

Ecosystems Mission Area—Species Management Research Program

Prepared in cooperation with the Bureau of Ocean Energy Management

Revised Marine Bird Collision and Displacement Vulnerability Index for U.S. Pacific Outer Continental Shelf Offshore Wind Energy Development



Data Report 1214

Cover. Guadalupe Murrelet (*Synthliboramphus hypoleucus*) on the water. Photograph used with permission by David Pereksta, Bureau of Ocean Energy Management, 2024.

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By Emma C. Kelsey, Jonathan J. Felis, David M. Pereksta, and Josh Adams

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Conversion Factors

International System of Units to U.S. customary units

Multiply	By	To obtain
	Length	
meter (m)	1.094	yard (yd)

Datum

Horizontal coordinate information is referenced to the World Geodetic System of 1984 (WGS 84).

Abbreviations

BOEM	Bureau of Ocean Energy Management
CV	Collision Vulnerability
DFA	Diurnal Flight Activity
DV	Displacement Vulnerability
FA	Flight Activity
FM	Foraging Mode
FS	Foraging Specificity
HF	Habitat Flexibility
HS	Habitat Specificity
MA	Macro-Avoidance
N&D	Nocturnal and Diurnal
NFA	Nocturnal Flight Activity
OWEI	offshore wind energy infrastructure
POCS	U.S. Pacific Outer Continental Shelf
PV	Population Vulnerability
RSZt	time spent in the Rotor Swept Zone
SS	Spatial Specificity

Revised Marine Bird Collision and Displacement Vulnerability Index for U.S. Pacific Outer Continental Shelf Offshore Wind Energy Development

By Emma C. Kelsey,¹ Jonathan J. Felis,¹ David M. Pereksta,² and Josh Adams¹

Abstract

The installation of offshore wind energy infrastructure (OWEI) at sea may affect marine birds by increasing the risk of mortality from collision with OWEI (Collision Vulnerability) and causing disturbance and displacement from important habitats (Displacement Vulnerability). In 2017, we published the first comprehensive database quantifying marine bird Collision Vulnerability and Displacement Vulnerability to potential OWEI in the region of the U.S. Pacific Outer Continental Shelf (POCS; waters within the Exclusive Economic Zone of California, Oregon, and Washington). We have updated this Vulnerability Index with new research and data, additional species present in the POCS, and an evolved understanding of the application and utility of the Index. Of the species assessed, phalaropes and Red-billed Tropicbird have the highest Collision Vulnerability, and gulls, terns, jaegers, skuas, and pelicans have moderately high Collision Vulnerability. Boobies, sea ducks, and pelicans have the greatest Displacement Vulnerability. The overall trends in ranked Vulnerability among marine birds in the POCS were consistent between Version 1 and Version 2 although new data and revised calculations updated the outcomes. Alcids,

loons, storm-petrels, Brant, and phalaropes ranked higher for Collision Vulnerability in Version 2 compared to Version 1; sea ducks, cormorants, skua, and jaegers ranked lower for Collision Vulnerability in Version 2 compared to Version 1. Displacement Vulnerability ranks were higher in Version 2 for gulls, pelicans, sea ducks, and alcids and lower for albatrosses, terns, and loons. Vulnerability Index Version 2 is an up-to-date, representative, and transparent assessment of marine bird vulnerability to potential offshore wind energy development. This updated Vulnerability Index can assist resource managers and others in understanding and addressing potential interactions between OWEI and marine bird species that inhabit the POCS.

Introduction

Offshore wind energy is a rapidly developing renewable energy source for coastal communities. Seabirds are among the most threatened groups of birds, due in part to their exposure to cumulative anthropogenic threats (Croxall and others, 2012; Maxwell and others, 2013; Phillips and others, 2023). The installation of OWEI at sea may affect seabirds and other marine bird species in several ways, including adding potential collision with OWEI (Collision Vulnerability [CV]) and changing foraging and movement costs associated with disturbance and displacement of individuals within their habitats at sea (Displacement Vulnerability [DV]).

¹U.S. Geological Survey Western Ecological Research Center, Santa Cruz, CA 95062.

²Bureau of Ocean Energy Management Pacific OCS Region, Camarillo, CA 93010.

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The U.S. Pacific Outer Continental Shelf (POCS; the Exclusive Economic Zone off California, Oregon, and Washington) supports diverse and abundant marine bird species that breed in or migrate to and through the California Current Large Marine Ecosystem (fig. 1). Marine bird species of conservation concern are found throughout the POCS, including several listed as threatened or endangered under the Endangered Species Act of 1973 (<https://www.govinfo.gov/app/details/STATUTE-87/STATUTE-87-Pg884>, as amended); several also listed as State species of conservation concern within California, Oregon, and Washington; and several long distance migrants that are recognized as endangered in other countries (for example, Pink-footed Shearwater [*Adrenna creatopus*]). In 2017, we published the first comprehensive database to quantify marine bird vulnerability to potential OWEI in the POCS (Adams and others, 2017; Kelsey and others, 2018). This Vulnerability Index Version 1 built upon similar indexes created for the OWEI in the North Sea and the U.S. Atlantic Outer Continental Shelf (Garthe and Hüppop, 2004; Desholm, 2009; Furness and Wade, 2012; Furness and others, 2013; Robinson Willmott and others, 2013). By drawing from metrics that quantified marine bird life history, characteristics, and behaviors, Version 1 generated relative Population Vulnerability (PV), CV, and DV for all marine bird species in the POCS.

Since Version 1 was completed, new research and data have become available, increasing our understanding of marine bird vulnerability to OWEI. In addition, changing oceanographic conditions have brought new species into the POCS. Furthermore, our understanding regarding the development and application of Vulnerability Indexes have evolved based on practitioners' use of Version 1 within the POCS and studies in other parts of the world. Thus, to better inform potential offshore wind energy development in the POCS, we have updated the marine bird Vulnerability Index to include the following:

- New research and data
- Additional species present in the POCS
- Calculation updates to better reflect the application of the index

Herein, we present Version 2 of our Vulnerability Index, which provides a current (as of 2024), transparent, and representative quantification of marine bird vulnerability to potential OWEI in the POCS. In cooperation with BOEM and to support their management decisions, the Vulnerability Index Version 2 can be used to inform research, evaluation, and planning for offshore wind energy development in this region.

