OCS Study
BOEM 2018-031

Environmental Sensitivity and Associated Risk to Habitats and Species Offshore Central California and Hawaii from Offshore Floating Wind Technologies

Volume 1: Final Report

US Department of the Interior
Bureau of Ocean Energy Management
Pacific OCS Region

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List of Abbreviations and Acronyms

AGG	Aggregation
AL	Artificial Light
AS	Accidental Spills
BOEM	Bureau of Ocean Energy Management
BS	birds and bats
CA	California
CAS	Collisions with Above Surface Structures
CA DFW	California Department of Fish and Wildlife
CMX	Mexico/Central American DPS
CON	Construction
CSE	Collisions with Subsurface Structures, Entanglement
CSF	complete structure failure
DFA	Diurnal Flight Activity
dp	deep
EFH	Essential Fish Habitat
EL	Egg Location (fish / invertebrates)
EMF	Electromagnetic Fields
EX	Exploration
EEZ	Economic Exclusion Zone
FM	Feeding Method
FS	fish and invertebrates
HD	Habitat Disturbance
HDF	Hierarchical Data Format
HF	Habitat Flexibility
HI	Hawaii
HI DLNR	Hawaii Department of Land and Natural Resources
HU	Habitat Use
HYP_Min	Hypothetical Minimum
HY_Max	Hypothetical Maximum
ICF	Impact-Causing Factor
IUCN	International Union for Conservation of Nature
JAL	Juvenile/Adult Location (fish / invertebrates)
KNB	Knowledge Network for Biocomplexity
LL	Larval Location (fish / invertebrates)
LoU	Level of Uncertainty

MA	Macro-Avoidance
MB	Marine Bottom Habitat
MT	marine mammals and sea turtles
MV	Movements
MW	Megawatt
NAV	Navigation
NFA	Nocturnal Flight Activity
nm	nautical mile
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NPP	Net Primary Productivity
NR	Night Roosting
OCS	Outer Continental Shelf
OFW	Offshore Floating Wind
OFWESA	Offshore Floating Wind Environmental Sensitivity Analysis
OP	Operation
PAM	Protected Area Modifier
PDR	Predator Detection
PHY	Physiology
Progression	Progression Hawaii Offshore Wind, Inc.
PRY	Prey Detection
PSF	partial structure failure
QA/QC	quality assurance and quality control
RSZ	Rotor Sweep Zone
SA	Site Assessment
sh	shallow
SME	Subject Matter Experts
S/N	Sound/Noise
SS	sensitivity score
USFWS	United States Fish and Wildlife Service
VS	Vessel Strikes
WTG	Wind Turbine Generator

1 Introduction

1.1 Study Overview and Objectives

The marine waters of the Outer Continental Shelf (OCS) of the United States (U.S.) are rich in biological resources that may be sensitive to offshore floating wind (OFW) development. Because water depths become extremely deep at short distances from U.S. west coast and near the Hawaiian Islands shore, the use of monopole and other offshore wind technologies found in other parts of the U.S. and in Europe are precluded. In the near future, OFW construction and operation may commence, including the associated supporting activities such as various surveys, wind resource measurements and vessel traffic. This combination of potentially sensitive resources and potential impacts due to OFW construction and operation increases the risk for potentially harmful effects on the environment. In addition, OFW turbines are a relatively new application of older technologies (land-based wind and mobile offshore drilling units). A limited number of pilot programs are currently in place including pilot programs in Japan, Norway, Scotland, and Portugal. Nonetheless, uncertainty exists over how OFW development will impact the environment or particular species and populations in proposed areas of development.

The general objectives of this study were to conduct a scoping-level analysis of relative risk to help to identify and prioritize areas of risk to species and habitat, as well as ecological resources at risk to renewable energy development. The Offshore Floating Wave Environmental Sensitivity Analysis (OFWESA) model was developed for this study to help assess the potential effects of the site assessment, construction, and operations and maintenance of OFW on the nation's marine and coastal environmental resources. The major objectives of this study were to:

- Identify and define the potential impact-causing factors (ICFs) associated with all phases and components of OFW development;
- Revise and expand the previous BOEM Relative Environmental Sensitivity Assessment model with the OFWESA model to make it applicable to OFW technologies analyzed at a smaller spatial scale with additional parameters;
- Implement an initial iteration of the revised OFWESA model to analyze the environmental sensitivity of three study areas offshore of California and Hawaii; and
- Identify the species, habitats, seasons, and regions that are potentially most sensitive to various ICFs of OFW for further study.

All factors contributing to environmental sensitivity were assessed in the OFWESA model on a categorical classification system. This assessment involved the development of a detailed model of region- and season-specific environmental sensitivity for the U.S. OCS and coastal regions based on water column and seafloor habitat characteristics, seasonal presence/absence of species, species sensitivity to OFW ICFs, and species recovery potential. The model and results are intended as a screening-level assessment of relative renewable energy risk in the Pacific OCS to aid BOEM environmental analysis and decision making and is not intended to determine the exact magnitude or location, of impacts.

The results of the study described in this report reflect the initial implementation of the OFWESA model focused on buffered zones around three proposed areas near central California and the island of Oahu in Hawaii. Species and habitat sensitivity information was combined with rates of large-scale events (LSEs) that may lead to partial or complete structural failure of OFW fields, potentially increasing the impact of particular ICFs. Baseline environmental conditions in each study area were also considered within the OFWESA model as a proxy for cumulative effects of human activities in the OCS. Finally, mitigation measures that could reduce the impact of OFW were incorporated into model calculations to compare unmitigated and mitigated scenarios. These five main components (species and habitat sensitivity, LSE rates, baseline environmental conditions, and mitigation measures) were the building blocks used to construct the OFWESA model used in this study.

An overview of the chapters and appendices in this report is provided below.

- Chapter 1 is an introduction to the study and describes the overview, objectives, scope, and assumptions of the analysis.
- Chapter 2 describes the impact-causing factors that were included in the analysis, the process and rational behind their selection, and the general impacts they may have on different species and species subgroups included in the analysis.
- Chapter 3 provides an overview of the background and methods used in the study and in the OFWESA model. This includes a review of the model concept, the structure of the model, the model inputs and implementation, the application of hypothetical maximum and minimum values in the model and analysis, the impact magnitude of each ICF and the mitigation options, and the LSE analysis inputs and results.
- Chapter 4 presents an analysis of the model output results.
- Chapter 5 presents an analysis of knowledge gaps identified during the study.
- Chapter 6 presents a summary of major conclusions.
- Appendix A contains detailed definitions and literature background regarding impact-causing factors.
- Appendix B contains the assessment metric species scoring tables and equations used to calculate the impact of individual ICFs on each species.
- Appendix C contains written-out equations for the model calculations.
- Appendix D contains the model input data and output tables.
- Appendix E contains the over 530 references cited in the database for the species sensitivity assessment literature review.
- Appendix F provides a summary of the background research conducted during model development and the large-scale event analysis.

1.2 Spatial and Temporal Scope

For this study, the initial iteration of the OFWESA model was conducted at the spatial resolution of the BOEM OCS lease blocks offshore of California and Hawaii, where unsolicited lease applications have been made (referred to as study areas throughout this report). The model was designed to assess environmental sensitivity at this general spatial scale (thousands of square kilometers) and can be expanded to include additional BOEM OCS lease block regions in the future. The analysis was conducted in a buffered region of 25 nautical miles (nm) around three BOEM OCS lease block regions: California (CA), Hawaii North (HI_N), and Hawaii South (HI_S; Figure 1 and Figure 2).

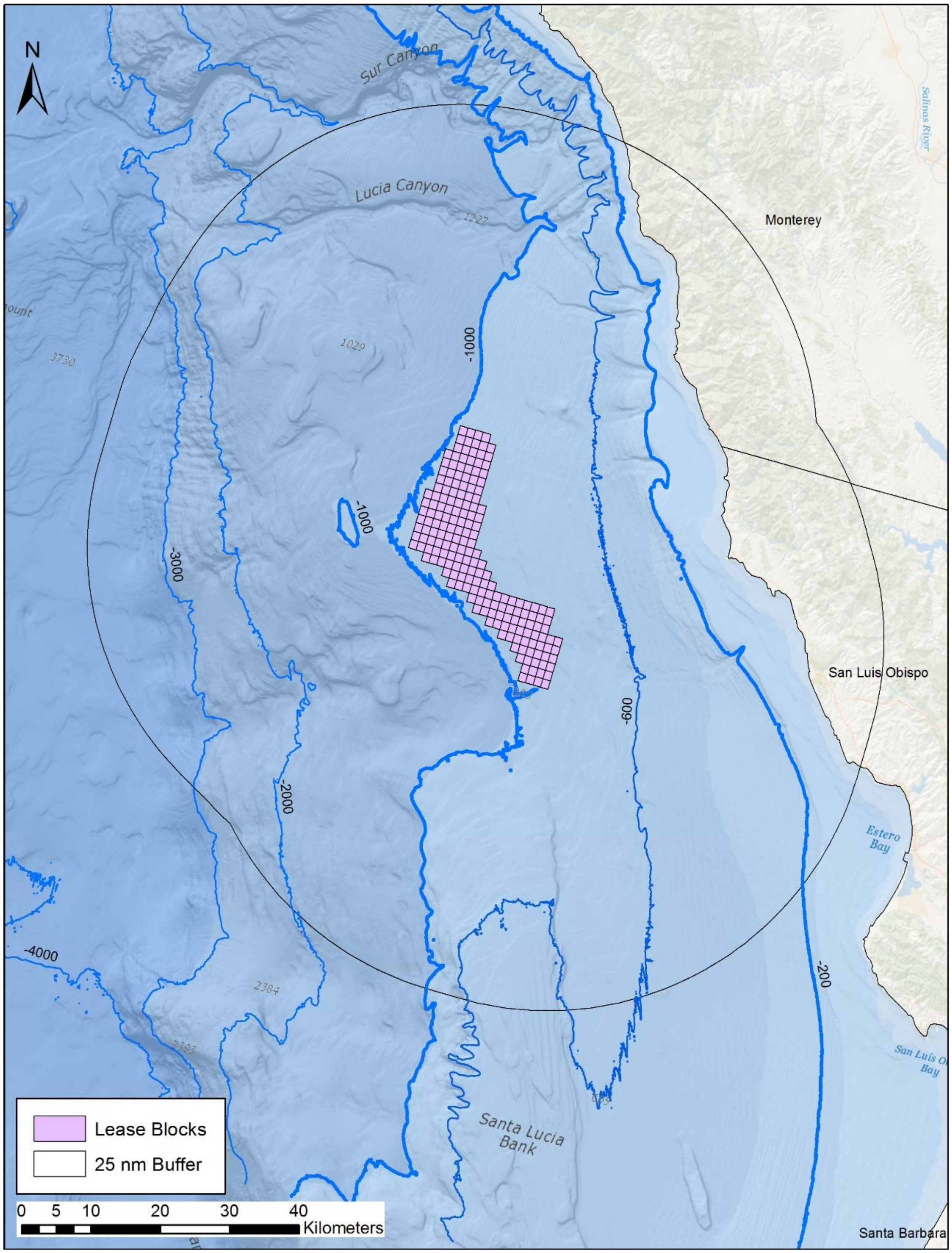

Figure 1. California study area
Offshore of central California between Monterey and Morro Bays

