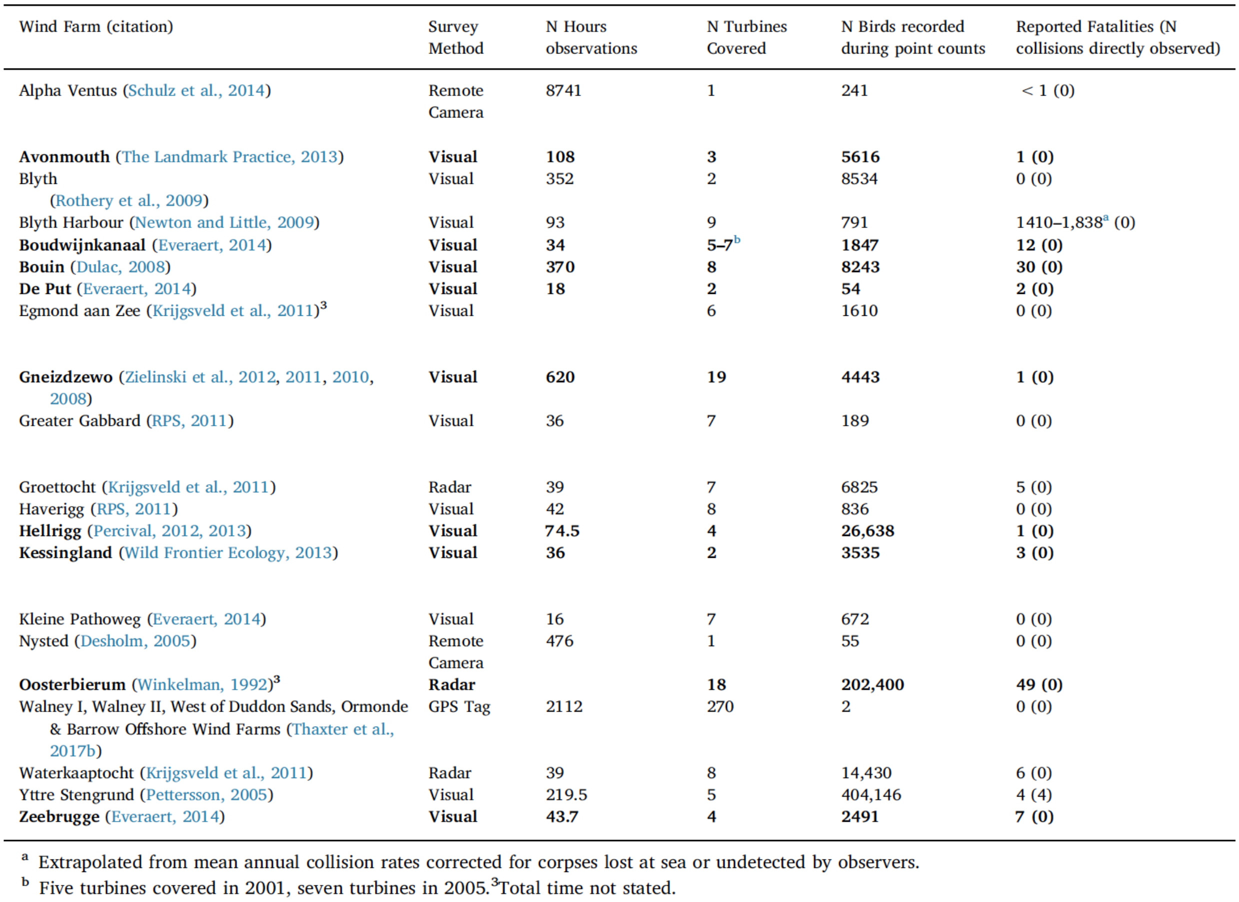
While none of the birds detected and tracked by cameras collided, it is unknown how many birds went undetected from the system entirely. This conclusion is optimistic but it should be said that there were major limitations of the study, especially when applying the findings to other geographic regions like California. In the AOWFL study area there were a total of eleven turbines, 8.6 MW rated, 164 m rotor diameter, and 108.5 m hub heights. Again, the California turbines are expected to have plate ratings of 12-15 MW, and hub heights of over 250 m. While the number and arrangement of turbines in California is yet unknown, the fully built out areas will likely contain hundreds of turbines.

Overview of Case Study Findings

In 2018 researchers in the U.K. synthesized the findings from various real collision studies to quantify the micro and meso avoidance rates of several gull species common in Europe (Cook et al. 2018). Their synthesis of information, in addition to Table 3 of this analysis, is useful in having a broad understanding of collision rates in offshore wind turbines. With the exception of the Blyth Harbor wind farm, reported fatalities from collisions have been very low (Table 5). It should be noted that the Blyth Harbor wind farm, similar to the Zeebrugge farm in Belgium outlined above, is very near shore and along a rock pier extending from the harbor (Newton and Little 2009). It is therefore not representative of the further offshore WEAs planned in California.