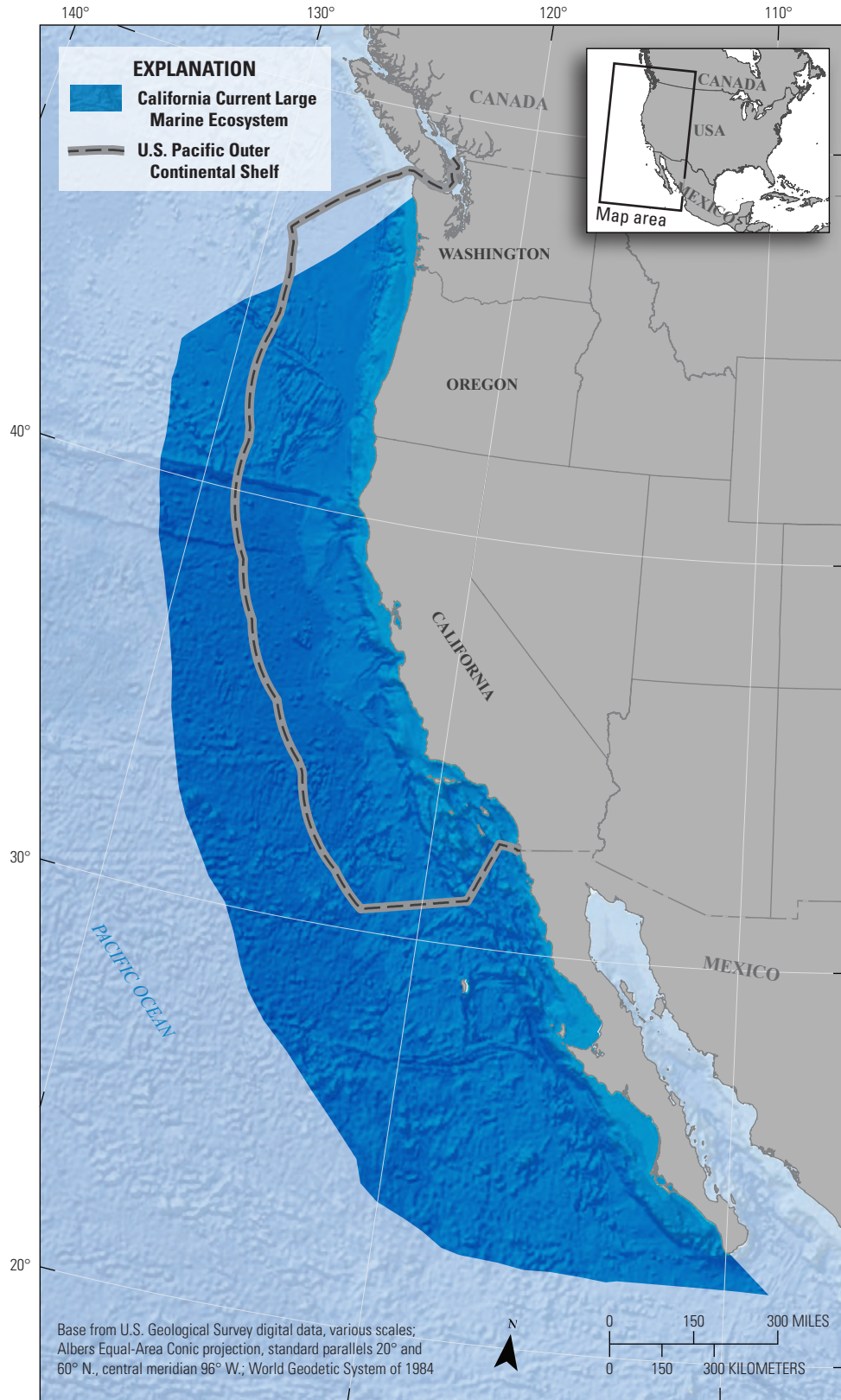


Figure 1. Map of the U.S. Pacific Outer Continental Shelf (gray line with dashed-black line) in relation to the California Current Large Marine Ecosystem (dark-blue shading) along the west coast of North America, including California, Oregon, and Washington.

Methods

Herein, we describe general methodological updates since our Vulnerability Index Version 1, including species selection, literature used, and equation and metric updates. We also describe our specific methods for generating Collision Vulnerability and Displacement Vulnerability.

Vocabulary

The words “vulnerability” and “sensitivity” are used to describe the quantification of marine bird interactions with OWEI. Garthe and Hüppop (2004) used both terms, creating a Sensitivity Index that quantified metric values of marine bird interactions with OWEI and then applied it spatially to species distributions to generate “vulnerability” values. Desholm (2009) also used “sensitivity” to refer to their Index values. Furness and others (2013) used “vulnerability” to refer to their Index values. Robinson Willmott and others (2013) used the terms “sensitivity” and “vulnerability” in describing their marine bird index values; however, they

use “sensitivity” to refer to their Index values (for example, Population Sensitivity, Collision Sensitivity, and Displacement Sensitivity). Since the publication of these indexes quantifying marine bird interactions with OWEI, as well as Version 1 of this index, these terms have continued to be used and defined in the context of marine bird interactions with OWEI (Goodale and Milman, 2016; Guşatu and others, 2021; Croll and others, 2022). We recognize that the way we use the term “vulnerability” to describe the indexes of Collision Vulnerability and Displacement Vulnerability presented in this study may differ from the use of the term in other studies; however, this usage is consistent with Version 1 and understood by outside user groups. The abbreviations, names, and definitions of the Vulnerability Indexes and their associated metrics are found in [table 1](#).

We define marine birds as all species that spend a significant portion of their time in the waters of the POCS. We include additional, rarely-seen species (even if they are in low abundance) that rely on important habitats in the POCS. Refer to the “[Species Selection](#)” section below for more details.