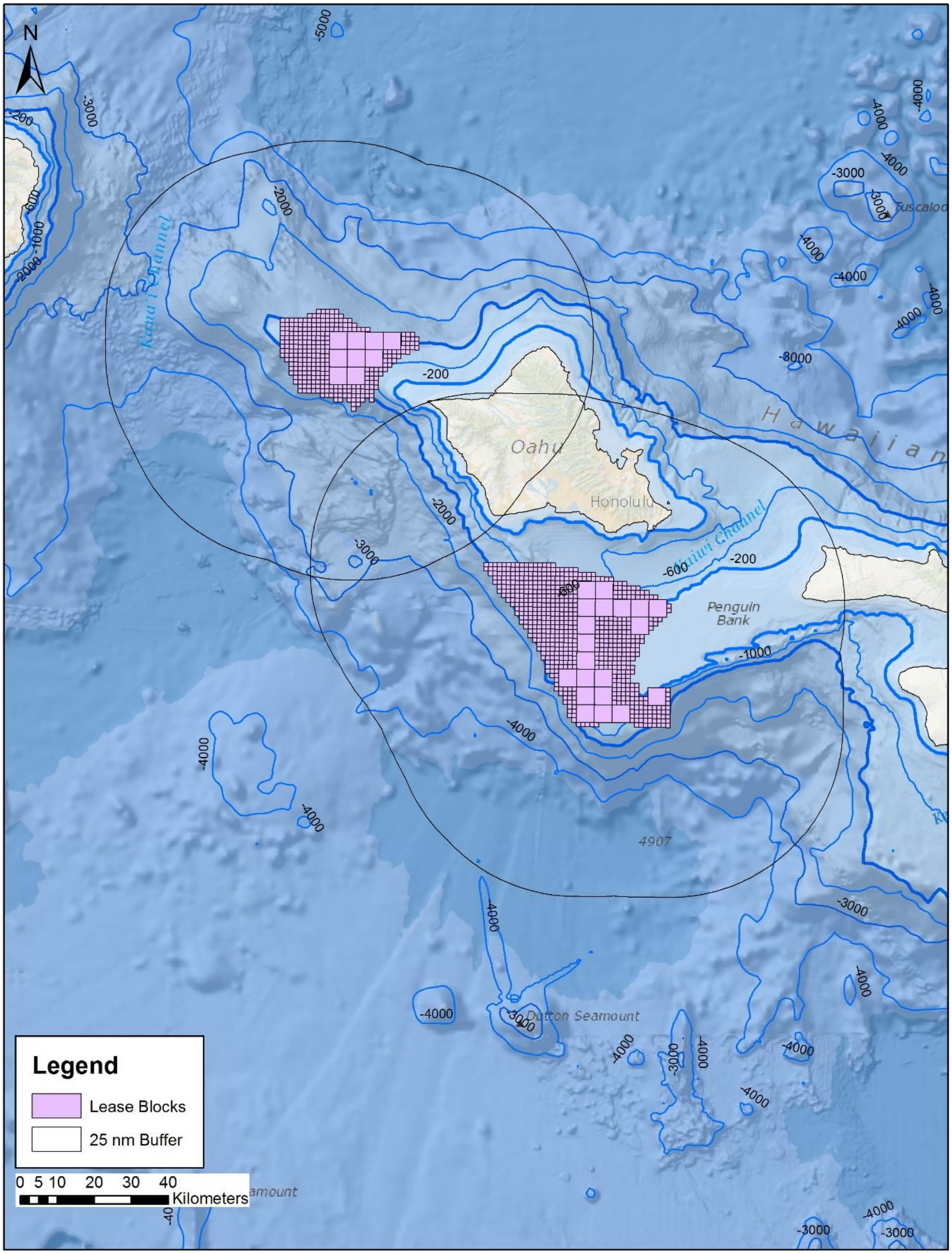

Figure 2. Hawaii North and South study areas
Offshore of Oahu

Six “seasonal” periods were included in the model to capture variations in species presence, water column habitat sensitivity, and risk of LSE occurrence throughout the year. Each period consists of two months. For the purposes of this report, the terms “period” and “season” are used interchangeably.

1.3 Key Assumptions

The model results presented herein were developed as a screening-level assessment of environmental sensitivity of species and habitats to OFW in 25-nm-buffered study areas around BOEM OCS lease block regions. Its goal is to identify regions, seasons, habitats, and species within the U.S. OCS with high environmental sensitivity, the calculation of which incorporates the potential frequency of incidents (i.e., LSEs) that may increase the impact of OFW activities, as well as the pre-existing level of anthropogenic stress in an area (i.e., baseline conditions). The sensitivity of socioeconomic resources (such as recreation, commercial fishing, subsistence activities, cultural resources, tourism, etc.) were not included in the OFWESA model.

The effect of ICFs on species and habitats was modelled for each region as a whole. Realistically, impacts will not be evenly distributed within each region, and will tend to be driven by local conditions and species presence. Likewise, the environmental sensitivity of each region varies within the larger lease area boundaries, which was not captured within this model.

Sensitivity scoring for each region/season was based on the assumption that each respective ICF (e.g., collisions, habitat disturbance) directly affects each type of species and marine habitat within a region. In other words, when assessing the effects of an ICF on a habitat, the model assumes that there is complete overlap between the occurrence of the factor and that habitat. Similarly, the presence of each species in a region during a particular season is assumed to overlap with each applicable ICF. The assumption of spatial and temporal overlap leads to a conservative assessment of environmental sensitivity. In reality, ICFs and environmental receptors are not likely to fully overlap in space and time.

2 Impact-Causing Factors and Large-Scale Events

The ICFs related to each phase of OFW development are defined in this section. The project phases are described, general effects of ICFs on different species groups and mitigation options are discussed, and the relationship between LSEs and ICFs is evaluated.

2.1 Phases of Offshore Wind Development

Three phases of production of OFW turbines are included for the selection of ICFs in the OFWESA for the OCS. The three phases of production include site assessment, construction, and operation and are described in detail below. Decommissioning of a wind turbine array is not included in this analysis since it would involve similar activities to those occurring in the construction phase; leave no permanent infrastructure on the seabed, and involve minimal acoustic disturbances (Trident Winds LLC. 2016). Accordingly, potential decommissioning impacts are already included in the ICF magnitudes for other project phases. Activities that typically occur during each phase of the OFW lifecycle are described below. While specific details associated with the phases may vary for a given project, the intent of this section is to generally describe the types of activities and potential sources of environmental impact associated with each project phase that were evaluated to identify an appropriate suite of ICFs to include in this study.

2.1.1 Site Assessment

Before installation, site-specific characterizations need to be conducted to collect data on seafloor characteristics and unidentified hazards (e.g., for mooring and undersea transmission), potential environmental impacts (e.g., to migratory bird routes, benthic habitats, and coastal sediment transport processes), potential archaeological impacts, and possible conflicting uses (e.g., radar interferences, commercial fishing, and U.S. Department of Defense training and operations). On-site and desktop characterizations of the site may be conducted. Integrated marine geophysical/hydrographic surveys and geotechnical/sediment sampling programs provide data to assess and characterize existing seafloor and sub-seafloor conditions to select appropriate design, construction, and installation techniques. The objectives of these surveys and programs are generally to identify water depths, seafloor morphology and structural features, sub-seafloor stratigraphy, and natural or human-made obstructions on or below the seafloor.

2.1.2 Construction

Once site assessment has confirmed the presence of a commercially viable location, the next phase of renewable energy development is construction of commercial-scale sites. In general, the following activities would be conducted in the construction of an OFW farm on the OCS.

2.1.3 Onshore Manufacturing and Transport

Components to be fabricated onshore include anchoring devices (most commonly made of steel, but concrete may also be used), turbines, rotors (most commonly made of composite materials), transformers, and transmission cables.

Certain components of two floating foundation wind turbine generator (WTG) units, Hywind and WindFloat, are produced and assembled onshore. WindFloat units have a shallow draft that allows for depth-independent siting and wet-towing fully assembled out of dry-docks (Progression Hawaii Offshore Wind Inc. 2015). The assembly of Hywind units is finished in sheltered nearshore waters at least 90 m deep to accommodate the sub-surface ballast cylinder before towing to the installation site (Statoil 2015).

Transport of components to the port location would occur by truck, rail, and/or marine vessel (for large components). Existing ports may require expansion to accommodate the equipment needed for WTG unit assembly. If a suitable port is not available nearby, construction work including dredging and dock expansion may be needed.

2.1.4 Offshore Construction and Installation

Installation technicians would be transported by vessel or helicopter to the wind farm site. Specific components to be installed include anchors, mooring systems, inter-array cables, export cables, and WTG units. Offshore substations may be installed as well, depending on the design of the array.

Conventional anchors would be used to moor the floating WTG units; examples include suction anchors, torpedo anchors, and drag-embedded anchors. Mooring systems may include mooring chains, steel wires, shackles, fairleads, and chain stoppers to connect the WTG units to the anchors. Inter-array electric cables connect individual WTG units in the water column below the water’s surface. Wind farms may also include floating collector substations. If included, these would be assembled in a manner similar to the WTG units, with as much assembly as possible onshore, and offshore assembly and installation conducted from special purpose vessels.

Subsea cable installation would include both (1) medium-voltage inter-turbine cables[1] within the wind farm array to collect the electricity generated from the individual devices and transmit it to the transformer, and (2) high-voltage export cables[2] for transmission from the transformer(s) on substations to the shore. Export cables are either buried in or laid on the ocean floor. Special cable-laying vessels designed specifically for both transport and installation would likely be to install and/or bury using jet-plow technique about 1 – 3 m below the seafloor. This technique simultaneously lays and embeds submarine cable in one continuous trench. It is possible that in deep waters, where the cables would not interfere with other marine uses, the cables would not be buried. Additional precautions would be needed if it were deemed necessary to transmit the energy over rocky or seismically active areas, although implementation of BOEM best management practices would result in the avoidance of hard-bottom areas. Slant drilling can occur nearshore to place export cables under sensitive reef and shallow water ecosystems. Horizontal directional drilling can be used for cables that need to cross beaches onshore.

Components of submarine cables may vary including the type of insulation, number of conductors (e.g., single versus “three-core” cables), screening, sheathing, and armor. Armor is the overall jacket to which corrosion protection is applied. Mostly likely, environmental impact may be caused by corrosion protection if it includes a biocide.

2.1.5 Operation and Maintenance

Routine operations of OFW farms generally would not require occupation of stationed offshore personnel. The control and monitoring of devices and transformers would be carried out remotely using fiber-optic cables or other communication devices (e.g., radio- or satellite-based telemetry) by onshore personnel, potentially conducting around-the-clock monitoring. However, periodic maintenance and inspection would be required. Based on descriptions of the Statoil Hywind Scotland Pilot Park, the export cables, inter-array cables, and mooring systems would be inspected and serviced once every 1 – 4 years. Wind turbines would be inspected and serviced annually, with vessel activity for all planned annual maintenance resulting in 4 to 5 vessel days per year (Statoil 2015).

In their lease applications for the Northwest and South Oahu sites, AlphaWindEnergy proposed 2-4 maintenance visits per turbine, per year. For a 400 megawatt (MW) farm consisting of 67 6-MW turbines, this would results in a maximum of 268 vessel trips per year (AW Hawaii Wind LLC. 2015a; 2015b). For the Hornsea 3 fixed offshore wind farm in the United Kingdom (U.K.), 2,822 return trips per year are expected over 35 years of operation for the maximum design scenario. This represents a 22% increase over the baseline level of vessel activity (12,755 return trips per year; Ørsted 2018). The Hornsea 3 environmental statement also summarized vessel movements expected from several proposed or approved offshore wind farms in the U.K., most of which ranged between approximately 1,000 – 4,000 return trips per year. These U.K. developments involve fixed turbines and it is possible that the maintenance requirements of floating offshore wind technology could be lower.

Additional service trips could be required for unplanned maintenance such as corrections of malfunctions. For the Hywind Scotland Pilot Park, Statoil assumed an upper estimate in their project design envelope of up to 10 trips per WTG unit per year for unforeseen events (Statoil 2015). Technicians would likely be transported by marine vessel to the WTG unit, where they would either work directly on the turbine, or they would disconnect it from its mooring and tow the unit to shore for repair before returning it to the site. While offshore systems may need to be returned periodically to shore for maintenance or replacement, remote monitoring and supervisory controls are expected. Occasional transport by helicopter may occur less frequently.

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[1] The operating current in a medium-voltage cable is discretionary and is determined by the owner/operator of a wind farm. It could include voltages such as 20 kv, 33, kv, 34.5 kv, etc.

[2] High-voltage export cables typically operate at voltages between 100 and 220 kv.

2.2 ICF Selection

2.2.1 ICF Stressors

The process of selecting ICFs for use in this study began with an identification of the potential impacts of OFW development (i.e., stressors) on habitats and species (receptors). ICFs considered were derived from OFW turbines, OFW substations, and associated OFW subsea cables. Using the *Programmatic Environmental Impact Statement for Alternative Energy Development and Production and Alternate Use of Facilities on the Outer Continental Shelf* (MMS 2007), recent offshore wind energy lease applications, and academic and industry-led OFW studies, an initial list of potential ICFs was compiled and reviewed. Some ICFs were omitted from this study (e.g., electrocution, chemical leaching, and change in flow regime). Additional details regarding the ICFs used and omitted in this study are included in Appendix A.

The ICFs included for analysis in this study are those shown to objectively cause a negative impact on species or habitats during different phases of OFW development (see Table 1 below). These include accidental spills (AS), artificial light (AL), collisions above the water's surface (CAS), collisions and sub-surface entanglements (CSE), electromagnetic fields (EMF), habitat disturbance/displacement (HD), sound/noise (SN), and vessel strikes (VS).

Table 1. Model Set of Impact-Causing Factors

Technology	Phase	AS	AL	CAS	CSE	EMF	HD	SN	VS
Offshore Floating Wind Turbines	Site Assessment	X	X		X		X	X	X
	Construction	X	X		X		X	X	X
	Operation and Maintenance	X	X	X	X		X	X	X
Offshore Floating Substations	Site Assessment	X	X		X		X	X	X
	Construction	X	X		X		X	X	X
	Operation and Maintenance	X	X		X		X	X	X
Marine Cables	Site Assessment				X		X		
	Construction				X		X		
	Operation and Maintenance				X	X	X		

Environmental receptors (birds/bats [BB], fish/invertebrates [FI], marine mammals/turtles [MT], and marine bottom habitat [MB]) potentially sensitive to the different ICFs were determined. Table 2 identifies the ICFs that were included in the study, the phases of development during which those ICFs may occur, and the potential receptors for each ICF. Vulnerability to all eight selected ICFs is discussed in the following subsections.