Table 5: Overview of Additional Case Studies in Europe

Compilation of surveys performed on seabird collision with offshore wind farms in Europe from 1992 to 2017 (Cook et al. 2018). Nysted and Zeebrugge listed below are explored in this analysis as well, however with later publications of the findings. The other wind farms are not explored here, and this table supplements the results found with the case studies in Table 3.



Wind Farm (citation)	Survey Method	N Hours observations	N Turbines Covered	N Birds recorded during point counts	Reported Fatalities (N collisions directly observed)
Alpha Ventus (Schulz et al., 2014)	Remote Camera	8741	1	241	< 1 (0)
Avonmouth (The Landmark Practice, 2013)	**Visual**	**108**	**3**	**5616**	**1 (0)**
Blyth (Rothery et al., 2009)	Visual	352	2	8534	0 (0)
Blyth Harbour (Newton and Little, 2009)	Visual	93	9	791	1410–1,838[a] (0)
Boudwijnkanaal (Everaert, 2014)	**Visual**	**34**	**5–7**[b]	**1847**	**12 (0)**
Bouin (Dulac, 2008)	**Visual**	**370**	**8**	**8243**	**30 (0)**
De Put (Everaert, 2014)	**Visual**	**18**	**2**	**54**	**2 (0)**
Egmond aan Zee (Krijgsveld et al., 2011)[3]	Visual		6	1610	0 (0)
Gneizdzewo (Zielinski et al., 2012, 2011, 2010, 2008)	**Visual**	**620**	**19**	**4443**	**1 (0)**
Greater Gabbard (RPS, 2011)	Visual	36	7	189	0 (0)
Groettocht (Krijgsveld et al., 2011)	Radar	39	7	6825	5 (0)
Haverigg (RPS, 2011)	Visual	42	8	836	0 (0)
Hellrigg (Percival, 2012, 2013)	**Visual**	**74.5**	**4**	**26,638**	**1 (0)**
Kessingland (Wild Frontier Ecology, 2013)	**Visual**	**36**	**2**	**3535**	**3 (0)**
Kleine Pathoweg (Everaert, 2014)	Visual	16	7	672	0 (0)
Nysted (Desholm, 2005)	Remote Camera	476	1	55	0 (0)
Oosterbierum (Winkelman, 1992)[3]	**Radar**		**18**	**202,400**	**49 (0)**
Walney I, Walney II, West of Duddon Sands, Ormonde & Barrow Offshore Wind Farms (Thaxter et al., 2017b)	GPS Tag	2112	270	2	0 (0)
Waterkaaptocht (Krijgsveld et al., 2011)	Radar	39	8	14,430	6 (0)
Yttre Stengrund (Pettersson, 2005)	Visual	219.5	5	404,146	4 (4)
Zeebrugge (Everaert, 2014)	**Visual**	**43.7**	**4**	**2491**	**7 (0)**

[a] Extrapolated from mean annual collision rates corrected for corpses lost at sea or undetected by observers.
[b] Five turbines covered in 2001, seven turbines in 2005.[3]Total time not stated.

3.3 Modeled Collision Risk

As demonstrated in the case studies above, detecting and counting real collisions with operating offshore wind farms poses many challenges (Drewitt and Langston 2006). In the terrestrial environment, collided birds fall to the ground where they can be found and counted by pedestrian surveys (Smallwood and Thelander 2008). While some carcasses are removed by scavengers before surveyors find them, counts can be improved by more frequent surveys and the use of dogs to find carcasses (Barrientos et al. 2018). Collision carcasses in the offshore environment will likely fall into the ocean where they will never be detected (Drewitt and Langston 2006).

For both terrestrial and offshore wind farms, emerging technology to detect collisions or approaching birds are being developed. Ground surveys and human observations in the terrestrial environment can be used to verify collision counts made by new technologies (McClure et al. 2018). But emerging technologies to detect proximate birds and collisions in the offshore environment are more difficult to validate through other detection means (Drewitt and Langston 2006). Collision Risk Models, therefore, are an important tool for anticipating the harm to seabirds of a proposed offshore wind project (Cook et al. 2018)

Modeled collision vulnerability requires the following information that are each an aggregate of multiple data: 1) Flight altitude (height off the water surface) and flight maneuverability of the birds in relation to the rotor-swept zone of the wind farm in question; 2) Avoidance rates, that is how often a species avoids the wind farm area or turbines, considered on the macro, meso, and micro scales; and 3) the likelihood of the bird to hit a blade if the turbine isn't avoided (Furness et al. 2013, Cook et al. 2018, Kelsey et al. 2018, Scottish Government 2022). This third parameter is based on the bird's flight speed, the rotation speed of the blade, and how often (how likely in time) the turbine is running and therefore spinning at a fast enough rate to cause collision when the turbine was not avoided. Other important considerations are how often a bird flies at night or in low visibility conditions like fog, what percentage of time the bird is flying as opposed to sitting on the water, and how specialized a bird is in their habitat selection (often a result of food specialization and food availability on the seascape) (Furness et al. 2013).