Table 1. Abbreviations, names, and definitions of Version 2 Vulnerability Indexes, and their associated metrics, used to quantify marine bird vulnerability to potential offshore wind energy infrastructure (OWEI) in the U.S. Pacific Outer Continental Shelf Region.

[—, not available; m, meter]

Abbreviation	Index name	Metric name	Definition	Notes
CV	Collision Vulnerability	—	Relative proportion of time vulnerable to collision with OWEI.	—
DV	Displacement Vulnerability	—	Relative likelihood of displacement from important habitat by OWEI.	—
FA	—	Flight Activity	Proportion of time in flight, as opposed to on land or water.	NFA = Nocturnal Flight Activity, DFA = Diurnal Flight Activity
RSZt	—	Time spent in Rotor Swept Zone	Proportion of flight time spent flying at rotor swept height (20–200 m above water).	—
MA	—	Macro-Avoidance	Probability of being displaced from OWEI areas.	—
HS	—	Habitat Specificity	Inability to fulfill habitat needs elsewhere, if displaced by OWEI. ¹	Redefined from Habitat Flexibility (HF) in version 1.

¹Unlike the other three metrics, HS is not directly quantifiable, refer to section 2.6.1 for details.

Species Selection

In Version 1, we generated relative Vulnerability values for 81 marine bird species in the POCS. The selection of 81 species was based on historical survey records and was supplemented with species that did not appear on surveys but are known to exist in the POCS based on the available literature (K.T. Briggs, Pacific OCS Region Minerals Management Service, unpub. data, 1981; K.T. Briggs, Pacific OCS Region Minerals Management Service, unpub. data, 1983; Briggs and others, 1992; Mason and others, 2007; Adams and others, 2014). We added eight new species to Version 2 based on an improved understanding of some species' distributions and range shifts that brought new species into the POCS (Orta and others, 2020; Kirwan and others, 2023; Mlodinow and Pyle, 2023; Howard and others, 2024). Along with the 81 species from Version 1, the 8 new species included in Version 2 are Guadalupe Murrelet (*Synthliboramphus hypoleucus*), Red-billed Tropicbird (*Phaethon aethereus*), Townsend's Storm-Petrel (*Hydrobates socorroensis*), Red-footed Booby (*Sula sula*), Cocos Booby (*Sula brewsteri*), Masked Booby (*Sula dactylatra*), Nazca Booby (*Sula granti*), and Blue-footed Booby (*Sula nebouxii*). We also specify that only one subspecies of Northern Fulmar (Pacific Northern Fulmar [*Fulmarus glacialis rodgensisii*]) is present in the POCS (Mallory and others, 2020). Herein, we provide updated vulnerabilities for 89 species in the POCS (table 2). Species are listed in the database and reported upon herein, based on the 2023 avian taxonomic order (Clements and others, 2023). In the database of POCS marine bird vulnerability associated with this report, we also provide the American Ornithological Society taxonomic ordering (Chesser and others, 2024; Kelsey and others, 2025).

Literature Used

We reviewed and added relevant literature published since Version 1 was published in 2017 (Adams and others, 2017). In 2016, we established a Google Scholar alert to receive notifications of any newly published literature using the following search terms: (1) seabird "offshore wind farm" and (2) seabird with either "vulnerab*" or "sensitiv*."

Since 2016, we have saved any relevant literature identified with this Google Scholar alert. For Version 2, we also searched for sources in the Tethys Knowledge Base which is an up-to-date compilation of all documents, publications, and information relevant to the environmental effects of wind energy (Tethys, 2023). We filtered the Tethys Knowledge Base using the following keyword and timeframe filter options: (1) Technology: "Wind Energy"; (2) Receptor: "Seabirds," "Waterfowl," "Shorebirds"; and (3) Year published: "2016–23."

We also performed focused literature searches for the eight new species added to the database in Version 2; all literature selected using these criteria were reviewed and data were added to the Version 2 database along with the appropriate citation for reference. When sources used to generate Version 1 metric values were still relevant, we maintained those values and associated citations. When we found pertinent review papers, we tried to seek out any relevant referenced sources and used available primary sources.

In some cases, recognizing literature unrelated to OWEI research can also inform metric values, we performed additional, metric-specific searches. The methods for metric-specific searches are described in the following four metric method sections: "Flight Activity," "Time Spent in Rotor Swept Zone," "Macro-Avoidance," and "Habitat Specificity."

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To increase transparency and implement more appropriate quantification in Version 2, we updated the CV and DV equations metrics and equations. The specific updates to the Index metrics and equations in Version 2 are described in detail in the “Collision Vulnerability” and “Displacement Vulnerability” sections. Our general approaches for deriving metric values from published data relevant to a species in the POCS are described here. If a data source provided multiple values or a range of values, we used the midpoint of those values in the database. When we obtained values from multiple sources, we took the median of all values as the final metric value. When metric value data were unavailable for a given species, we used data from a similar species. Similar species included similar POCS species and their most similar counterparts globally (for example, gulls). In cases where similar species were data rich, we further focused on taxonomic groupings (for example, large gull, medium gull, and small gull). Thus, if data didn’t exist for a given POCS species, we used the best available information in the absence of species-specific data.