Table 2. OFW ICFs and Relevant Project Phases and Potential Receptors

ICFs	Phases*			Potential Receptors**			
	SA	CON	OP	BB	FI	MT	MB
Accidental Spills (AS)	X	X	X	X	X	X	
Artificial Light (AL)	X	X	X	X	X	X	
Collisions Above Surface (CAS)			X	X			
Collisions, Subsurface Entanglement (CSE)	X	X	X			X	
Electromagnetic Frequencies (EMF)			X		X		
Habitat Disturbance (HD)	X	X	X	X	X	X	X
Sound/Noise (SN)	X	X	X	X	X	X	
Vessel Strikes (VS)	X	X	X		X	X	

*SA=site assessment, CON=construction, OP=operation.

**BB=birds/bats, FI=fish/invertebrates, MT=marine mammals/turtles, and MB=marine bottom habitat.

2.2.2 Species-Receptor Selection

Habitat and species sensitivity to the identified set of ICFs was evaluated through an intensive literature review of over 530 sources (see Appendix E of this report). The three main components of species sensitivity evaluated included: the presence/absence of a population, ICF impact level (i.e., how severely a species could be affected by different ICFs), and recovery potential (i.e., how quickly the species population would be able to recover from impact).

Species included in this study were categorized into three broad receptor groups: marine mammals and sea turtles (MT), birds and bats (BB), and fish and invertebrates (FI). For each of two study areas (CA and HI_N/HI_S) 22 species were chosen, with 7 or 8 species included for each species group in each study area. Specific species were selected to be representative of species that: fill a variety of ecological roles; have ranges both endemic to study area or are globally distributed; are of conservation concern; and/or are commercially important.

Details of the species selection process and a table describing the different sub-groups can be found in Appendix D, Section D.4.2.1. These sub-groups were intended to capture potential effects of OFW based on differences in the air-water interface interactions between niche groups. For example, seabirds that spend most of their time flying over water and occasionally diving for food (aerial seabirds) were differentiated from seabirds that spend more time roosting or floating on the water's surface in addition to diving for food (surface seabirds). Both types would potentially be exposed to ICFs affecting the water column while feeding, but surface seabirds would have a greater likelihood of encountering ICFs at the water's surface because of the larger amount of time spent inhabiting it. Thus, vulnerability to ICFs such as accidental spills would be higher for surface seabirds than for aerial seabirds. Including behavioral sub-groups during the species selection process was intended to capture such subtle differences for a more complete picture of the ecosystem in each study area.

2.2.3 Species-Receptor Vulnerability and Recovery

To evaluate receptor vulnerability to each ICF, a categorical ranking scheme was developed consisting of 7 to 13 assessment metrics (i.e., questions based on ecological characteristics of a species group) for each species group. The assessment metrics were designed to evaluate the same general ecological themes for each group:

- encounter (i.e., likelihood of overlap with ICF based on behaviors such as escape behavior, time spent on the water surface, and attraction/avoidance responses to light/noise/chemicals);
- concentration/aggregation (i.e., the degree to which a species aggregates in a given location);
- physiology (i.e., physiological characteristics [e.g., fur] that may affect magnitude of impact); and
- habitat flexibility/feeding specificity (i.e., how the effects of an ICF on lower trophic levels may affect the species of interest).

For each individual species, assessment metrics are scored on a categorical ranking scale to answer to the assessment question based on behaviors or life history characteristics informed by literature review and are combined into an ICF-specific vulnerability score for each species. Details about each assessment metric and their related ICF vulnerability ranks are available in the species scoring tables in Appendix B.

In addition to impact vulnerability, a species' recovery potential was assessed with 4 to 5 life history questions to evaluate how quickly a population would be able to recover in the event of an impact. These included questions about a species' conservation/population status, reproductive potential, species range while in the study area, adult survival rate, and how much a species forages for their young.

For some species, like an endangered, long-lived whale, the loss of one individual could result in detrimental effects at the population level. Other hypothetical examples of potential population-level effects include a flock of migrating birds passing through an OFW farm with high mortality from collisions; an accidental spill in an area occupied by a night roosting breeding colony of birds; a low-fecundity species endemic to an area injured by habitat disturbance; and species with little habitat flexibility avoids a wind farm or perceives it as a barrier and experiences indirect effects of extra energy expenditure to find the prey or habitat it requires.

Recovery potential is an important counterpoint to impact vulnerability, as certain species (e.g., Pacific sardine) may suffer a large impact from a given ICF on an individual level, but are less sensitive overall if they would be able to recover quickly due to large population numbers and high fecundity. The recovery metric categories assigned for each species were based on a thorough review of historic stock population data, the literature, and web databases. Further details and tables containing the recovery scoring scheme are available in Appendix B, Section B.5.

2.3 General Effects of Impact-Causing Factors

The means by which each ICF may affect receptors, potential mitigation methods to address those effects, and the assessment metrics used to rank species vulnerability to each ICF are discussed in the subsections below.

2.3.1 Accidental Spills

The categories of oil and chemical spills that may potentially be associated with OFW facilities include:

(1) spills from wind facility components caused by damage from external environmental forces (natural events), including earthquakes, tsunamis,[3] and storms (hurricanes);

(2) spills caused by fires and explosions in facility structures;

(3) spills resulting from structural or equipment failures in facility structures;

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[3] Tsunamis usually occur as a result and in the aftermath of an earthquake, though not all earthquakes cause tsunamis. Volcanic eruptions can also cause tsunamis. The seismic-related consequences of earthquakes are also different from the consequences of tsunamis. For these reasons, they are considered independently.

(4) operational spills (refueling, maintenance);

(5) spills caused by intentional damage (vandalism, terrorism, war);

(6) spills from wind facility components due to vessel allisions with wind facility structures;

(7) spills from vessels due to vessel allisions with wind facility structures; and

(8) spills from vessels resulting from vessel collisions and groundings attributable to presence of OFW facility.[4]

The types and quantities of chemicals and oils that would likely be contained in OFW facility components are shown in Table 3 through Table 5. This information is largely derived from information provided for the analyses conducted for the proposed Cape Wind Energy Project off Massachusetts (Etkin 2006a; MMS 2009) and results of a study conducted for BOEM assessing the environmental risks, fate, and effects of chemicals associated with wind turbines on the Atlantic OCS (Bejarano et al. 2013). The hazardous substances and quantities in Table 5 through Table 7 are some examples; however, other similar types of chemicals and oils may be present, depending on the specifications of the particular wind facility components. Because each proposed facility may have different specifications the volumes and chemical/oil types may differ. Even considering different OFW facilities and generating capacities, the volumes would not be expected to differ significantly from those presented here.

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[4] The issue of vessels colliding with each other due to the presence of wind facility structures was addressed in detail in analyses conducted for Cape Wind (Etkin 2006b; Etkin 2008). Interference with radar systems and visibility, especially in fog, were considered in those analyses as part of a conservative approach.

Table 3. Hazardous Materials in Electric Service Platforms

Component	Fluid Medium Function	Fluid Type	Approximate Quantity	Total Storage
115 kV Power Transformers (4)	Insulation/heat transfer	Naphthenic mineral oil	10,000 gallons each 40,000 gallons total	Oil: 41,210 gallons
Diesel Engines (2)	Internal component lubrication	Motor oil	5 gallons each 10 gallons total	
Diesel Engine Day Tanks (2)	Emergency generation fuel	Diesel oil	100 gallons each 200 gallons total	
Fuel Oil Storage Tank (1)	Emergency generation fuel	Diesel oil	1,000 gallons total	
Diesel Engine Radiators (2)	Heat transfer	Water/glycol	15 gallons each 30 gallons total	Non-Oil: 365 gallons
Uninterruptible Power Supply	Electrolyte	Sulfuric acid	335 gallons	

(Source: MMS 2009; Bejarano et al. 2013)

Table 4. Hazardous Materials in Wind Turbine Generators

Component	Fluid Medium Function	Fluid Type	Approximate Quantity	Total Storage
Drive Train Main Bearing	Bearing lubrication	Mobil SCH 632	19 gallons	Oil: 214.25 gallons
Drive Train Main Bear Box	Gear lubrication	Optimol Synthetic A320	140 gallons	
Drive Train Cooling Systems	Cooling and lubrication	Optimol Synthetic A320	21 gallons	
Hydraulic System Brake	Brake fluid	Mobil DTE 25	2 gallons	
Hydraulic System Rotor Lock	Hydraulic fluid	Mobil DTE 25	19 gallons	
Hydraulic Crane Cylinder	Transmission fluid	ATF 66	5 gallons	
Yaw System (Drive Gear)	Gear lubrication	Mobil SHC 630	7 gallons	
Pitch System (Pitch Gear)	Gear lubrication	Mobil SHC XMP 220	0.25 gallon	
Pitch System (Pitch Gear)	Gear lubrication	Mobil SHC XMP 460	1 gallon	
Oil Coolers	Heat dissipation	Water/glycol	20 gallons total	Non-Oil: 20 gallons

(Source: MMS 2009; Bejarano et al. 2013)

Table 5. Additional Hazardous Materials Associated with Wind Farms

Component	Location	Fluid Medium Function	Fluid Type(s)	Approximate Quantity
Sloshing Dampers	Near wind turbine generator nacelle	To dampen motion in offshore wind energy turbines	Ethylene Propylene glycol	≤ 220 gallons in sealed containers
Oil	Wind turbine generator	Emergency generation fuel	Diesel oil	214 gallons
Transformer Oil	Wind turbine generator	Insulating liquid within each transformer	Biodegradable ester oil	370 gallons
Hydraulic Oil	Wind turbine generator nacelle			90 gallons each
Gear Oil	WTG turbine nacelle	Lubrication	Examples: Polyalphaolefin ester-based products Polyalkylene glycol-based products Flender-approved synthetics[5] with bio-based content over 50% (for extreme pressure)	220 gallons total

(Source: Bejarano et al. 2013)

Spills from wind facility components themselves could involve various chemicals and oils. The volumes of spillage would depend on the specific types of wind turbines and other facility structures, but would generally be small to moderate in size ranging from a few gallons to 40,000-100,000 gallons for electric service platforms. However, there is a low probability that a spillage of the entire contents (on the order of 40,000-100,000 gallons) of an electric service platform would occur (Bejarano et al. 2013). Therefore, the majority of these spills would not be considered "major" according to the criteria in the National Contingency Plan, which defines a "major" oil spill as one that involves a spillage of more than 100,000 gallons in coastal (marine) waters, and more than 10,000 gallons in inland waters (40 CFR § 300.5).

Spills that might occur from vessels that strike or allide with an OFW turbine or other facility component, or collide with each other because of the presence of the facility, could involve a number of fuel oils (gasoline, diesel, and/or a variety of intermediate or heavy fuel oils), as well as a large variety of vessel cargoes. Besides crude oil or refined petroleum products that may be carried on oil tankers, cargo on vessels might include chemicals, dry cargo (e.g., minerals, grain, sand, gravel, or coal), automobiles or trucks (on vehicle carriers or ferries), machinery, and containers, which themselves could contain any manner of contents, including hazardous materials. Given that the size of vessels that may transit near OFW facilities would range from smaller recreational and fishing vessels to large tankers and cargo ships (bulk carriers, car carriers, etc.), the volume of spillage could range from a few gallons to, at least theoretically, the entire cargo contents of the vessel. This worst-case discharge volume from a tanker

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[5] Oil viscosity cSt mm^2/s @ 40°C = 222; mm^2/s @ 100°C = 17.3

could conceivably be tens of millions of gallons, though there are no records of anything like this occurring anywhere worldwide with regard to OFW facilities.

The environmental impacts of a vessel spill would depend on the type of oil or chemical involved, the volume, the specific location of the incident, and the environmental conditions at the time of the spill and in its aftermath (particularly winds and currents). A vessel spill's impacts could be very localized if the volume is small, but could conceivably be large enough to reach shorelines if the volume is much larger. There is a vast literature that describes impacts of larger oil and chemical spills. The types of incidents that could occur in a particular lease block or region would depend on the specific vessel traffic in the area. This may vary over time depending on economic factors.

As part of their study for BOEM, Bejarano et al. (2013) assessed the potential environmental effects on selected marine resources (birds, marine mammals, sea turtles, fish, and invertebrates) from the accidental exposure to chemicals and oils used in offshore wind facilities based on available information in the scientific literature. Table 6 provides a summary of these potential effects.