Seabird flight heights vary depending on the species and weather, as well as whether they are foraging, migrating, or commuting short distances between breeding/roosting and foraging grounds (Rajpar et al. 2018). And while observations have been made from multiple surveys and sources, species specific flight heights are generally inconsistent (Kelsey et al. 2018). Birds with high wing loading, that is a higher body mass to wing area ratio, typically fly by flapping their wings constantly and quickly (Ainley et al. 2015, Curious Minds 2023). Birds with lower wing loading, that is a larger wing area compared to body mass, glide to stay in the air. Understanding whether a species is a "flapper" or "glider" is important for understanding how their flight height will change in changing weather patterns, and how quickly they can maneuver to avoid collision with an object such as a wind turbine (Ainley et al. 2015). Generally, flappers can maneuver faster and avoid collision easier, where gliders are at the mercy of the wind current they are riding and cannot change direction quickly to avoid potential collision (Ainley et al. 2015).

2012 U.K. Vulnerability Assessment

In 2012 researchers in the U.K. assessed the vulnerability of bird species there to offshore wind farms by creating a collision risk index based on several factors (Furness et al. 2013). The authors aggregated flight height data from multiple sources, and came up with likelihood percentages of the species flying as high as the turbine blades commonly used at the time, 20-150 m above the sea surface. Flight height foraging, migrating, and commuting were included and aggregated in the percentage calculation. Additionally, they scored each species on their maneuverability, percentage of time flying, nocturnal flight time, disturbance by structures and vehicles, and habitat specialization. These parameters plus a score of the species conservation status were combined into a total risk score. Total risk scores ranged from 0 at the lowest, to 1306 at the highest. While data availability was a challenge, and extrapolations had to be made to fill gaps, their assessment is useful in having a broad picture of the potentially most vulnerable species.

Fourteen of the species investigated and given total risk scores by the researchers in the 2012 paper can also be found in the Pacific OCS. Despite the limitations of data availability, and the fact that the percentage of time flying in the rotor-swept zone is specific to the hub height and blade dimensions of the turbines found in the U.K. in 2012, I have included the Furness et al. score in Table 4. The conservation status component of the score is potentially regional, based on local population vulnerability, so this should also be taken into consideration for validity. The California Pacific OCS species not included in their analysis were given extrapolated scores from the most closely related and similarly sized species which were scored. Species were matched on genus, and size based on weight within species. If there was not a genus match, scores were extrapolated from similarly sized species in the taxonomic family. Extrapolated scores are marked in Table 4. Albatross, Pelicans, and Phalaropes had no near relatives from the U.K. list, extending out to no shared species within their taxonomic families. They were therefore given the matched highest score, 1306, to be maximally precautionary in collision risk assessment.

While the scores themselves, and their extrapolation to other species should be considered limited in their ability to draw conclusions about vulnerability, it is useful to understand vulnerability relative to other species. For example, the researcher's calculations showed that generally, gull species (scored between 200 and 1306) should be considered more vulnerable than shearwater species (scored 0) (Furness et al. 2013). In this way it is helpful to apply this broad vulnerability comparison to our California species.

Several years after their initial vulnerability assessment, Scottish researchers investigated the uncertainty of data used to score the seabird's vulnerability to collision and displacement (Wade et al. 2016). The duck species, storm-petrel species, several tern species, grebes, and the smaller alcid species were found to have very high uncertainty in their flight height time within the rotor-swept zone. Alternatively, many of the larger tern and gull species were found to have very low uncertainty ratings (Wade et al. 2016). Since the gulls were found to be most vulnerable by Furness et al. (Furness et al. 2013), it's an important caveat to understand this conclusion and their modeled high vulnerability is more certain. Those species with high uncertainty should be a priority for future studies, surveys, and data collection on flight heights.

2015 Flight Behavior Based Vulnerability Assessment

Collision and displacement vulnerability assessments have been completed specifically for the seabirds found in the California current system of the Pacific OCS. In their 2015 paper, *Seabird Flight Behavior and Height In Response to Altered Wind Strength and Direction*, researchers used a linear mixed model analysis of flight height and wind speed to rank seabird groups in their likelihood to be flying as high as the rotor-swept zone, and therefore at risk of collision (Ainley et al. 2015). Their data was collected from various surveys off the west coast of North and South America, far out into the equatorial Pacific Ocean, and around the polar seas of Antarctica. Part of their survey region included the California current system. Interestingly, their findings of collision vulnerability based on flight behavior contradicted some of the conclusions found in the U.K.