Collision Vulnerability (CV)

We define Collision Vulnerability as the relative proportion of time a bird of a given species is vulnerable to collision with OWEI. It is important to note that CV values are not analogous to collision risk model outputs or the probability of collision for a given species. In Version 1, CV was defined in a mixed additive and multiplicative equation (Adams and others, 2017; eq. 1). Collision Vulnerability was then updated based on peer reviewer suggestions and revisions in Kelsey and others (2018; eq. 2), where Nocturnal Flight Activity (NFA) and Diurnal Flight Activity (DFA) were given equal weighting. In these original additive frameworks of equations 1 and 2, a bird would still have CV even if it spent no time flying within the Rotor Swept Zone (RSZt). In addition, the ordinal values used in equations 1 and 2 were not consistently or linearly related to raw values for each metric (table 3). For example, a “3” for NFA represented 41–60 percent time flying at night, whereas a “3” for RSZt represented 5–20 percent RSZt. Therefore, we determined that the equations in Adams and others (2017; eq. 1) and Kelsey and others (2018; eq. 2) yielded unequal weighting in values among metrics in the original Version 1 CV equation. In Version 2 (eq. 3), we removed the additive effects and replaced the ordinal scaling of metrics with continuous values (0–1) from raw data (table 3).

$$CV = \left(\frac{2(NFA) + DFA}{3} \right) + RSZt + MA \text{ (Version 1; Adams and others, 2017)} \quad (1)$$

where

- CV* is Collision Vulnerability,
- NFA* is Nocturnal Flight Activity,
- DFA* is Diurnal Flight Activity,
- RSZt* is time spent in the Rotor Swept Zone, and
- MA* is Macro-Avoidance*

$$CV = \left(\frac{NFA + DFA}{2} \right) + RSZt + MA \text{ (Version 1; Kelsey and others, 2018)} \quad (2)$$

where

- CV* is Collision Vulnerability,
- NFA* is Nocturnal Flight Activity,
- DFA* is Diurnal Flight Activity,
- RSZt* is time spent in the Rotor Swept Zone, and
- MA* is Macro-Avoidance*

Consistent with the other Vulnerability Index metrics, we used ordinal RSZt values in Version 1. Furthermore, due to the limited amount of flight height data available, we binned RSZt estimates into three large ranges in Version 1: (1) 5=greater than 20 percent, (2) 3=5–20 percent, and (3) 1=less than 5 percent. Since publishing Version 1, the number of studies quantifying marine bird flight heights has greatly increased, especially in the context of rotor swept zone height. Through a combination of Global Positioning System (GPS) tracking, range finders, and coupling radar and camera data, flight height estimations are becoming more accurate for a greater number of species. Therefore, in Version 2, RSZt values represent the estimated percentage of time spent flying within the 20–200-m rotor swept zone height for a given species (as a value between 0 and 1, or for a similar species when data for a given species were not available).

Macro-Avoidance (MA)

A bird’s likelihood of avoiding OWEI influences its potential CV (higher likelihood of avoidance leads to lower CV) and DV (higher likelihood of avoidance leads to higher DV). We recognize three broad types of avoidance behavior: (1) Macro-Avoidance (MA; change in flight course to avoid entering a wind farm area), (2) meso-avoidance (change in flight direction within a wind farm area to avoid wind turbines), and (3) micro-avoidance (last-minute flight movements to avoid a specific turbine; Cook and others, 2014). In our Vulnerability Index, we focus on MA, which affects CV and DV directly (albeit with the opposite effect). Cook and others (2014) highlight that gulls, in particular, display avoidance behavior but at a micro-avoidance level (for example, a Herring Gull is estimated to have an MA rate of 0 but a micro-avoidance rate of 0.99; Cook and others, 2014). Accordingly, we did not include values from studies that reported overall OWEI avoidance rates because these studies included micro-avoidance rates.

We define MA as the proportion of birds displaced from OWEI areas that would have been expected to be there otherwise (for example, MA=0.10 represents a decrease of 10 percent in species abundance compared to baseline abundance numbers; Cook and others, 2014). We retained existing MA data used in Version 1 of the Vulnerability Index and data from MA studies published since Version 1. Macro-Avoidance has been a major focus of post-construction studies at existing OWEI sites, and there were considerable new data available to incorporate. However, data are still deficient for many POCS species (for example, albatrosses and pelicans). When data were not available for POCS species, we estimated MA based on MA measured at OWEI for similar species.

In Version 1, MA was given inverse ordinal values for CV versus DV because MA has an inverse effect when considering the two types of Vulnerability (Adams and

others, 2017; Kelsey and others, 2018). Herein, with revised, continuous MA values (0–1) derived from the literature, we quantify MA the same way for CV and DV (low value is low MA, and high value is high MA). For CV, the focus is the birds that are not macro-avoiding OWEI, and thus, we used the inverse (1–MA) in our revised CV equation (eq. 3).

Displacement Vulnerability (DV)

We define DV as the likelihood that a bird of a given species will be displaced from its habitat by the presence of OWEI. In the Vulnerability Index Version 1, DV incorporated MA (described in the “Macro-Avoidance” section) and Habitat Flexibility (HF) for a species using an additive framework (table 4; eq. 4). In the Vulnerability Index Version 1 additive framework, the ordinal values assigned for each metric were not linearly related to raw values, which gave unequal weighting to values across metrics in the final equation. Therefore, we changed the DV equation to be multiplicative. In Version 2, DV (eq. 5) is the proportion of birds from a given species expected to be displaced from their preferred habitat by OWEI (see the “Macro-Avoidance” section), times the inability of that species to fulfill their habitat needs elsewhere (HS; table 1). Consistent with the Version 2 CV, in Version 2 DV, we used continuous values (0–1) for the MA metric instead of ordinal 1–5 values. In addition, we reworked Version 2 HS to be more quantifiable. In Version 1, we called this metric HF and generated subjective, ordinal values to represent it. In Version 2, we renamed the metric to better describe the specificity of a given species’ habitat as opposed to its flexibility; we restructured the values on a 0–1 scale (consistent with other Version 2 metrics), and we made edits to the structure of the information inputs to make the HS metric more quantifiable (table 4; eq. 5).

$$DV = MA + HF \text{ —Version 1} \quad (4)$$

where

DV is Displacement Vulnerability;
MA is Macro-Avoidance; and
HF is Habitat Flexibility.

$$DV = MA \times HS \text{ —Version 2, used in this analysis.} \quad (5)$$

where

DV is Displacement Vulnerability;
MA is Macro-Avoidance; and
HS is Habitat Specificity.