Table 6. Summary of Potential Adverse Effects on Marine Resources from Accidental Spills of Hazardous Substances from Offshore Wind Facilities

Marine Resources	Oil/Chemical Type from Offshore Wind Facilities	Potential Adverse Effects from Spills
Invertebrates and Fish	Diesel	Acutely toxic when directly exposed to the spilled material. Small spills in open water dilute rapidly reducing the likelihood of massive kills.
	Biodiesel	Based on the available information, not acutely toxic, and low likelihood of large kills.
	Dielectric insulating fluids	
	Sulfuric acid	Acutely toxic when directly exposed to the spilled material. Small spills in open water dilute rapidly reducing the likelihood of large kills.
	Ethylene glycol	
Sea turtles	Diesel	Direct exposure of sensitive tissues (e.g., eyes, mucous membranes) and inhalation of fumes can lead to temporary irritation and inflammation. Large mortalities are unlikely because of the short time the oil is on the water surface.
	Biodiesel	Based on the available information, not acutely toxic, and low likelihood of large kills.
	Dielectric insulating fluids	
	Sulfuric acid	Direct exposure of sensitive tissues (e.g., eyes, mucous membranes) can lead to temporary irritation and inflammation.
	Ethylene glycol	
Marine mammals	Diesel	Direct exposure of sensitive tissues (e.g., eyes, mucous membranes) and inhalation of fumes can lead to temporary irritation and inflammation. Large mortalities are unlikely because of the short time the oil is on the water surface.
	Biodiesel	Based on available information, not acutely toxic, and low likelihood of large kills. There is considerable risk of smothering of fur-marine mammals.
	Dielectric insulating fluids	
	Sulfuric acid	Direct exposure of sensitive tissues (e.g., eyes, mucous membranes) can lead to temporary irritation and inflammation.
	Ethylene glycol	
Birds	Diesel	Direct contact can cause negative effects, but large mortalities are unlikely because of the short time the oil is on the water surface. Could be higher if large congregations coincide spatially with large diesel spills.
	Biodiesel	Based on the available information, not acutely toxic, but there is considerable risk of smothering.
	Dielectric insulating fluids	
	Sulfuric acid	Direct exposure of sensitive tissues (e.g., eyes, mucous membranes) can lead to temporary irritation and inflammation.
	Ethylene glycol	

(Source: Bejarano et al. 2013)

Accidental spills may cause both direct and indirect mortality to bird species through poisoning from oil consumption or consumption of polluted prey, oiling of feathers with resulting reductions in insulative abilities, starvation because of a reduction in prey resources, and complete reproductive failure from high toxicity levels being transferred from adults to chicks (Szaro 1977; Bejarano et al. 2013). Specific to biodiesels and dielectric fluids, the increased viscosity of these substances can lead to a greater potential for fouling and smothering of birds than refined light oils (Mudge 1995; Calanog et al. 1999; Bejarano et al. 2013). Dielectric insulating fluids may also cause mortality to birds by hypothermia from matted feathers. Direct exposure of ethylene glycol and sulfuric acid to birds could lead to temporary irritation and inflammation of their sensitive tissues (e.g., eyes and mucous membranes; Bejarano et al. 2013).

Species in the marine mammal and turtle species group are vulnerable to accidental spills if they are fur-bearing, surface frequently to breathe and forage, or aggregate in large groups. Marine mammals and sea turtles surfacing to breathe in areas with high concentrations of volatile compounds (such as ethylene glycol and sulfuric acid) may experience irritation of the respiratory track and inflammation of their sensitive tissues (e.g., eyes and mucous membranes); however high concentrations of these compounds would likely be localized and limited mostly to areas with large quantities of surface slicks (Bejarano et al. 2013). Specific to dielectric insulating fluids and biodiesels, though these substances have relatively low toxicity, their low to moderate viscosity may pose a risk of smothering after a spill particularly to fur-bearing mammals such as pinnipeds who spend most of their time at the water surface and whose fur loses its ability to repel water or thermoregulate when coated with oil. Although impacts from biodiesels and dielectric fluids to marine mammals could include fouling and smothering, glycols and sulfuric acid have lower viscosity and higher water solubility and the chances of animal encounters with concentrations that may cause such impacts are unlikely (Bejarano et al. 2013).

Fish and invertebrates may be vulnerable to accidental spills because oil entrained in the water column or slicked on the surface can result in mortality through smothering or oil toxicity (Neff et al. 2000). Pelagic fish and invertebrates would be vulnerable to accidental spills due to a relatively high encounter likelihood because of the time they spend in the water column. For instance, given the moderate toxicity of diesel and its great potential for natural dispersion and entrainment into the water column, drifting pelagic organisms (e.g., eggs and larvae of many fish and invertebrates species or plankton) may be at a high risk of exposure as these organisms may not be able to avoid contact with oil droplets (Neff et al. 2000; API 2011; Bejarano et al. 2013). However, it is likely that for most instantaneous spills, the exposure to plankton from this toxicity would be for a maximum of one day due to water mixing and dilution (Bejarano et al. 2013). Biodiesel, dielectric insulating fluids, ethylene glycol, and sulfuric acids are known to biodegrade faster and have a lower water solubility than petroleum diesel; thus, resulting in a lower potential for chronic toxicity to fish and invertebrates and food chain bioaccumulation (Bejarano et al. 2013). Fish and invertebrate species are commonly observed to be attracted to manmade structures and may be artificially attracted to the OFW area, increasing exposure to potential accidental spills.

Accidental spills are most likely to originate from transportation failures and accidents, or from catastrophic events (e.g., hurricane, earthquake, tsunami) leading to structural failure of the turbine or substation. General best practices and operating procedures for construction and operation dictate mitigation measures relating to accidental spills originating from low level accidents. During construction, operation, and potential LSEs, it is assumed that mitigation practices will include enhanced emergency response to address large spills. However, due to challenges in responding with 100% effectiveness, enhanced emergency response is not assumed to completely remove the potential for impacts from accidental spills. The application of mitigation measures for accidental spills in the OFWESA model analysis reduced the accidental spill impact scale and impact level scoring values across all project phases.

Table 7 provides a summary of the assessment metrics relevant to accidental spills along with the behaviors and traits of each species group that were associated with lower and higher vulnerability to the ICF.

Table 7. Assessment Metrics for Each Species Group Used to Calculate Vulnerability to Accidental Spills. Behaviors resulting in lower and higher vulnerability are noted. See Appendix B for details.

Species Group	Assessment Metric	Lower Vulnerability to ICF	Higher Vulnerability to ICF
Birds / Bats	Concentration - Aggregation	Mostly solitary in area	Large flocks or colonies in area
	Encounter - Feeding Method	Does not forage in marine habitat	Feeds from surface waters
	Encounter - Macro-Avoidance/Attraction	Highly avoidant	Highly attracted
	Encounter - Night Roosting	Never roosts on marine waters	Nearly always roosts on offshore marine waters
	Flexibility - Habitat Flexibility	Opportunistic/generalist	Highly specialized food or habitat needs
Fish / Invertebrates	Concentration - Aggregation	Mostly solitary in area	Large schools in area
	Encounter - Egg Location or Larval Location or Juvenile/Adult Location	Pelagic, demersal, or freshwater	Neustonic
	Encounter - Feeding Method	Benthic planktivore, piscivore, or scavenger	Surface feeding or sessile filter feeder
	Encounter - Macro-Avoidance/Attraction	Highly avoidant	Highly attracted
	Encounter - Movement	Fast moving or large home range	Stationary or surface drifting/planktonic
	Flexibility - Habitat Flexibility	Opportunistic/generalist	Highly specialized food or habitat needs
Marine Mammals / Turtles	Concentration - Aggregation	Mostly solitary in area	Large pods or colonies in area
	Encounter - Feeding Method	Benthic forager or pelagic piscivore	Surface feeding
	Encounter - Habitat Use	Portion of life history is not marine	Primary surface water use
	Encounter - Macro-Avoidance/Attraction	Highly avoidant	Highly attracted
	Flexibility - Habitat Flexibility	Opportunistic/generalist	Highly specialized food or habitat needs
	Physiology - Sensitive Features	No fur for thermoregulation	Has fur for thermoregulation

2.3.2 Artificial Light

Offshore wind facilities involve a variety of lighting sources, including temporary construction lighting, vessel lights, navigational lighting for mariners, obstruction lighting for aviators, and work lighting for maintenance and operation, all of which have potential direct and indirect impacts on birds, bats, marine mammals, sea turtles, and fish.

Artificial light related to OFW facilities can affect birds by increasing the chance of collision with turbine blades, disorienting internal navigation signals, attracting individuals to a food source, and skewing migratory pathways (Orr et al. 2013, Weiss et al. 2012, Montevecchi 2006, Longcore and Rich 2004).

Because bats are primarily terrestrial, artificial light from OFW turbines that are far offshore may have a diminished effect; however, many bat species undertake long migrations, use barrier islands as stopovers, and have been observed flying and feeding up to 14 km offshore (Arnett et al. 2016; Ahlen 2009; Johnson et al. 2011). However, Hein and Schirmacher (2016) reported that in some studies, the red-flashing lights on turbines required by the Federal Aviation Administration either decreased or did not increase bat fatalities in terrestrial wind farms, so bats may not be as vulnerable as birds that migrate through the study area.

The direct effects of artificial lighting on marine mammal distribution, behavior, or habitat is relatively minimal and unknown. Artificial light could have an indirect effect on marine mammals by influencing the location and density of their prey and by affecting their foraging behavior when in search of prey (Orr et al. 2013). Increased light at night may trigger avoidance behaviors that lead to missed forage opportunities and reduced body condition. Alternatively, artificial lighting during construction and operation of OFW can attract marine mammals and turtles to the source due to increased foraging visibility and prey availability, which can increase exposure to other ICFs (Depledge et al. 2010; Yurk and Trites 2011). However, in general, most studies have found that artificial lighting during the operational phase of OFW development is considered a low risk with low levels of negative effects (Orr et al. 2013).

In the marine environment, artificial light can cause unnatural accumulation of species (e.g., cephalopods) in non-preferable habitats that can make them more vulnerable to predation. Fish and invertebrate species attracted to light, such as sardine and anchovy species, tend to form aggregations at or around the light source, which may facilitate the over-exploitation of these species by natural predators and anthropogenic fishing activities (Ben-Yami 1976; Witherington 1997). Artificial light can also influence diel vertical migration patterns of plankton (including planktonic life stages of some fish species) in the surface waters and lead to migrations that occur outside of the optimal window for that species (Gibson et al. 2001).

Nightingale et al. (2006) also noted that some of the main adverse impacts of artificial lighting on fishes include: delays and changes in migratory behavior caused by changes in direction and disorientation induced by artificial night lighting; temporary blindness that could increase the risk of predation; attraction of predators and disruption of predator-prey interactions; and loss of opportunity for dark-adapted behaviors, including foraging and migration (Orr et al. 2013). Fishes will likely not be affected by navigational lighting for mariners or obstruction lighting for aviators; however, the effects of artificial light on fish and other marine organisms needs additional study (Perkin et al. 2011; Orr et al. 2013).

Because federal aviation regulations dictate some minimum requirements presently required for lighting on turbines, no complete mitigation measures are available to eliminate potential impacts from artificial light emissions (Manville 2005). In general, for offshore wind energy; (1) fewer lights are preferable to more lights, (2) lower intensity lights are preferable to higher intensity lights, (3) white lights are the least preferable choice for lighting structures, and (4) installation of lighting deflectors are the baseline mitigation measures (Orr et al. 2013; Blew et al. 2013; Gartman et al. 2016). The application of mitigation measures for artificial light in the OFWESA model reduces the artificial light impact scale and impact level values for the construction and operation project phases. No mitigation measures for artificial light during the site assessment phase in were identified for use in the OFWESA model analysis.

Habitats are not anticipated to be affected by artificial light.

Table 8 provides a summary of the assessment metrics relevant to artificial light along with the behaviors and traits of each species group that were associated with lower and higher vulnerability to the ICF.

Table 8. Assessment Metrics for Each Species Group Used to Calculate Vulnerability to Artificial Light. Behaviors resulting in lower and higher vulnerability are noted. See Appendix B for details.