Their ranked slope values are included in Table 4. Sea ducks were not included in their analysis and surveys so I assigned them the matching highest value for maximum precaution in predicting collision vulnerability. Any slope greater than 0 can be interpreted as the species does fly as high as the rotor-swept zone and is at risk of collision (Ainley et al. 2015). In particular diving shearwaters, large alcids, and terns were found to be most vulnerable to collision. Large gulls were found to be least vulnerable, however the authors noted that this could have been due to the fact that the large gull data mostly came from commuting Western Gulls (*Larus occidentalis*), which may be flying lower than migrating large gulls in the U.K (Ainley et al. 2015). This conflict raises the importance of having region specific flight behavior data to assess collision vulnerability.

In addition to the collision vulnerability assessment performed under normal wind conditions, the researchers performed a cluster analysis on seabird survey data to determine how various birds change their flight style from flapping to gliding or gliding to flapping in increased wind speed conditions (Ainley et al. 2015). Species with a positive correlation between increased gliding style and increased wind speed are put at greater risk of collision in higher wind speeds. Species who tend to flap more than glide in increased wind speeds can potentially maneuver away from turbines in windier conditions.

2018 Population, Collision, and Displacement Assessment for California

In 2018 a comprehensive assessment was published in the Journal of Environmental Management (Kelsey et al. 2018). Researchers from BOEM and the U.S. Geological Survey systematically collected data for 81 species and performed calculations to score each species on their vulnerability to collision, displacement, and a general population vulnerability. Their best estimate values for population vulnerability and collision vulnerability are included in Table 5. Additionally, species were grouped and the group's population vulnerability estimates were compared to collision vulnerability (Kelsey et al. 2018).

While population vulnerability was diverse among taxons, species within groups were relatively consistent in their collision vulnerability, showing that groupings can be applied to species assumptions for collision vulnerability (Figure 14). Their conclusions were similar to those found in the U.K. with the most collision vulnerable species groups being skuas and jaegers, pelicans, terns, and gulls. They found that alcids and loons had the lowest collision vulnerability. Procellariiformes, sea ducks, and cormorants were found to be most uncertain. Pelicans, and the Brown Pelican (*Pelecanus occidentalis*) particularly, were found to be the species with the highest relationship between collision vulnerability and population vulnerability (Kelsey et al. 2018).