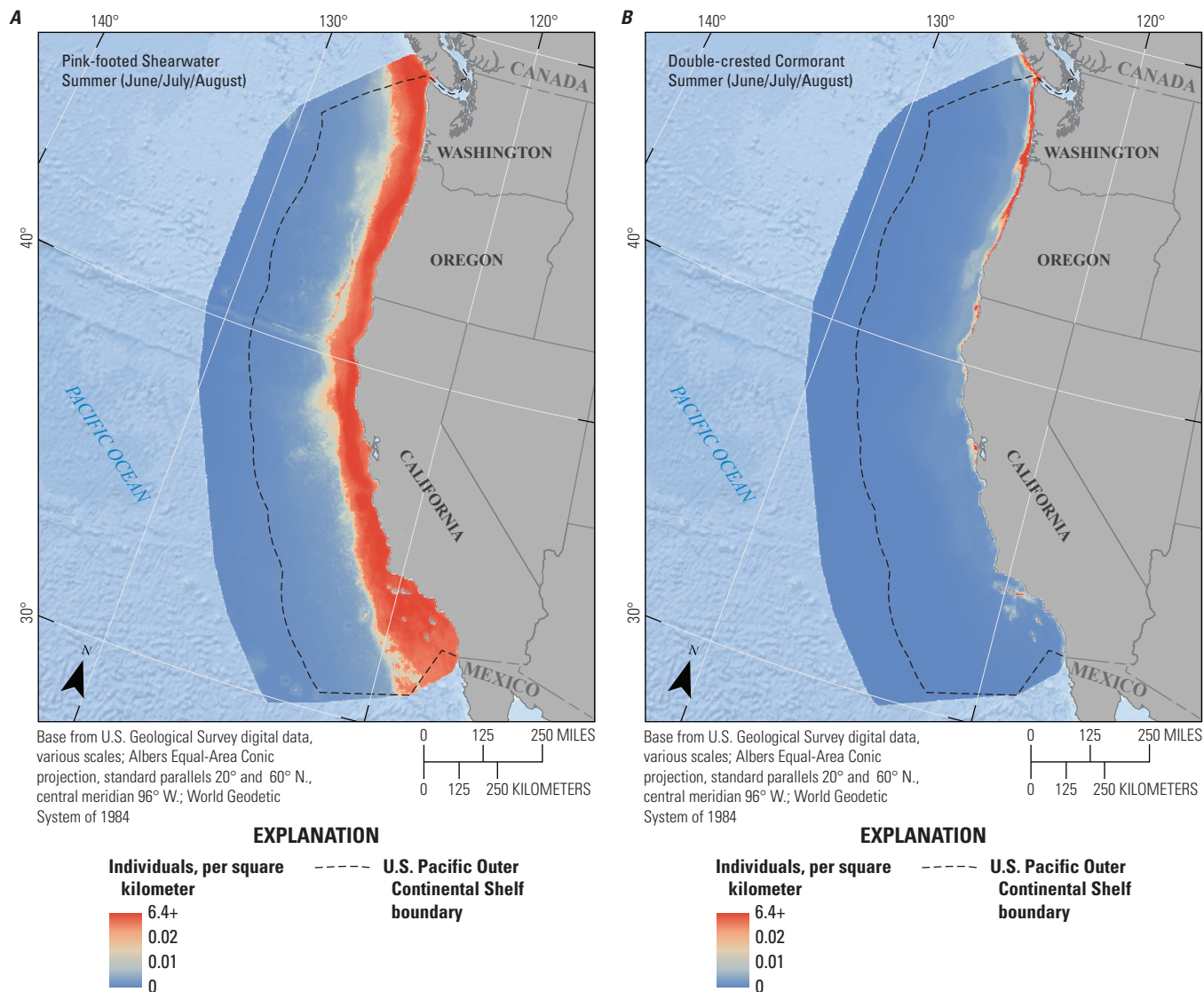


Figure 2. Summer species distribution models for *A*, Pink-footed Shearwater; and *B*, Double-crested Cormorant (Leirness and others, 2021). Cormorants were more aggregated in space than shearwaters (in other words, cormorants have a greater skew value), illustrated by the shape of the cumulative distribution of predicted density (red box).

Table 5. Options of Foraging Modes (FM) and Prey Size/Trophic Levels (ST) used by the U.S. Pacific Outer Continental Shelf (POCS) marine bird species.

[To determine each species’ foraging specificity; FM and ST were enumerated, rescaled across all species FM and ST respectively, and averaged. **Abbreviation:** —, no data]

FM	ST
Deep diving	One prey size and/or trophic level
Shallow diving	Two prey sizes and/or trophic levels
Surface dipping, surface seizing, or aerial pursuit	Three prey sizes and/or trophic levels
Plunge diving	More than three prey sizes and/or trophic levels
Kleptoparasitism	—
Scavenging	—

Pink-footed Shearwaters forage via shallow diving and surface seizing/aerial pursuit, gaining them two FM points. Double-crested Cormorants, which forage via deep diving and shallow diving, also got two FM points (table 5). Across all species, the maximum number of FM points was 4. Thus, the rescaled FM score for Pink-footed Shearwaters and Double-crested Cormorants was 2 out of 4, or 0.50. For ST, Pink-footed Shearwaters feed on small forage fishes and squids representing two prey sources, giving them an ST score of 2. In comparison, Double-crested Cormorants forage on small- and medium-sized forage fishes and invertebrates, gaining them an ST score of 3. Across all species, the maximum number of ST points was 4. Thus, Pink-footed Shearwaters got a rescaled score of 2 out of 4, or 0.50, and Double-crested Cormorants got a score of 3 out of 4, or 0.75. The final FS score was calculated by taking 1 minus the mean FM and ST scores and rescaling all scores from 0 to 1, resulting in a score of 0.67 for Pink-footed Shearwater and 0.5 for Double-crested Cormorant.

Quantifying Uncertainty

We assessed three potential sources of uncertainty associated with metric values for each species: (1) whether metric values were available for the species in question, or whether values were drawn from a similar species or estimated when no species-specific values were available; (2) the number of literature sources contributing metric values for a given species; and (3) the range of values from the data in those literature sources.