Species Group	Assessment Metric	Lower Vulnerability to ICF	Higher Vulnerability to ICF
Birds / Bats	Concentration - Aggregation	Mostly solitary in area	Large flocks or colonies in area
	Encounter - Feeding Method	Does not forage in marine habitat	Feeds from surface waters
	Encounter - Macro-Avoidance/Attraction	Highly avoidant	Highly attracted
	Encounter - Nocturnal Flight Activity	Very low percent of night flights	Very high percent of night flight
	Encounter - Night Roosting	Never roosts on marine waters	Nearly always roosts on offshore marine waters
	Encounter - Rotor Sweep Zone	Rarely or never flies at turbine height	Frequently flies at turbine height
	Physiology - Light Sensitivity	No major migration or bioluminescent prey	Migrates using celestial patterns to navigate or consumes bioluminescent prey
Fish / Invertebrates	Concentration - Aggregation	Mostly solitary in area	Large schools in area
	Encounter - Feeding Method	Bottom feeding	Surface feeding
	Encounter - Juvenile/Adult Location	Not neustonic or epipelagic	Neustonic or epipelagic
	Encounter - Larval Location	Not neustonic or epipelagic	Neustonic or epipelagic
	Encounter - Macro-Avoidance/Attraction	Highly avoidant	Highly attracted
	Encounter - Movement	Stationary on seafloor	Drifting/planktonic at surface
Marine Mammals / Turtles	Encounter - Feeding Method	Benthic forager or pelagic piscivore	Surface feeder
	Encounter - Habitat Use	Primarily nearshore or shoreline use	Primary surface water use
	Encounter - Macro-Avoidance/Attraction	Highly avoidant	Highly attracted

2.3.3 Collisions Above Surface

Birds and bats are the only species group vulnerable to collisions above surface. The degree of vulnerability is species-specific and based in this analysis on time spent flying offshore, proportion of diurnal and nocturnal flight activity, attraction or avoidance to offshore structure, and light sensitivity (Gill 2005; Adams et al. 2016). Large, long-lived, coastal species that take frequent, short, low-level flights between feeding and roosting sites are most at risk of collision (Gill 2005; Wilson et al. 2010). In addition, species that form large aggregations or migrate in large groups offshore could be more vulnerable to collisions because more individuals could be displaced, injured, or killed at one time.

Birds that regularly migrate from offshore forage locations to coastal nesting sites have the highest potential for collision, especially if they fly at the same height as the turbine rotor sweep zone (Furness et al. 2013). Increased nocturnal flight also increases the vulnerability of collisions with turbines as reduced visibility at night and navigational confusion induced by artificial lights can distract birds or limit maneuverability (Furness et al. 2013; Adams et al. 2016). Some bird species have been found to actively avoid OFW and are less likely to be vulnerable to collisions with rotors; however, such avoidance may results in habitat displacement and could potentially decrease an individual's fitness or survival by using extra energy resources to avoid the structures (Boehlert and Gill 2010).

Many bat species were observed to be attracted to wind turbines in terrestrial wind farms worldwide (Arnett et al. 2017). These include tree-roosting bats as well as cave-roosting bats that spend a large portion of time feeding or flying through open air. Collisions do not appear to be chance events, with fatalities ranging from 600,000 – 888,000 bats killed at wind farms in the U.S. in 2012 (Hein and Schirmacher 2016). Bats have been observed actively foraging around wind turbines (Foo et al. 2017). Cryan et al. (2014) used infrared video to determine that bats are attracted to the leeward side of the turbine blades, particularly on moonlit nights, and may orient towards turbines by sensing air currents and using vision to look for roosts or prey around a tree-like structure. It is currently not known if bats will regularly traverse to areas as far offshore as the study areas evaluated in this report, but if so, they would potentially be vulnerable to collisions.

Mitigation measures that may be used to reduce collisions include modification of artificial light, and active deterrence methods including acoustic, electromagnetic, and visual methods (Gartman et al. 2016). Acoustic deterrence techniques include bird distress calls, pyrotechnics, and sounds of gunfire (Bishop et al. 2003; Mascarenhas et al. 2015). Visual cues such as flashing, rotating, strobe lights/lasers, or moving/shiny devices can be added to turbine fields to help reduce bird collisions (Bishop et al. 2003; Clarke 2004; Cook et al. 2011; Gilsdorf et al. 2002; Mascarenhas et al. 2015). For bats, effective mitigation was observed in terrestrial wind farms by feathering turbine blades to increase the wind speed at which the turbine begins to turn by 1.5 m/s, which reduced fatality by 50% (Arnett et al. 2016). Current investigations into visual deterrents and modified operation protocols may result in updated mitigation measures in the future.

The application of mitigation measures for collisions above surface in the OFWESA model reduces the collisions above surface impact scale and impact level values for the operation phase. No mitigation measures for collisions during the site assessment or construction phases were identified for use in the OFWESA model analysis. Habitats, marine mammals/turtles, and fish/invertebrates are not assumed to be affected by collisions above surface.

Table 9 provides a summary of the assessment metrics relevant to accidental spills along with the behaviors and traits of the bird/bat species group that were associated with lower and higher vulnerability to the ICF.

Table 9. Assessment Metrics for the Birds/Bats Group Used to Calculate Vulnerability to Collisions Above the Surface. Behaviors resulting in lower and higher vulnerability are noted. See Appendix B for details.

Species Group	Assessment Metric	Lower Vulnerability to ICF	Higher Vulnerability to ICF
Birds / Bats	Concentration - Aggregation	Mostly solitary in area	Large flocks or colonies in area
	Encounter - Diurnal Flight Activity	Very low percent of day flights	Very high percent of day flight
	Encounter - Macro-Avoidance/Attraction	Highly avoidant	Highly attracted
	Encounter - Nocturnal Flight Activity	Very low percent of night flights	Very high percent of night flight
	Encounter - Rotor Sweep Zone	Rarely or never flies at turbine height	Frequently flies at turbine height
	Physiology - Light Sensitivity	No major migration or bioluminescent prey	Migrates using celestial patterns to navigate or consumes bioluminescent prey

2.3.4 Subsurface Collisions / Entanglement

Entanglements refer primarily to marine mammal and turtle interactions with the inter-array cables, mooring lines, and submerged portions of the turbines. Collisions with the sub-surface portion of the tower structure are also included here as some whales seek out stationary hard surfaces to rub against, increasing collision and entanglement risk as they circle the turbine structures (Benjamins et al. 2014). For all species, entanglement may occur if cables and anchor lines go undetected because of poor visual ability of the animal, turbidity or lack of light, stormy conditions, and bubbles or noises masking sound signals. In addition, some cases suggest that mooring lines may not be perceived as a threat, individuals may become distracted while hunting prey and not notice underwater structures, or they may be attracted to the structures for foraging purposes (Benjamins et al. 2014; Neilson et al. 2012).

Species that utilize echolocation or other sounds for feeding, communication, or travel are more likely to be negatively affected by sound/noise and may have increased potential for entanglements if their perception of the environment or communications are masked by anthropogenic noise (Erbe et al. 2016). In addition, echolocating cetaceans can become acoustically blind to objects farther away than their intended prey when they are actively feeding, which could limit their ability to detect objects underwater with enough time to escape (Wilson et al. 2006). While it is likely that a species' feeding method may affect its likelihood of entanglement (e.g., a benthic feeding species becoming entangled in a marine cable, a lunge feeder catching a line in its wide-open mouth), there is inadequate research to distinguish differences among feeding methods and correlations with entanglements. Species that have been found to actively avoid OFW are less likely to be negatively affected by subsea entanglements or collisions.

While research into physiology and behaviors that lead to collision/entanglement risk has been conducted (Wilson et al. 2006; Kropp 2013; Benjamin et al. 2014), there is conflicting information in the literature about how the different sensory systems of marine mammals aid or are hindered in detection of the underwater components of OFW technology. Erbe et al. (2016) state "There is evidence that marine mammal species – with and without specialized biosonar capabilities – rely on biological sounds to find prey and avoid predators, and likely use environmental sounds to support spatial orientation and navigation in three-dimensional marine habitats". The likely chronic increase in low-frequency noise from OFW operation and vessel traffic during all phases, result in the potential for masking of sounds used for navigation (Erbe et al. 2016; Peng et al. 2015). Depending on the frequency and degree of auditory masking, reduced detection of underwater structures may result in species that relied on echolocation or other sound for feeding and navigation (Copping et al. 2016). This may then increase collision and entanglement vulnerability. However, there is uncertainty around the risk of entanglement of marine mammals in mooring lines, and modelling and validation studies are needed (Copping et al. 2016). A categorical relative risk model such as the OFWESA model used in this study makes its assumptions clearly visible in assessment metric scoring tables (see Appendix B) that can be revised to incorporate new information in future iterations of the model. This may be useful in situations where uncertainty exists around a species' behavior and new studies may change earlier assumptions.

Entanglements with mooring cables are anticipated to occur infrequently, particularly if mooring lines and cables are designed to be taut, which is the mooring configuration that presents the least risk (Benjamin et al. 2014; Harnois 2015). No mitigation measures (e.g., deterrent sounds) are anticipated to be required if taut moorings are used, but improved detection of black-and-white paint patterns (Kot et al. 2012) and fishing lines that reflect ultraviolet light (Wang et al. 2013) have been noted for minke whale and sea turtles, respectively, and may serve as mitigation options to explore for mooring lines and inter-array cables. However, since the anchoring and mooring methods for OFW turbines will generally be similar to existing technology for offshore floating oil rig platforms in which mitigation measures are not employed (Adaramola 2015), mitigation measures for sub-surface collisions or entanglement were not used in the OFWESA model analysis.

Table 10 provides a summary of the assessment metrics relevant to sub-surface collisions and entanglement along with the behaviors and traits of the marine mammal/turtle species group that were associated with lower and higher vulnerability to the ICF.

Table 10. Assessment Metrics for the Marine Mammals/Turtles Group Used to Calculate Vulnerability to Sub-surface Collisions and Entanglements. Behaviors resulting in lower and higher vulnerability are noted. See Appendix B for details.

Species Group	Assessment Metric	Lower Vulnerability to ICF	Higher Vulnerability to ICF
Marine Mammals / Turtles	Concentration - Aggregation	Mostly solitary in area	Large pods or colonies in area
	Encounter - Habitat Use	Portion of life history is not marine/is on shoreline	Pelagic water column and marine sediment use
	Encounter - Macro-Avoidance/Attraction	Highly avoidant	Highly attracted
	Physiology - Sensitive Features	Not reliant on sound or echolocation	Reliant on sound or echolocation

2.3.5 Habitat Disturbance / Displacement

For the analysis, the habitat disturbance ICF includes both disturbance of habitats and displacement of species avoiding the OFW development.

Marine bottom habitats are vulnerable to disturbance from OFW turbine anchoring, seafloor cable laying, and any increased turbidity from construction activities. The construction associated with OFW facility development will lead to a direct loss of habitats and potential increase of turbidity (Gill 2015). Also, if any contaminated sediments are present in the area, they may be mobilized. The addition of physical structures to a relatively featureless, soft bottom/water column habitat may provide habitat for larval settlement and cause an artificial reef effect. This may increase local biodiversity or cause increased predation to nearby communities by attracting predators (Boehlert and Gill 2010).

During construction, a local loss of sedentary infauna would be expected as well as the displacement of non-sedentary marine benthos (Gill 2015). It is also possible that shells that may fall off anchors and lines could create new hard bottom habitat, and this new habitat could be a catalyst for the introduction of new communities and specifically invasive species (Boehlert and Gill 2010). The level of effect from OFW turbine construction activities depends on the duration and intensity of the disturbance (Van Dalfsen et al. 2000; Gill 2005) and the resilience of the infauna in the area (Drabsch et al. 2001; Gill 2005). In general, recolonization of benthic and infaunal organisms can take months to years with polychaetes and amphipods recolonizing first and epifaunal species assemblages following later (Gill 2005). The degree of impact is also dependent upon the structure and composition of the benthic assemblage and the physical structure of the sediment (Jennings et al. 2001; Gill 2005). For instance, as bottom habitats become more stable, the effects of disturbance are more extreme and long-lasting; thus corals and hard bottom habitats with slow recovery times are more vulnerable to disturbance than soft bottom habitats that are quickly recolonized.

For bird species, habitat disturbance or displacement occurs when species are attracted to, or avoidant of OFW facilities. Attraction or avoidance behavior varies between species and may be a result of vertical turbine presence, artificial light on turbines, or changes in prey source distribution around the OFW facility. For avoidant species, OFW facilities can act as barriers, disrupting and displacing regular seasonal migrations or movements between breeding colonies and forage areas (Gill 2005; Boehlert and Gill 2010; Humphreys et al. 2015). These barrier effects can increase the time and energy it takes to accomplish these regular movements, which may then reduce overall fitness of an individual.

Displacement not only affects birds that use the offshore habitats, but birds in the areas where displaced birds move to as this increased competition among regional bird populations, especially during resource-limited seasons (Goss-Custard et al. 2002; Gill 2005; Humphreys et al. 2015). Bird species attracted to the turbines also experience habitat disturbance and displacement impacts as increased activity around turbines can increase the risk of being affected by other ICFs, such as collisions with rotor blades.

Marine mammals that primarily occupy the offshore pelagic environment will have higher levels of habitat disturbance or displacement than those that spend more time nearshore or onshore, as pelagic habitat use spatially overlaps with the presence of OFW structures. Whether a species is attracted to or avoidant of OFW, the presence of OFW structures within the water column alter the regional marine habitat used by marine mammals. Avoidance behavior exhibited in response to presence of OFW facilities can cause a barrier effect, forcing animals to alter migratory or feeding movements, potentially displacing other animals in nearby habitats (Gill 2005; Wilson et al. 2006). Attraction to turbines increases an animal's risk of being impacted by other ICFs, such as entanglement, noise, or vessel strikes.