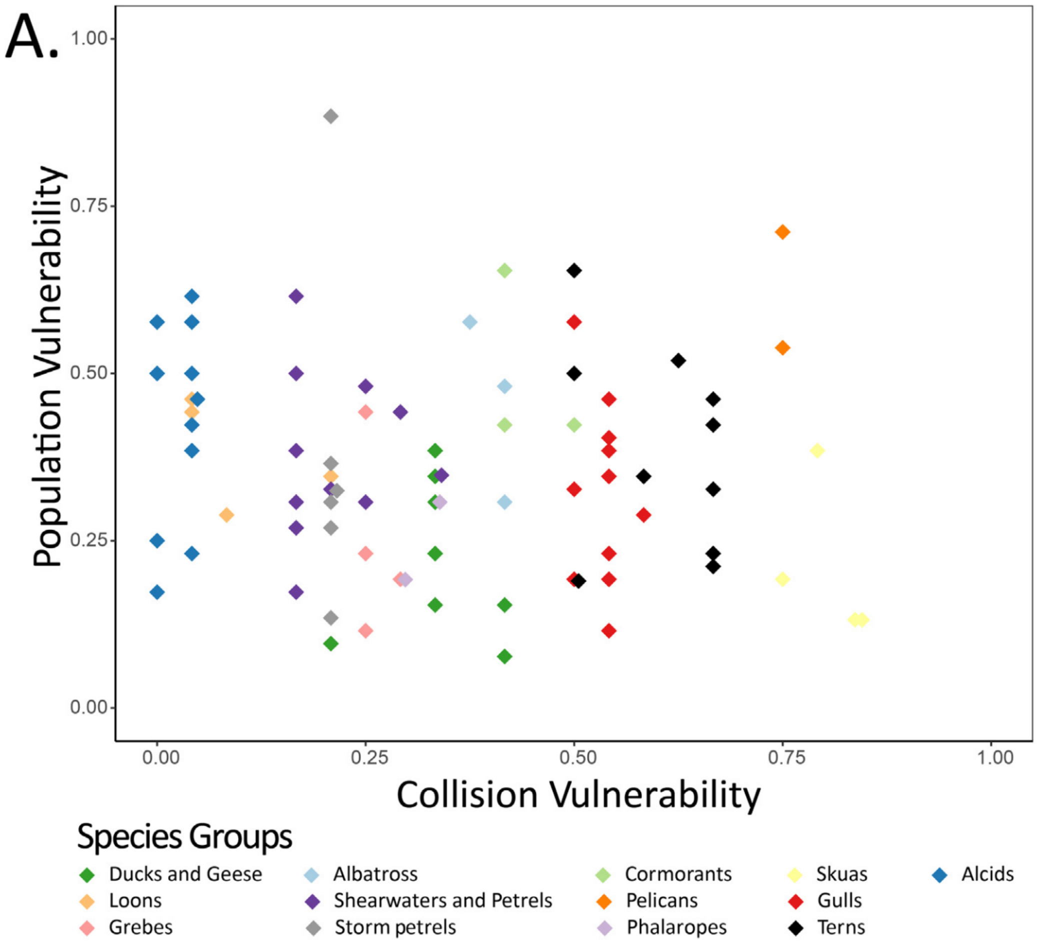


Figure 14: Population and Collision Vulnerability of California Seabird Groups

Percent rank values of grouped species population (y-axis) vs. collision (x-axis) vulnerability scores (Kelsey et al. 2018). Species with the highest population vulnerability percent ranks were Ashy Storm-Petrels, shown in gray, and Brown Pelican, shown in orange. This figure also shows how species within groups were consistent in their collision vulnerability.

The researchers created calculations for each of the vulnerability indexes. Because the population vulnerability and collision vulnerability indexes were calculated with different and specific values, they cannot be used in comparison to each other. For example one species' collision vulnerability score cannot be compared to its own, or another's population vulnerability score (Kelsey et al. 2018). For population vulnerability the following data were used in the calculation: global population size, annual occurrence in the Pacific OCS, proportion of the global population present in the Pacific OCS, threat status, annual adult survival, and a breeding score based on how likely the species is to be foraging to feed young in the Pacific OCS (Kelsey et al. 2018). For the collision vulnerability calculation the following data were used: percentage of time flying at night, percentage of time flying during the day, percentage of time spent in the rotor-swept zone based on flight height, and macro-avoidance rates (Kelsey et al. 2018).

For each of the vulnerability indexes calculated in the analysis, uncertainty was also included. The researchers used the uncertainty percentages to produce minimum, maximum, and best estimate values for each index for each species. Their paper was not specific in terms of the turbine height and blade length used to calculate the rotor-swept zone, but they referred to Furness, Johnston, Ainley, and others for this dimension, so it is assumed they considered the same turbine specifications previously discussed

4. Conclusions and Management Recommendations

Introducing human infrastructure into any environment, including the marine environment, will surely have impacts on natural ecosystems (Thaxter et al. 2015). Because anthropogenic activities such as burning fossil fuels have led to our current climate, and concurrent biodiversity crises we need clean energy solutions (Pörtner et al. 2022). Making informed management recommendations must start with understanding the most harmful impacts of these solutions. Because seabirds are long-lived and slow to reproduce, novel sources of harm such as turbine collision could have significant impacts to populations (Drewitt and Langston 2006). Additionally, a large number of the species found in the Pacific OCS are considered vulnerable, near threatened, or are already endangered, making their protection critically important (Table 1).

Seabird collision rates are generally very low, in most cases less than 1%, and in several cases with operating offshore wind farms no collisions were detected. Higher collision rates occurred when turbines were placed between breeding grounds and foraging grounds or in low visibility conditions with disorienting artificial lights. Modeled assessments concluded the most vulnerable species groups are pelicans, terns, albatross, medium and large gulls, sea ducks, phalaropes, and jaegers/skuas. Although the Humboldt and Morro Bay WEAs are not near breeding colonies, seabirds have large commuting routes extending as far as the shore to the WEAs and beyond. Additionally, the majority of species present are winter and non-breeding residents so their routes are potentially less predictable than migratory routes and must be better understood before construction.

Both the real case studies and the theoretical modeling showed increased collision vulnerability in low visibility conditions, both nighttime flying of birds and flying during foggy or misty weather conditions (Petersen et al. 2006, Hüppop et al. 2006, Kelsey et al. 2018). Specific weather visibility conditions in the offshore WEAs in California should be well understood and considered for operations of the wind turbines. Lights on offshore infrastructure compound the collision risk (Hüppop et al. 2006). More discussion on lighting recommendations will be made in Section 4.1.3.