We quantified the three potential sources contributing to uncertainty (listed in the paragraph above) on a 0–1 scale for each species and metric value; for details, see the “Values from the Actual Versus Similar Species,” “Number of Literature Sources,” and “Range of Published Values” sections. We took the geometric mean of these three values to generate a singular uncertainty value for each species metric. The exception was the HS metric, for which the third uncertainty source (the range of input values) was not relevant because only one value was generated for each species (see the “Habitat Specificity” section for details). Thus, Habitat Specificity is generated from the geometric mean of the two relevant uncertainty values (actual versus similar species and the number of literature sources). We then multiplied the metric uncertainties for CV and DV to generate a final CV uncertainty (uCV) and DV uncertainty (uDV) value for each species (eqs. 6, 7).

$$uCV = uFA \times uRSZt \times uMA \tag{6}$$

where

- uCV is the Collision Vulnerability uncertainty;
- uFA is the Flight Activity uncertainty;
- uRSZt is the Time Spent in the Rotor Swept Zone uncertainty; and

uMA is the Macro-Avoidance uncertainty.

$$uDV = uMA \times uHS \tag{7}$$

where

- uDV is the Displacement Vulnerability uncertainty;
- uMA is the Macro-Avoidance uncertainty; and
- uHS is the Habitat Specificity uncertainty.

Values from the Actual Versus Similar Species

We assumed there was greater uncertainty associated with species for which no metric values were available in the literature, and thus, values were derived from similar species. To quantify the uncertainty associated with the difference between data from actual or similar species being used, we assigned uncertainty values between 0 and 1. Given that we used values from the most closely associated species when species-specific values weren’t available, the uncertainty values were quantified as follows:

- 0.25 Values used were from the species in question.
- 0.50 Values used were from a similar species within the same taxonomic family.
- 0.75 Values used were from a species from a different taxonomic family, or values used were estimates when no values were available that could be associated with the species in question.

Number of Literature Sources

We assumed that there was greater uncertainty associated with metric values derived from only one literature source, as opposed to metric values for which data from multiple literature sources were available. For each species, we quantified the number of sources (from the species in question or from similar species when data were lacking) used to determine the metric value. We tried to avoid referencing review papers; however, review papers were included in this count when the original source was unavailable. We found that most metric values were derived from five or fewer sources. Thus, we determined any metric value with six or more sources to be a high number of sources. When quantifying the number of sources used, we capped the number of sources at six (for example, any metric value with more than six sources used was given a source value of six). We then rescaled this value from 0 to 1 (with low numbers representing low uncertainty) by dividing the source’s value by 6 and subtracting that value from 1.

Table 6. Collision Vulnerability (CV) for the 89 U.S. Pacific Outer Continental Shelf species along with the metric values used to generate CV.—Continued

[Note that for calculating CV, MA is subtracted from 1 in the calculation (eq. 3). **Abbreviations:** FA, Flight Activity; MA, Macro-Avoidance; RSZt, time spent in the Rotor Swept Zone]

Species name	FA	RSZt	MA	CV
Petrels and Fulmars				
Northern Fulmar	0.410	0.002	0.280	0.00059
Murphy's Petrel	0.400	0.002	0.390	0.00049
Mottled Petrel	0.360	0.002	0.390	0.00044
Hawaiian Petrel	0.610	0.002	0.390	0.00074
Cook's Petrel	0.360	0.002	0.390	0.00044
Shearwaters				
Pink-footed Shearwater	0.470	0.00060	0.390	0.00060
Flesh-footed Shearwater	0.330	0.00042	0.390	0.00042
Buller's Shearwater	0.350	0.00045	0.390	0.00045
Sooty Shearwater	0.199	0.00026	0.390	0.00026
Short-tailed Shearwater	0.250	0.00032	0.390	0.00032
Manx Shearwater	0.345	0.00042	0.390	0.00042
Black-vented Shearwater	0.348	0.00045	0.390	0.00045

Table 6. Collision Vulnerability (CV) for the 89 U.S. Pacific Outer Continental Shelf species along with the metric values used to generate CV.—Continued

[Note that for calculating CV, MA is subtracted from 1 in the calculation (eq. 3). **Abbreviations:** FA, Flight Activity; MA, Macro-Avoidance; RSZt, time spent in the Rotor Swept Zone]

Species name	FA	RSZt	MA	CV
Boobies				
Red-footed Booby	0.415	0.198	0.865	0.01109
Cocos Booby	0.228	0.198	0.865	0.00608
Masked Booby	0.323	0.126	0.865	0.00549
Nazca Booby	0.348	0.126	0.865	0.00591
Blue-footed Booby	0.348	0.126	0.865	0.00591
Cormorants				
Brandt's Cormorant	0.018	0.080	0.205	0.00116
Pelagic Cormorant	0.018	0.080	0.205	0.00116
Double-crested Cormorant	0.026	0.080	0.205	0.00164
Pelicans				
American White Pelican	0.269	0.305	0.865	0.01108
Brown Pelican	0.269	0.305	0.865	0.01108