Fish and invertebrate species attracted to or avoidant of OFW facilities will experience the highest level of habitat disturbance or displacement. Previous research indicates that many fish species are attracted to manmade offshore structures (e.g., fish aggregation devices), which draw organisms away from original habitats where they may have been more protected (Grossman et al. 1997). Alternatively, this kind of disturbance can be categorized as a benefit if it develops new productive habitat and increases biodiversity. However, fish attraction to turbines can also increase predation or disturbance pressure on benthic, sessile species present before the turbines were in place. In addition, fish or invertebrate species attracted to the wind turbine structures will have a higher risk of being impacted by other ICFs.

Avoidance behavior reduces overall regional habitat for some organisms whose ranges once overlapped with the facility and increases pressure on adjacent habitats (Gill 2005).

Habitat disturbance and displacement occurs during the construction of OFW facilities and remains a persistent fixture through the life of the project. Habitat disturbance is mitigated through careful macro- and micro-site planning. Although many siting decisions are made based on above-water characteristics (e.g., vessel traffic, wind patterns, avian flight patterns), benthic habitats also play a role in where turbines are anchored. In general, sites to be disturbed should have a low diversity and resilient biological community comprising opportunistic species, like those found on soft sediments. More stable and productive hard bottom, coral/sponge, and eelgrass/kelp benthic habitats with low recovery rates should be avoided when possible, reducing potential impacts on habitats and associated species (Gill 2005, Gartman et al. 2016) The orientation of OFW arrays should be considered to avoid barrier effects across restricted areas or migratory pathways. These measures represent best practices for placement of OFW developments that were assumed to be employed for the OFWESA analysis; thus no additional mitigation is included in the model for habitat disturbance or displacement.

Table 11 provides a summary of the assessment metrics relevant to habitat disturbance/displacement along with the behaviors and traits of each species group and marine bottom habitat that were associated with lower and higher vulnerability to the ICF.

Table 11. Assessment Metrics for Each Species Group, and Marine Bottom Habitat, Used to Calculate Vulnerability to Habitat Disturbance and Displacement. Behaviors or habitat types resulting in lower and higher vulnerability are noted. See Appendix B for details.

Species Group	Assessment Metric	Lower Vulnerability to ICF	Higher Vulnerability to ICF
Birds / Bats	Encounter - Feeding Method	Does not forage in marine habitat	Feeds from surface waters
	Encounter - Macro-Avoidance/Attraction	Neither attracted nor avoidant	Highly attracted or avoidant
	Flexibility - Habitat Flexibility	Opportunistic/generalist	Highly specialized food or habitat needs
	Physiology - Light Sensitivity	No major migration or bioluminescent prey	Migrates using celestial patterns to navigate or consumes bioluminescent prey
Fish / Invertebrates	Concentration - Aggregation	Mostly solitary in area	Large schools in area
	Encounter - Feeding Method	Pelagic non-filter feeder	Surface/pelagic filter feeder
	Encounter - Macro-Avoidance/Attraction	Neither attracted nor avoidant	Highly attracted or avoidant
	Flexibility - Habitat Flexibility	Opportunistic/generalist	Highly specialized food or habitat needs
Marine Mammals / Turtles	Encounter - Feeding Method	Forages in benthic sediments	Surface feeding
	Encounter - Habitat Use	Portion of life history is not marine/is on shoreline	Pelagic water column and marine sediment use
	Encounter - Macro-Avoidance/Attraction	Neither attracted nor avoidant	Highly attracted or avoidant
	Flexibility - Habitat Flexibility	Opportunistic/generalist	Highly specialized food or habitat needs
Marine Bottom Habitats	Short- and long-term impact and community recovery	Anthropogenic, volcanic, shallow soft bottom	Coral/sponge, kelp, seagrass, and deep hard bottom

2.3.6 Electromagnetic Fields

Some fish and invertebrate species—including some elasmobranch, tuna, and lobster species—use electromagnetic sense for orientation and predator/prey detection. If EMF interferes with these senses, the function of these key ecological mechanisms would be impacted (Riefolo et al. 2016). The impacts of EMF will differ among species depending on whether their electrosense is used for predator detection, prey detection, and/or navigation (Claisse et al. 2015; Normandeau et al. 2011). Currently, there is very little data as to the effect of cable EMF on most species, with some recent studies indicating slight behavioral changes around cable EMF but no clear negative impacts (Love et al. 2017; Hutchinson et al. 2018).

Although there is some evidence that certain cetacean and sea turtle species have magnetosensitivity, EMF was not considered an ICF for this species group because their pelagic nature and high mobility limits exposure to EMF from submarine power cables (Normandeau et al. 2011). In addition, the majority of evidence indicating magnetosensitivity in cetaceans is theoretical and suggests cetaceans use these senses to map and monitor topographic fluctuations during migration rather than relying on them for directional information (Klinowska 1990; Normandeau et al. 2011).

Research on EMF impacts is ongoing; there are no proposed mitigation methods available in scientific literature or government documentation. It is likely that as technology progresses, cable sheathing technology may help to reduce EMF impacts in the water column. If species-specific migratory impacts are found to be associated with EMF, potential time-of-year restrictions for operation may need to be enacted. As no exact mitigation measures are currently available to reduce impacts of EMF, mitigation reductions for EMF were not used in the OFWESA model analysis.

Table 12 provides a summary of the assessment metrics relevant to electromagnetic fields along with the behaviors and traits of the fish/invertebrate species group that were associated with lower and higher vulnerability to the ICF.

Table 12. Assessment Metrics for the Fish/invertebrate group Used to Calculate Vulnerability to Electromagnetic Fields. Behaviors resulting in lower and higher vulnerability are noted. See Appendix B for details.

Species Group	Assessment Metric	Lower Vulnerability to ICF	Higher Vulnerability to ICF
Fish / Invertebrates	Encounter - Feeding Method	Surface or pelagic feeding	Bottom feeding
	Encounter - Juvenile/Adult Location	Epipelagic or pelagic	Demersal or semi-demersal
	Physiology –Predator Detection or Prey Detection or Navigation	No negative impact or currently unknown	Documented reduced ability to avoid predators, locate prey, or navigate

2.3.7 Sound / Noise

Sound and noise are generally of greatest concern during the construction phase of most marine development (Boehlert and Gill 2010). One benefit of OFW turbines compared to fixed turbines embedded in the seafloor is that OFW construction does not involve pile driving, which is usually one of the largest sources of acoustic impact, particularly for marine mammals that use sound to communicate and fish that can experience barotrauma. The intensity and frequency of OFW sound changes between project phases, with operation phase noise of lower intensity and generally expected to add to the normal background acoustic environment over time (Thomsen et al. 2006; Boehlert and Gill 2010). The constant, low-level frequency emitted by the rotation of the rotor blades peaks at 50, 160, and 200 Hz at moderate-strong wind speeds of 12 m/s (Thomsen et al. 2006). Ship noise is another source of potential impact, with most generating frequencies between 20 Hz and 10 kHz. During site assessment, seismic surveys may be another source of significant noise pollution, causing avoidance and potential injury, but is considered a temporary source of potential effect if it occurs. Overall, data to quantify noise thresholds have been lacking (Boehlert and Gill 2010), but the current state of knowledge on temporary and permanent threshold shifts for marine mammals is summarized in the NOAA Technical Memorandum "2018 Revisions to: Technical Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing" (NMFS 2018).

There is very little information on the direct effects of operational noise from OFW technology on birds. It is likely that the noise or vibratory output of operational turbines or increased vessel traffic noise causes disturbance, displacement, or masking of important sound cues in some bird species (Drewitt and Langston 2006). For example, noise from terrestrial wind turbines masked low frequency bird sounds and affected the territorial defense songs of the European robin, which authors suggested leads to increased physical disputes and bodily injuries (Zwart et al. 2016; Rydell et al. 2017).

In addition, low-frequency noise from vehicular traffic, which is thought to be similar to sound from turbines, have had adverse effects on bird behavior, communication, and overall fitness (reviewed in Spellman 2014). Birds that fly offshore or roost near/on the water's surface may have increased vulnerability to turbine noise as these species must already hear above background noise from waves and wind (Exo et al. 2003). Alternatively, habituation or indifference to turbine noise, which reduces direct habitat disturbance impacts, can increase the risk of collision for some species during low visibility conditions (Larsen and Guillemette 2007).

Noise is of concern to marine mammals, as many species communicate via songs or echolocate, which can be masked by underwater noise pollution (Gill 2005; Madsen et al. 2006; Clark et al. 2009; Peng et al. 2015; Erbe et al. 2016; Goodale and Milman 2016). In addition to avoidance behavior or habitat disturbance, marine mammals can be physically injured by loud sounds with both temporary and permanent shifts in hearing thresholds possible depending on sound source and received levels (NMFS 2018). Increased noise from boat traffic has resulted in long-term displacement of some marine mammals and may lead to reduced energy intake and reproductive success because of decreased foraging opportunities and increased travel time between suitable forage locations (Lusseau 2005; Williams et al. 2006; Gedamke et al. 2016).

Noises of primary concern related to OFW are vessel traffic and seismic activity during site assessment. Operational noise from OFW is a secondary concern since it is lower frequency and less physically damaging (Nowacek et al. 2007). Studies based on simulated and observed responses to fixed offshore wind turbines estimated that responses of porpoises (mid-frequency hearing specialist) occurred within 20 – 79 m of the turbine, and harbor seals (phocid pinniped) responded within 100 m to several kilometers from of the turbine (Koschinski et al. 2003; Tougaard and Henrikson 2009). Effects of offshore wind noise on baleen whales have not been explicitly studied, but Northern right whales (low frequency specialist) may show responses on the order of kilometers from the sound source (Madsen et al. 2006). Noise modeling at the Hornsea 3 fixed offshore wind farm (6 MW turbines) in the U.K. indicated that operational noise from monopiles would cause injury to marine mammals within 10 m of the turbine, and that sound levels were expected to return to ambient levels within a few hundred meters (Ørsted 2018).

Floating offshore wind turbines are expected to generate less underwater noise than turbine foundations in contact with the seafloor, so noise effects may be of lower concern during the operation and maintenance phase for OFW developments, particularly when compared to vessel traffic noise during the site assessment and construction phases. The range of noise detection and response also depends on wind speed (higher speeds result in louder sounds emitted from turbine), ambient noise in the area, and characteristics of the water column that affect noise propagation (salinity, temperature, depth, turbidity). Species that can hear low frequency sounds, like baleen whales, may be the more vulnerable to operational noise generated by OFW farms because turbines put out long-term (> 20 year project lifespans) low frequency noise that could theoretically mask whale communications over a considerable time period and wide geographic range, as has been demonstrated by a loss of communication space due to vessel traffic noise (Hatch et al. 2012).

All fish have hearing structures that allow them to detect sound particle motion. Some fish also have swim bladders near or connected to the ear that allow them to detect sound pressure, as well, which increases hearing sensitivity and broadens hearing abilities (reviewed in Popper et al. 2014; Hawkins and

Popper 2017). In general, increased sound sensitivity and the presence of a swim bladder make fish more vulnerable to injury from anthropogenic noises as loud noises can cause swim bladders to vibrate with enough force to inflict damage to tissues and organs around the bladder (Halvorsen et al. 2011; Casper et al. 2012). The least sound-sensitive fish species, or hearing non-specialists, include those that do not have a swim bladder, such as flatfish, or those that have a swim bladder that is not connected to the inner ear and can be semi-deflated via the gut, such as salmonids. Hearing generalists have swim bladders filled with air that are close to, but not connected to the inner ear, such as cod, and can detect both particle motion and a limited amount of sound pressure (Wahlberg and Westerberg 2005; Halvorsen et al. 2011).

The most sensitive species, or hearing specialists, are those with swim bladders connected to the inner ear, such as fish in the Clupeidae family. These species can acquire recoverable and mortal injuries at lower noise levels than other species (Thomsen et al. 2006; Popper et al. 2014). Most crustacean species lack swim bladders and are considered less sensitive to sound, though behavioral responses to sound have been observed (orienting towards reef noise during settlement); however, resolution of information on invertebrates and sound is coarse (Edmonds et al. 2016). It is unlikely that continuous noise from vessels or turbines can cause mortal injury, however, they can cause avoidance behavior that interferes with feeding and breeding, alter schooling behaviors and migration patterns, and mask important environmental cues or communication during critical periods (e.g., spawning) (CBD 2012; Barber 2017; Stanley et al. 2017).