4.1 Management Recommendations

Despite the overall low risk of collision, seabirds found in the Pacific OCS are particularly vulnerable to population declines and already face significant threats. Every effort should be made to ensure collisions are in fact low and do not pose a threat. There are several key factors that impede a bird's ability to avoid turbines, increasing their risk of collision: placement of turbines and wind energy areas in relation to breeding or roosting grounds and foraging locations, visibility conditions, artificial lights, and attraction to the wind energy area through food availability and roosting opportunities. These factors and the management recommendations to mitigate their impacts will be discussed in more detail below. Additionally, more information will be needed to prevent seabird collision in the offshore wind energy areas in California and those needs are outlined.

4.1.1 Understanding High Traffic Zones

The frequency of commuting trips between breeding or roosting colonies and foraging grounds puts birds at higher risk of turbine collision when the turbines interrupt the spaces between those two important habitat areas. One of the most alarming case studies was that of the Zeebrugge Belgium wind farm located on a breakwater just off the harbor (Everaert and Stienen 2007). Over a 2-year study period 329 terns were found deceased from collision with wind turbines. The primary reason for that high mortality was the location of the wind turbines directly between the tern's breeding colony and their foraging ground. Several times a day the terns needed to cross through the turbines in order to get to their food source.

While the Humboldt and Morro Bay WEAs are not proximal to any known breeding colonies, more surveys are needed to understand the foraging patterns of the seabirds in the WEAs. Some seabird species travel extreme distances, daily, to forage grounds from both breeding and non-breeding season roosting colony sites. Mapping of all the bird species movements and their prey movements should be performed to understand the high traffic areas in and around the WEAs.

4.1.2 Low Visibility Conditions

Collision risk is generally low because seabirds use vision to navigate through their environment. In good visibility they can see and avoid WEAs with several kilometers buffer.

Therefore, collision risk increases in low visibility conditions. Low visibility includes night-time movement as well as fog and misty conditions. In the German Bight case study for example, 50% of the collision deaths occurred in only two nights of low visibility (Hüppop et al. 2006). Some species regularly forage and migrate at night and their movement should be a priority for data gathering and surveys. It may be that while collision risk increases in fog and mist, birds tend to fly less, offsetting the risk, but this should be studied further. To understand increased collision vulnerability we need to learn if our California Pacific OCS seabird species fly less when weather creates poor visibility conditions.

One way to potentially mitigate collisions in low visibility or other conditions is to curtail wind operations. Curtailment means stopping operation of a particular turbine, or an entire array for a period of time. Effectiveness of curtailment is unknown, birds can still collide with wind turbines not actively spinning (Croll et al. 2022). But once turbines are deployed, it's the only way to potentially reduce collisions. More information on curtailment efficacy should also be studied.

4.1.3 Curbing Artificial Lights

Artificial lights distract, disorient, and attract birds (Brown et al. 2023). The marine environment is no exception, and birds have shown attraction to lights on offshore wind infrastructure (Hüppop et al. 2006, Croll et al. 2022, Brown et al. 2023). Compounded with low visibility conditions, lights attract birds to the offshore wind turbine areas and increase collision risk. Light impacts can be improved with the following simple measures: minimizing the amount of lights to the absolute minimum required, directing light downward, using blue or green lights instead of broad-spectrum or red and white lights, and using slow intermittent flashing lights rather than permanent (Drewitt and Langston 2008, Farr et al. 2021, Croll et al. 2022).

4.1.4 Preventing Attraction to WEAs

Seabirds can be attracted to WEAs for two primary reasons: roosting opportunity and foraging opportunity (Boehlert and Gill 2010, Croll et al. 2022). Large-scale offshore wind energy projects have the ability to attract and protect fish populations, becoming refuges for fisheries and artificial reefs for stationary invertebrates (Inger et al. 2009, Boehlert and Gill 2010). While the reef effect may be beneficial for some fish species, it could attract birds to the area for foraging grounds. Little is known about preventing this effect from happening but more research is needed, and certainly more monitoring of birds in and around the area is needed to better understand the extent of the issue.

The case study from the Kalmar Sound in Sweden investigated staging birds who foraged in the waters underneath the wind turbines (Pettersson 2005). They found no collision with these staging birds and hypothesized the reason to be the configuration of turbines. The Kalmar Sound wind farm was made up of one bow shaped row of turbines. Birds foraging around the turbines would take off from underneath the turbines and fly low out and away. There wasn't an additional row or rows of turbines to collide with when entering or exiting the area. This likely will not be the case with the Humboldt and Morro Bay WEAs where turbines are expected to be in a grid formation. However, if forage attraction is proven to be an issue in these WEAs based on future surveys, single row turbine configurations may be a potential solution for other wind energy areas off the California coast.

Most seabirds are social roosters, and some need time perched up out of the water for preening and rest. The offshore wind infrastructure such as turbines and their platforms may be attractive to seabirds as a roosting and perching opportunity, bringing them near the turbines and at greater risk of collision. Perching and roosting attraction can be prevented with anti-perching designs, and it is recommended that these anti-perching designs are included from the first turbine deployments.