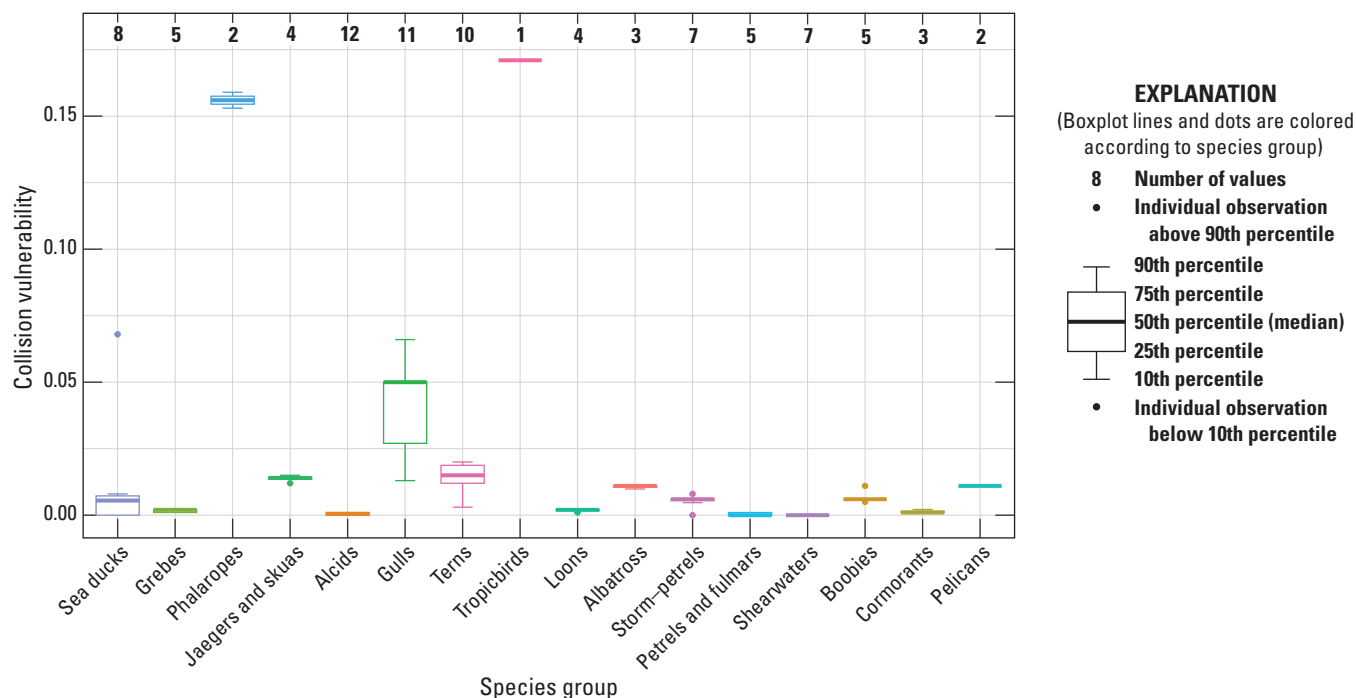


Figure 3. Final Collision Vulnerability by species group for the 89 species present in the U.S. Pacific Outer Continental Shelf Region. The number of species in each species group is shown along the top of the figure, and species present in each species group are listed in table 1.

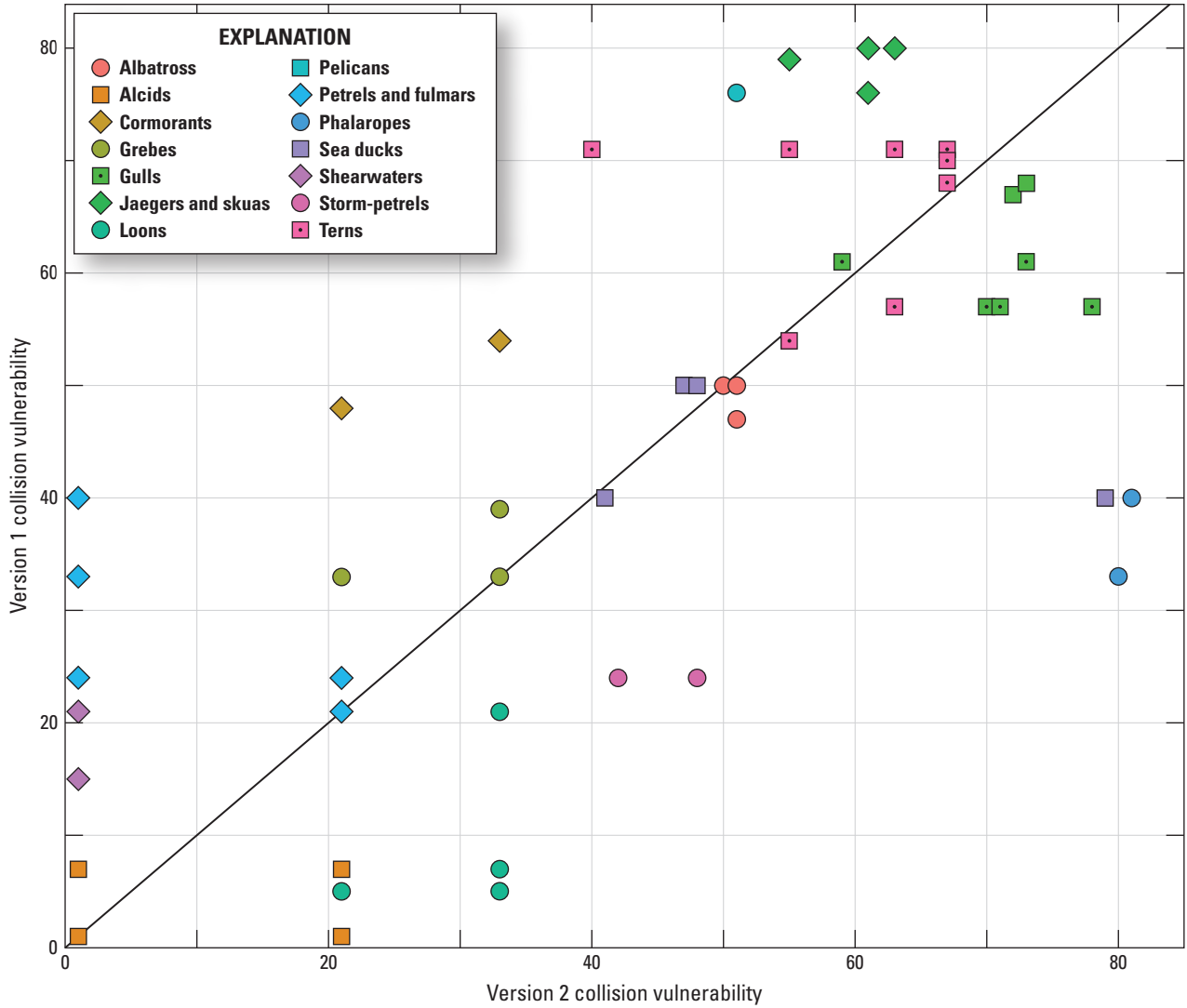


Figure 5. Ranked Collision Vulnerability (CV) values for Version 1 (Adams and others, 2016; Kelsey and others, 2018) versus ranked CV values for Version 2 for the 81 species that were included in Version 1 of the Vulnerability Index (excluding the 8 species added in Version 2). The gray one-to-one line indicates the location of points if CV ranks did not change between Versions 1 and 2.