During the construction phase, impacts from noise on species in the water column can be mitigated through the use of passive acoustic monitoring or active monitoring such as Marine Mammal Observers (Baily et al. 2010 2014; Thompson et al. 2010) to alert construction operators to the presence of sensitive species. Additionally, it is generally recommended that timing restrictions are implemented for construction in order to reduce disturbance to critical functions such as breeding, migration, spawning, calving, and feeding (Bergström et al. 2014; Drewitt and Langston 2006; SMRU 2009). Further mitigation measures to reduce sound/noise impacts during construction include bubble curtains, shell-in-shell systems, hydro sound dampers, and cofferdams (Bellman et al. 2015; Verfuß 2014). No planned mitigation measures were identified for operational noise, which may have impacts on marine mammals, fish, and benthos (Pine et al. 2014; van Opzeeland 2014). The application of mitigation measures for sound/noise in the OFWESA model reduces impact scale and impact level values across all three project phases (site assessment, construction, and operation) in the OFWESA model analysis.

Table 13 provides a summary of the assessment metrics relevant to sound/noise along with the behaviors and traits of each species group that were associated with lower and higher vulnerability to the ICF.

Table 13. Assessment Metrics for Each Species Group Used to Calculate Vulnerability to Sound and Noise. Behaviors resulting in lower and higher vulnerability are noted. See Appendix B for details.

Species Group	Assessment Metric	Lower Vulnerability to ICF	Higher Vulnerability to ICF
Birds / Bats	Concentration - Aggregation	Mostly solitary in area	Large flocks or colonies in area
	Encounter - Feeding Method	Does not forage in marine habitat	Feeds from surface waters
	Encounter - Macro-Avoidance/Attraction	Highly avoidant	Highly attracted
	Encounter - Night Roosting	Never roosts on marine waters	Nearly always roosts on offshore marine waters
	Encounter - Rotor Sweep Zone	Rarely or never flies at turbine height	Frequently flies at turbine height
Fish / Invertebrates	Concentration - Aggregation	Mostly solitary in area	Large schools in area
	Encounter - Macro-Avoidance/Attraction	Highly avoidant	Highly attracted
	Physiology - Sound Sensitivity	Hearing non-specialist (no swim bladders or contain little air) or hearing unknown	Hearing specialist (with swim bladder connected to inner ear)
Marine Mammals / Turtles	Concentration - Aggregation	Mostly solitary in area	Large pods or colonies in area
	Encounter - Feeding Method	Benthic forager	Surface feeder
	Encounter - Habitat Use	Portion of life history is not marine/is on shoreline	Surface, pelagic water column, and marine sediment use
	Encounter - Macro-Avoidance/Attraction	Highly avoidant	Highly attracted
	Physiology - Sensitive Features	Not reliant on sound or echolocation	Reliant on sound or echolocation
	Physiology - Sound Sensitivity	High-frequency cetacean (porpoises with range from 275 Hz to 160 kHz)	Low-frequency cetaceans and pinnipeds (baleen whales, seals, and sea lions, with ranges from 7 Hz to 86 kHz)

2.3.8 Vessel Strikes

There are documented reports of cetaceans being struck by ships in the oceans throughout the world (Glass et al. 2008; Jensen and Silber 2004; Laist et al. 2001). Because there would likely be additional vessel traffic during site assessment and construction of renewable energy projects, impacts to marine mammals and sea turtles may result. As noted in Section 2.1.5 above, upper estimates of vessel traffic during operation and maintenance may reach 10 trips per WTG unit per year for unforeseen events

(Statoil 2015). The AlphaWindEnergy lease applications for the Northwest and South Oahu sites proposed a maximum estimate of 268 vessel trips per year (2-4 trips per turbine per year; AW Hawaii Wind LLC 2015a; 2015b). Fixed turbine offshore wind farms in the U.K. reported expected vessel movements to be anywhere between 1,000 – 4,000 return trips per year over 35 years of operation; for the Hornsea 3 development, the vessel traffic expected during operations and maintenance represents a 22% increase to the baseline level of vessel activity (12,755 return trips per year; Ørsted 2018). However, as mentioned previously, these estimates involve fixed turbine developments and it is possible that the maintenance requirements of floating offshore wind technology could be lower.

Vessel traffic during the operation phase is likely to be less frequent than during construction and existing levels of vessel traffic are taken into account in the determination of lease areas. Collisions with vessels greater than 80 m in length are usually either lethal or result in severe injuries (Laist et al. 2001) and a few vessel classes associated with OFW development would exceed this length including cable-laying vessels, offshore construction vessels, bulk carriers, deck barges, crane barges, repair barges, anchor-handling tugs, and multi-purpose vessels (Porter and Philips 2016). Debilitating injuries may have negative effects on a population through impairment of reproductive output (MMS 2003). Species that form large aggregations are more likely to be negatively affected by vessel strikes because there is a higher probability of encounter that could affect a larger proportion of the population at once (Jensen and Silber 2003). Large amounts of time spent swimming at the surface or attraction to manmade offshore structures also increases a species' vulnerability to project-related vessel strikes.

For most fish species, vessel strikes are rare, as fish are small and agile enough to move away from oncoming vessels. However, vessel strikes have been documented for larger, slower species like sturgeon, sharks, and sunfish and the increased vessel traffic associated with OFW could affect these species if present in the study areas (Brown and Murphy 2010; Towner et al. 2012; Peel et al. 2016).

Vessel strikes are a concern for marine mammals. During all stages of OFW development, active observing and passive acoustic monitoring techniques can be used to reduce the potential for vessel strikes. However, because OFW arrays may aggregate vessel traffic outside of the restricted area in which the array is located, there is an additional possibility of increased vessel strikes in the surrounding area. No feasible mitigation practices to address this issue were identified. Analyses by Vanderlaan and Taggart (2007) provide evidence that as vessel speeds fall below 15 knots, there is a substantial decrease in the probability of a vessel strike killing a large whale. The application of mitigation measures for vessel strikes in the OFWESA model reduces impact scale and impact level across all three project phases (site assessment, construction, and operation) in the OFWESA model analysis.

Table 14 provides a summary of the assessment metrics relevant to vessel strikes along with the behaviors and traits of the fish/invertebrate and marine mammal/turtle groups that were associated with lower and higher vulnerability to the ICF.

Table 14. Assessment Metrics for the Fish/Invertebrate and Marine Mammal/Turtle Species Groups Used to Calculate Vulnerability to Vessel Strikes. Behaviors resulting in lower and higher vulnerability are noted. See Appendix B for details.

Species Group	Assessment Metric	Lower Vulnerability to ICF	Higher Vulnerability to ICF
Fish / Invertebrates	Physiology - Strike Risk	Small, agile, deep-dwelling species	Large, slow-moving, surface-associated species
Marine Mammals / Turtles	Concentration - Aggregation	Mostly solitary in area	Large pods or colonies in area
	Encounter - Habitat Use	Portion of life history is not marine/is on shoreline	Primary surface water use
	Encounter - Macro-Avoidance/Attraction	Highly avoidant	Highly attracted

2.4 Large-Scale Events

LSEs represent ICFs that occur outside of normal operational parameters of OFW facilities and include natural events, such as earthquakes, tsunamis, and storms (e.g., hurricanes), as well as accidents from vessels servicing or transiting by an OFW facility that might cause spills. LSEs were considered categorically within the OFWESA model as those that could lead to partial or complete structural failure of an OFW turbine or field. Specifically, these events could cause or increase the occurrence of accidental spillage of oil and/or chemicals from wind turbine generators and other facility structures; bird collisions with above-surface facility structures; entanglement by fish and other marine organisms with sub-surface structures, and/or habitat disturbance (Table 15). Because a structural failure would not necessarily result in spillage in all cases, the probability of spillage resulting from structural damage is also incorporated into the analysis. Effects of LSEs were incorporated into the model by increasing the impact scale and impact level score for each relevant ICF and project phase, thus increasing impact magnitude scores for some ICFs and phases (see Appendix D and F of this report).

Table 15. Relationship between Large-Scale Events and Impact-causing Factors that might be Increased by Occurrence of the Event

Large-Scale Event	Related ICFs
Storm/Hurricane	Accidental Spill
	Collisions with Above-Surface Structures
	Entanglement with Sub-Surface Structures
	Habitat Disturbance/Displacement
Earthquake	Accidental Spill
	Habitat Disturbance/Displacement
Tsunami	Accidental Spill
	Collisions with Above-Surface Structures
	Entanglement with Sub-Surface Structures
	Habitat Disturbance/Displacement
Significant Vessel Accident	Accidental Spill (from Wind Facility Structure)
	Habitat Disturbance/Displacement

2.4.1 Hurricane Damage to OFW Facilities

Wind is both a source of power and a threat to OFW facilities. Wind speed increases power generation until it reaches the wind turbine's rated speed, at which time it levels off until it reaches its "cut-out speed." For example, for a 3.6 MW turbine, the cut-out speed is 60 mph (27 m/s). At that time, the turbine shuts-in and is not generating power. At wind speeds up to about 100 mph (45 m/s), the turbine is shut-in, but damage is unlikely. Above 100 mph, as for hurricanes of categories 2 through 5, there is the potential for damage to the structures. The exact engineering specifications of each OFW component would determine the rated and cut-out speeds.

Reported damage to OFW turbines and other wind facility components from hurricanes is anecdotal (e.g., Clausen et al. 2007). There is a report of a wind turbine off the coast of Scotland being damaged by winds of 150 mph causing it to burst into flames (Diamond 2012). There have also been reports of extreme wind damage to monopile cement grouting, but this has not been connected to any kind of spillage (Diamond 2012). According to Diamond (2012), wave heights exceeding 15 meters (over 49 feet) may cause structural damage to OFW turbines, including turbine blades. However, there have not been enough incidents or consistent reporting of these incidents to develop any kind of statistically-robust data from which to derive probabilities.

A 2011 study by Rose et al. developed a probabilistic model to estimate the number of turbines that might be destroyed by hurricanes in an offshore wind farm. The model considered only tower buckling rather than damage to blades. The percentages of turbines expected to topple by wind speed according to the analysis are shown in Table 16. Note that toppling does not necessarily mean that there would be a spill.

Table 16. Expected Probability of Damage to Offshore Wind Turbines by Hurricane Category

Hurricane Category	Wind Speeds	% Damaged Turbine Towers
Category 2	101 mph	6%
Category 3	112 mph	46%
Category 4	131 mph	70%
Category 5	155 mph	94%

The actual effect of hurricanes on large OFW facilities may be complicated by the effect of the turbines on the hurricane winds themselves. Based on a computer simulation, researchers concluded that OFW facilities with large arrays of turbines (300+ GW installed capacity) may actually mitigate hurricane damage by reducing wind speeds by 56 to 92 mph and storm surges by 6% to 79% (Jacobson et al. 2014).

Category 4 hurricanes would be expected to cause partial structural failure of wind turbines and potentially cause a small spill. Category 5 hurricanes would be expected to cause a major structural failure and a larger spill. In the OFWESA model, it is assumed that a Category 4 hurricane would cause the same damage to OFW facilities in all locations; thus, the critical issue for the OFWESA model is the probability of a Category 4 (or greater) hurricane occurring in each location and using estimates of hurricane frequency. A more detailed fault tree analysis could be undertaken during a site assessment phase. In a fault tree analysis, a series of probabilities of various independent events are multiplied together to determine the overall probability of an event. In this case, the probability that there would be a hurricane would be multiplied by the probability that there would be damage to the components of the wind turbines and that there would be sufficient damage to cause leakage or a release of oil and/or chemicals. The probability that all of these events would occur would become increasingly smaller. The probabilities that are incorporated into the fault tree are specific to each site based on geography and the structure and design specifications of the wind facility components.

2.4.2 Earthquake Damage to OFW Facilities

Seismic activity can also potentially cause damage to OFW facility structures. The effects could be due to direct seismic effects (shifting, tremors), or due to landslides and/or tsunamis. While there are no specific data to categorize earthquake damage to OFW facility structures, it is assumed that there would be damage causing partial structural failure above Richter 5.0 and major structural damage at 7.0 for the OFWESA model. This is consistent with the assumptions for earthquake damage applied for other offshore wind farm studies (e.g., Etkin 2006a; Etkin 2008).

2.4.3 Tsunami Damage to OFW Facilities

Tsunamis (also called "seismic sea waves") occur when there are undersea earthquakes of at least 7.5 on the Richter scale. The massively destructive tsunami in Southern Asia in December 2004 followed a 9.3 Richter scale earthquake in the Indian Ocean. Tsunamis are most common in the Pacific Ocean, but have occurred in the North Atlantic Ocean, including one that followed the 1775 Lisbon earthquake. That tsunami was 23 feet high in the Caribbean Sea. Although rare, tsunamis can also occur after volcanic eruptions, landslides, or extraterrestrial collisions (e.g., meteors). Massive underwater landslides on the continental shelf, which are often related to or caused by earthquakes, could also cause tsunamis.