4.1.5 Ongoing Data Collection and Monitoring

Data collection should begin before, to establish baseline conditions for comparison, and continue after offshore wind turbines are deployed in the WEAs (Desholm et al. 2006). Long term data collection and monitoring should be implemented (Croll et al. 2022). By using state-of-the-art technology included on the offshore wind infrastructure to track bird movement in and around the WEAs, we can learn more about bird avoidance rates and flight behavior to better site future wind energy projects. Data collection methods include radar, infrared camera systems, aerial surveys, and visual surveys from humans on ships. Validating and training data collection can be challenging in the offshore environment especially, but deploying multiple strategies together can improve data validation. Government agencies should require data collection, including public sharing of the data, as a condition of approval for their offshore wind energy projects.

4.2 Additional Information Needed for Predicting Collision Risk

More surveying, studying, and modeling is critical for ensuring the lowest possible collision events in the California offshore wind area, and future projects around the world. Data collection should begin before construction of turbines and continue after deployment. Methods for data collection should include technology able to detect bird collision without carcass recovery. Because birds follow their food sources in the marine environment, and those areas of increased abundance may change over time, long term multi-year studies are important for reducing harm to the marine environments generally, and bird collision specifically (Thaxter et al. 2015).

As outlined in Section 2.1, most of the seabird species present in California are resident species (Table 1). Their routes and use of the seascape are therefore not as easily predicted as a migration route as in the case of many of the case studies explored in this analysis. Weather conditions, prey availability and distribution, and roosting/breeding colony locations relative to foraging grounds will inform the movement of species across the seascape and therefore their susceptibility to turbine collision. Thoroughly understanding these resident species movements, in addition to migratory routes is critically important.

4.2.1 Region Specific Flight Behavior and Avoidance Rates

The key to predicting collision vulnerability is understanding avoidance rates and flight behavior. Because avoidance rates and flight behavior vary by species, weather conditions, turbine sizes, and the spatial patterns of turbine arrays, more data collection on California WEA specific parameters will ensure the safety of seabird populations. Once the COPs are produced, recalculations of collision vulnerability models should be performed with exact turbine specifications and region-specific flight behavior and avoidance rates.

Better data collection can also improve models and their ability to predict and thereby prevent collisions. One method for collecting bird flight route, altitude, and avoidance rates is GPS tracking (Cleasby et al. 2015). While GPS tracking can be resource intensive, and has some potential impacts to the individual birds tagged with trackers, it can return incredible amounts of information on how and when birds use their ocean resources in and around WEAs. High resolution GPS trackers can return data on precise flight paths of birds, giving more accurate flight height information as well as real avoidance rates on macro, meso, and micro scales (Figure 15).