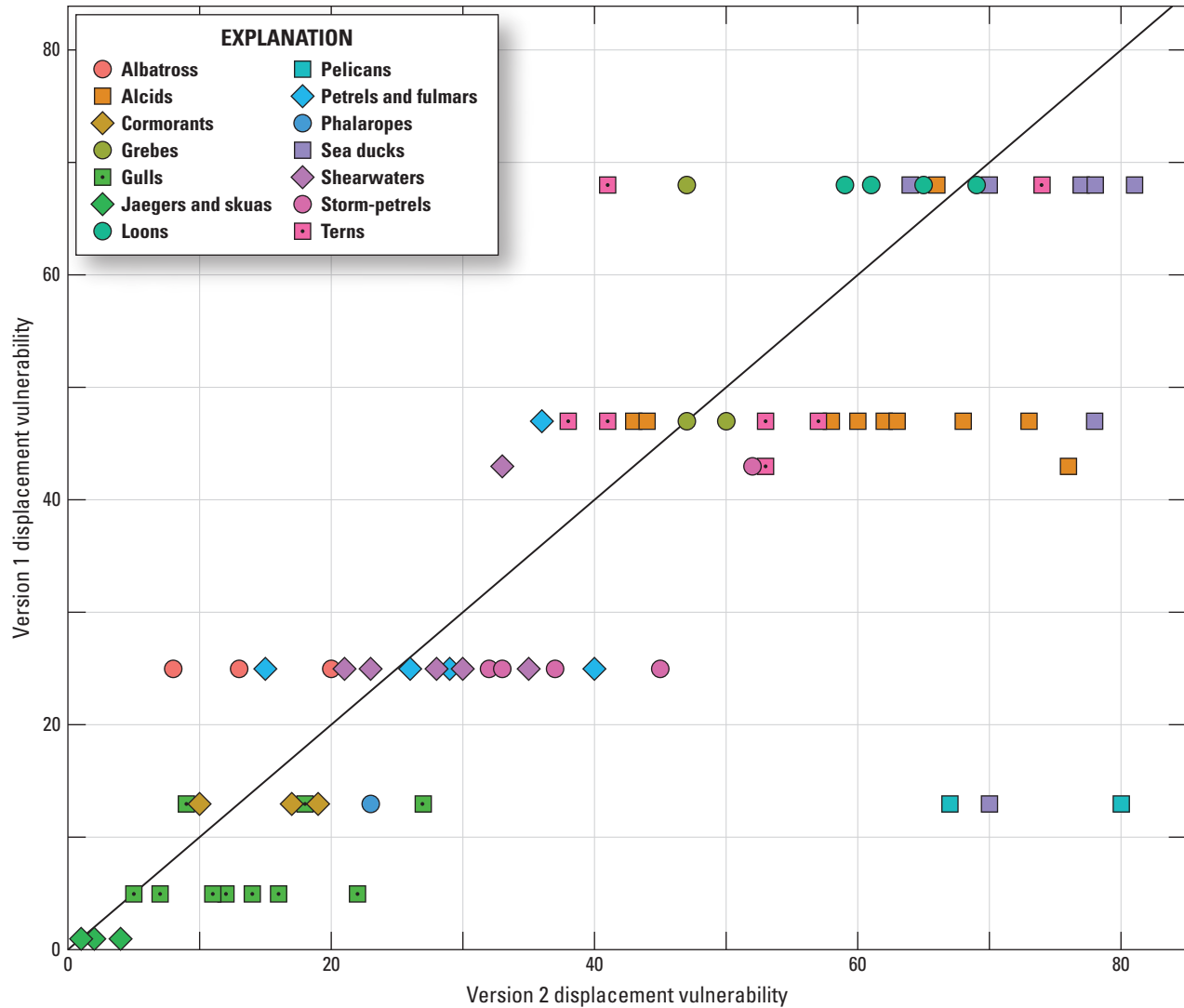


Figure 6. Ranked Displacement Vulnerability (DV) values for Version 1 (Adams and others, 2016; Kelsey and others, 2018) versus ranked DV values for Version 2 for the 81 species that were included in Version 1 of the Vulnerability Index (excluding the 8 species added in Version 2). The gray one-to-one line indicates the location of points if DV ranks did not change between Versions 1 and 2.

Conclusions

The Vulnerability Index Version 2 provides a current and transparent quantification of Collision Vulnerability (CV) and Displacement Vulnerability (DV) to potential offshore wind energy infrastructure (OWEI) for the 89 marine bird species in the U.S. Pacific Outer Continental Shelf (POCS). We quantified uncertainty to highlight species for which more studies on OWEI impacts may be warranted. Attention could be given to species with high vulnerability scores as well as high uncertainty associated with those scores. Red Phalarope, Red-necked Phalarope, and Red-billed Tropicbird have the highest relative Collision Vulnerability scores and also were in the top 15 percent for CV uncertainty. Heermann's Gull, Short-billed Gull, Ring-billed Gull, California Gull, Herring Gull, Iceland Gull, Black Skimmer, and Forster's Tern have a moderate CV and were also within the top 15 percent for CV uncertainty. Harlequin Duck, Long-tailed Duck, Common Merganser, Red-breasted Merganser, Horned Grebe, Red-necked Grebe, and Eared Grebe had some of the highest relative DV scores and also were within the top 15 percent for DV uncertainty. Additional research on these species could decrease the uncertainty associated with their vulnerability scores and better inform their relative vulnerability. The updated CV and DV index values and their associated uncertainties presented in this report can inform research, evaluation, and planning for offshore wind energy development in this region.

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For more information concerning the research in this report,
contact the

Director, Western Ecological Research Center

U.S. Geological Survey

3020 State University Drive East

Sacramento, California 95819

<https://www.usgs.gov/centers/werc>

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