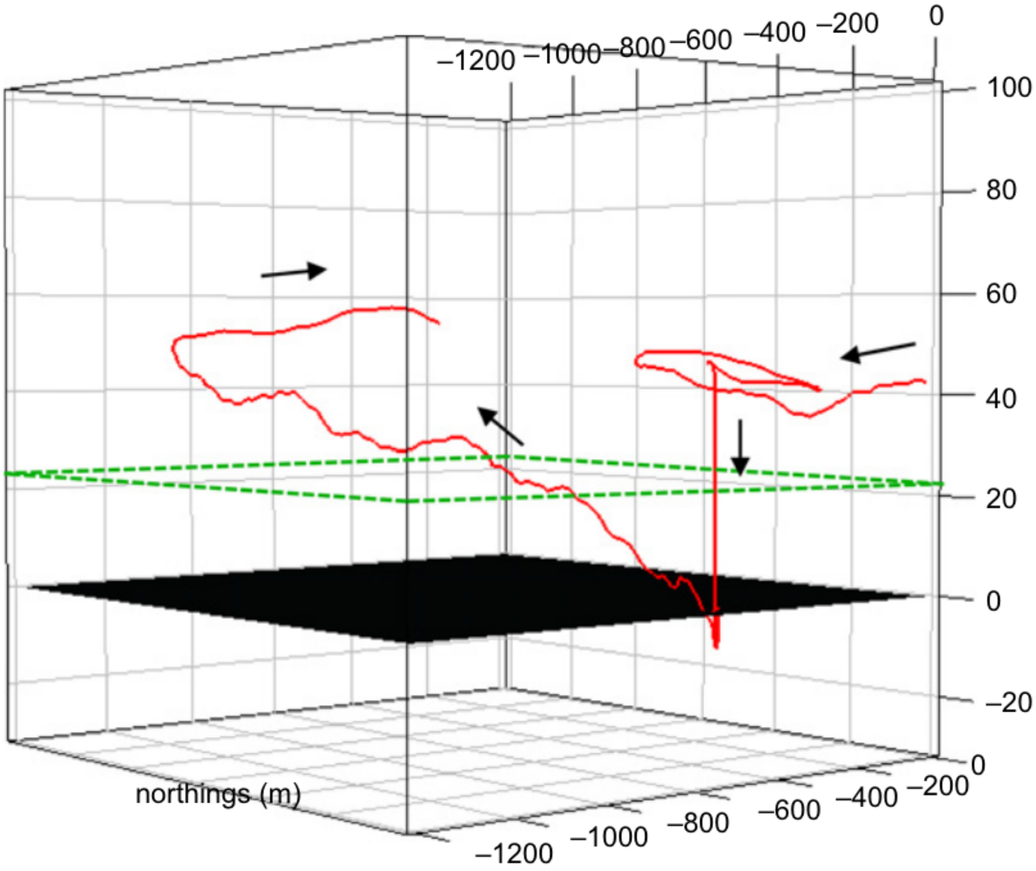


Figure 15: High Resolution GPS Tracking of a Gannet

Three-dimensional graph showing the movements of a gannet during a 5-minute period. The black square represents the water's surface. The bird plunge-dived under the water in this period. The green line at 22m altitude represents the area of potential collision risk with wind turbines (Cleasby et al. 2015).

4.2.2 Turbine Arrangement and Spacing

I was unable to find any case studies which looked at turbine density or spacing and bird collision rates, prompting the need for future studies. Only two studies suggested arrangement of turbines in rows running parallel to migration routes (Drewitt and Langston 2006, Hüppop et al. 2006). This suggestion makes intuitive sense, reducing the chances of a bird encountering the rotor-swept zone head on, creating a safe corridor through turbines. Surprisingly, this suggestion was not found in other sources. More information on the effectiveness of this method, its impacts on energy output, as well as better understanding of the California seabird's routes could reduce collision risk. Because many of the seabirds in California are not migrating, but rather seasonal or year-round residents, the effectiveness of this strategy may be limited. The routes California seabirds take around the seascape may not be unidirectional, as in a simple north-south migratory route. Again this calls for better tracking and region specific flight route mapping.

Spacing of turbines is another key component that may affect avoidance rates but is not well understood. In the real case studies as well as the modeled collision vulnerability assessments, turbine spacing was not stated nor analyzed, it is therefore not possible to consider for collision risk here. However, future studies in the Pacific OCS should consider turbine spacing for its potential to affect bird avoidance rates, especially macro-avoidance. Because the turbines in California are larger with mooring line footprints increasing the spacing between turbines, macro-avoidance rates may be affected. It is thought that birds avoid the entire wind farm area because it is functionally one solid obstacle to fly around. If there are less dense configurations, sprawling over a larger space in the seascape, it's possible the birds will not go around the entire WEA (Miles 2022). This further calls for region specific surveying, both before and after deployment of turbines.

4.2.3 Improved Visibility of Turbines

Painting turbine blades may improve avoidance in good visibility (Drewitt and Langston 2006), however this is not well understood nor well studied. More information is needed on the maximally visible turbine colors or paints such as UV paint. Studies should investigate the potential for improved avoidance with painted blades across weather conditions, and species-specific variation.

4.3 Additional Considerations for Seabirds and Offshore Wind

This analysis focused only on collision, one impact to one group of animals in an ecosystem of incredible biodiversity. Because collision causes mortality, collision avoidance is a primary concern. But when birds avoid collision, especially in the macro-avoidance scale, they are potentially displaced from critical habitat. In addition to displacement, or creation of barriers, going around WEAs causes the birds to expend additional energy. These secondary impacts of habitat loss through displacement, barriers, and added energy costs should be investigated fully.

The Humboldt Bay and Morro Bay WEAs are only the start to offshore wind in California. To meet our clean renewable energy goals, another 20 GW will need to be in operation by 2045, four times the energy generation potential of the combined WEAs discussed here. We should not only be investigating the impacts to the marine environment of the current projects, but the cumulative effects of the projects going forward in the long term future (Petersen et al. 2006). Displacement and habitat loss for seabirds now may be negligible, but when there are four or five times as many large WEAs off the California coast the impacts could be considerable.

That said, climate change is the largest threat birds and all other life face. We need large-scale clean renewable energy and offshore wind in California has the potential to be a reliable source. All energy infrastructure will have impacts on wildlife and the environment, especially habitat loss and displacement. If collisions with offshore infrastructure are very low, offshore wind can be compared to other energy sectors for its secondary and indirect impacts. Priority should be placed on energy sources with the least impact on the natural environment, considering their potential for maximal energy generation.

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