The NOAA National Centers for Environmental Information maintains a global historical tsunami database, the NGDC/WDS, which includes information on earthquakes, as well as tsunami events and damages since about 1800 (NOAA 2017d). Tsunamis that are primarily caused by earthquakes are characterized by earthquake magnitude. According to an analysis of the NGDC/WDS data, there is a rough correlation between the magnitude of the tsunami event (as defined by the earthquake magnitude) and wave height. Tsunamis of less than 6.0 create average wave heights of less than 5.0 feet. At a magnitude of 6.0, the average wave height increases to 8.0 feet, and rises sharply after that. Tsunamis of magnitude 9, have an average wave height of 131 feet.

Tsunamis in deep water are rapidly moving, low wave height, long wave length features. Since OFW turbines will be located in deep water, tsunamis could potentially cause floating turbines to experience structural failures, which may lead to spilling of oil and/or chemicals. There are no specific data that may be applied to estimate the damages from tsunamis to OFW facility structures, as there are no reports of tsunamis damaging OFW turbines. Given that tsunamis are usually caused by earthquakes and are characterized by earthquake magnitude, it was assumed that damages to wind facility structures would generally be correlated with earthquake magnitude.

OFW turbines are constructed to withstand the waves and sea states at the location for which they are designed (Butterfield et al. 2005). This would generally include waves that occur during storms that are not associated with hurricanes or cyclones. OFW turbines can withstand waves of 45 feet (Diamond 2012). OFW turbines would be constructed for the maximum tsunami that has occurred in the past in the location where the structures are to be installed. If the water is deep enough, the effect of a tsunami would be expected to be similar to that of tidal level and current. Based on engineering guidelines, the floating structures are supposed to be designed and installed so as not to collapse or drift at the time of an earthquake or tsunami (Kyoki 2012). However, since there are no records of the behavior of OFW facilities in significant tsunamis (or earthquakes), a conservative approach was taken for this study. It was assumed that if there would be an earthquake of 6.0 to 7.9, there might be a partial failure of the wind turbines, and if there were an earthquake of 8.0 or higher, there would be a major failure. However, all of these scenarios are highly unlikely.

2.4.4 Vessel Accidents

Vessel traffic in the vicinity of an OFW facility presents a risk of accidents, that, in turn, could cause oil, chemical, or other cargo spills from the vessels, and/or oil and chemical spills from the facility structures (Etkin 2006b; Etkin 2008; C&H Global Security 2013). Besides crude oil or refined petroleum products, cargo on vessels might include chemicals, dry cargo (e.g., minerals, grain, sand, gravel, or coal), automobiles or trucks (on vehicle carriers or ferries), machinery, and containers, which themselves could contain any manner of contents, including hazardous materials. The various vessel accidents that could conceivably occur and lead to spillage of oil, chemicals, or other substances include:

- vessels allisions[6] with OFW facility structures that result in damage to the facility structures with spillage of oil and/or chemicals from the structures;
- vessel allisions with OFW facility structures that result in damage to the vessels with spillage of oil and/or chemicals from the vessels; and
- vessel collisions with each other as a result of the presence of the OFW facility that result in damage to the vessels with the spillage of oil or other cargo and/or fuel.[7]

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[6] An "allision" occurs when a moving object, in this case a vessel, comes into contact with a stationary object (e.g., one of the wind turbines). This type of event is distinguished from a "collision" in which two moving objects, such as two vessels in transit, strike each other. While the term "collision" is often used colloquially in place of the term "allision", this is incorrect usage with regard to vessel casualty analyses and ship operations. The terms are used in this report as they are used in maritime contexts to distinguish between these two types of events.

[7] Groundings are unlikely to occur because the OFW facilities would generally be in areas deep enough to accommodate the draft of most vessels.

The environmental impacts of a vessel spill would depend on the type of oil or chemical involved, the volume, the specific location of the incident, and the environmental conditions at the time of the spill and in its aftermath (particularly winds and currents). A vessel spill's impacts could be very localized if the volume is small, but could conceivably be large enough to reach shorelines if the volume is much larger.

The type of substance spilled from vessels in vessel-OFW component allisions or from vessel-vessel collisions would depend on the types of vessels in transit in the area, their fuel oils, and their cargoes, which may be oil or a large number of other substances. The volume of spillage would depend on the vessel sizes (i.e., their fuel and cargo capacities), the type of vessel, the speeds and angle(s) at which the vessels encounter the OFW structures or each other, and the degree of outflow from the vessels' cargo and fuel tanks. The latter is dependent on the architecture of the vessels.

The vessel accidents that cause spillage from the OFW facility structures themselves were included in the OFWESA model as direct effects of the OFW facility. Quantifying the probability of spills from vessels, either caused by allisions with facility structures or collisions with each other due to indirect effects of the OFW facility, would require knowledge of several variables regarding the potential vessel cargo types and volumes, vessel traffic patterns, OFW facility development locations, and probability of accidents that cause vessel spills. Because of the number of unknown variables, impacts from vessels as a result of vessel allisions with OFW facilities or vessel collisions with each other due to the presence of OFW facilities cannot be appropriately factored into a relative risk model's probability ranking system. This does not imply that there would be no effects of vessel spills. Vessel spills could potentially have greater environmental impacts by spreading larger volumes of oil or chemicals over greater areas than smaller spills from the OFW structures.

Furthermore, there are few studies that specifically address the degree to which vessel allisions might cause damage to OFW facility structures (Bela et al. 2015; LeSourne et al. 2015). In general, the wind turbine generators are built to withstand significant accidents, though many of the studies conducted on their "crashworthiness" are for fixed-bottom turbines rather than floating turbines, which would likely react differently (LeSourne et al. 2015; American Bureau of Shipping 2011, 2013).

However, for the purposes of this study, a simplified approach is recommended and was applied. This approach categorized the number of vessel trips for each region by medium and large vessel sizes, and then normalized the number of vessel trips across categories and regions. To determine the relative likelihood of vessel allisions, the degree of vessel congestion (i.e., the density of vessel traffic in the area) is used as a proxy for the likelihood of an allision incident. The annual tonnage reflects the general nature of the vessel traffic in the region that may potentially affect the probability of an allision of a vessel with an OFW facility structure. The vessel trip numbers by medium and larger vessel size provide a relative probability of the likelihood of allisions that might cause either partial or major structural failure. This approach includes assumptions about the nature of potential allisions and collisions that are based on analogies with ports and open waters worldwide. Since vessel traffic density is related to increased risk of collisions and allisions based on a number of studies (e.g., U.S. Coast Guard 2016), vessel traffic data to determine density and overall makeup of the traffic in a particular area of concern can be applied to determine the relative likelihood of vessel accidents.

2.4.5 LSE Summary

For the natural events that could cause spills (hurricanes, earthquakes, and tsunamis), data that characterize the frequency and magnitude of these events for the two selected geographic regions (California and Hawaii) were analyzed. Based on the types of data that were readily available for natural event occurrence and the degree of damage that might occur to OFW structures, a simple algorithm was developed to classify the frequency of events on a geographic basis with regard to event magnitude. The likelihood of more than one OFW structure to fail or even topple was also considered and was determined to be extremely unlikely to result from vessel allisions, as the structures are too far apart for a vessel to allide with more than one structure in a single event. But, multiple structure failures could occur with hurricanes, earthquakes, or tsunamis.

The types of chemicals and oils that would likely be contained in OFW facility components are identified in Section 2.3.1. This information is largely derived from information provided for the analyses conducted for the proposed Cape Wind Energy Project off Massachusetts (Etkin 2006a; MMS 2009). The hazardous substances and quantities presented above are some examples; however, other similar types of chemicals and oils may be present, depending on the specifications of the particular wind facility components. Because each proposed facility may have different specifications the volumes and chemical/oil types may differ. If more than one structure fails and releases oil and chemicals, this would most likely constitute a moderate-sized spill. Each LSE has a rate or likelihood metric computed (dependent on available data) for two different levels of events: partial structure failure and complete structure failure. With regard to spills from wind facility structures, the volumes of spillage are likely to be limited in size with the exception of spills from substations, which may be somewhat larger. Spills are categorized as “minor” or “moderate” based on U.S. Coast Guard spill characterizations (40 CFR § 300.5). A “major” spill of 100,000 gallons or more is not likely from an OFW facility as there is not that much oil or chemicals stored on the structures.

Seasonal frequencies were calculated for hurricanes, while annual frequencies were calculated for earthquakes and tsunamis, which were converted to seasonal frequencies. These frequencies reflect the probability that there may be a hurricane, earthquake, or tsunami that could cause sufficient partial or major structural failures resulting in spillage from the OFW facility structures. The frequencies or probabilities do not indicate that there would necessarily be that type of damage and consequent spillage; rather, the frequencies indicate there is a possibility that it would occur. Whether or not the damage to the wind facility structures would be sufficient to cause spillage or otherwise increase the effects of ICFs would depend on the specific circumstances of each event.

To determine the relative likelihood of vessel allisions, the degree of vessel congestion (i.e., the density of vessel traffic in the area) was used as a simplified proxy for the likelihood of an allision incident. The annual tonnage and numbers of vessel trips were summarized. First, the overall tonnage reflects the general nature of the vessel traffic in the region that may potentially affect the probability of an allision of a vessel with a wind facility structure. Second, the number of vessel trips of two different categories of vessels (medium-sized, associated with partial OFW failure magnitude) and large (associated with full OFW failure magnitude) was used to estimate a per-vessel collision rate during the time that it might be passing an OFW facility (as explained in Appendix F). The probability of a vessel having an allision in the assumed 2-hour time it might be passing an OFW facility was calculated to be 1.370×10^{-7}. This probability multiplied by the number of vessel trips in each vessel size category resulted in annual vessel accident frequencies for each study area that were then divided by six to estimate seasonal vessel accident frequencies for use in the model. Overall, an increase in the vessel density (the number of vessels per unit area) increases the potential encounter rate between vessels or between vessels and stationary objects, such as wind turbines (Judson 1992).

3 Background and Methods

In light of an increase in renewable energy initiatives and the established viability of power generation by offshore wind farms, it is important to understand environmental implications and the general knowledge gaps that should be addressed prior to OFW development in the United States. This study consisted of a review of existing sensitivity analyses, a summary of OFW technology and a definition of its major ICFs, incorporation of LSE frequencies and impacts, a detailed geospatial analysis of various habitat characteristics, and a thorough literature review for 44 fish, invertebrate, mammal, turtle, bird, and bat species in one California and two Hawaii study areas to assess the potential impacts of large-scale OFW development on habitats and species. The species scoring method allowed for an informed assessment of potential impact and to quantitatively account for uncertainty in the data, highlighting the areas and species which knowledge gaps in the literature. This report also summarized the baseline conditions in each region as a proxy for a cumulative effects analysis.

The environmental sensitivity results of the model reflect the impact of OFW ICFs on receptors in the environment based on the underlying sensitivity of habitats and species present in each region and season. The ICF rankings form the basis for model analysis and the scoring matrices for each ICF on habitat and species sensitivity scoring are provided in Appendix B of this report. Understanding the model structure, model inputs, and how it is implemented is useful context for the analysis of model results, summarized in the body of this report. For details of the algorithms, refer to Appendix C.

3.1 Study Areas

The California study area is located 22 miles offshore of California, between Monterey Bay and Morro Bay, in waters 800-1,000 m deep approximately 26 nautical miles (48 km) from Point Estero, California (Trident Winds LLC. 2016). The 25-nm buffer zone around the OCS lease blocks encompasses an area of 11,430 km^2, with 1,211 km^2 of terrestrial habitat and 10,219 km^2 marine (89%). A substantial portion of the bottom habitat of the California study area is of unknown type (i.e., no data for these areas in the most comprehensive datasets found for the analysis).

The Hawaii North study area is located 9 miles off the northwest corner of Oahu, where Kaena Point State Park is located. The study area is over a 700-1,000 m deep plateau (AW Hawaii Wind LLC 2015a). The 25-nm buffer zone around the OCS lease blocks encompasses an area of 12,302 km^2, with 936 km^2 of terrestrial habitat and 11,366 km^2 marine (92%). The bottom habitat of the Hawaii North study area is comprised of a variety of types, including volcanic material, corals/sponges, and hard bottom habitats, although soft bottom habitats account for about half of the area. The buffer zone encompasses part of the Kauai Channel.

The Hawaii South study area is located 9 miles offshore of Oahu, south of Honolulu, on an approximately 5-700 m deep plateau (AW Hawaii Wind LLC 2015b). The 25-nm buffer zone around the OCS lease blocks encompasses an area of 15,849 km^2, with 1,519 km^2 of terrestrial habitat and 14,330 km^2 marine (90%). Like the Hawaii North study area, the Hawaii South study area is comprised of a variety of habitat types, including volcanic material, corals/sponges, and hard bottom habitats, although soft bottom habitats account for about half of the area. The buffer zone encompasses much of the Penguin Bank. In addition, the Hawaii North and South 25-nm buffer zones overlap each other in the center of Oahu.

3.2 Concept Review

The conceptual basis of earlier sensitivity methodologies offer the basis for the current model. Questions addressed by these models include:

- how likely is a species/habitat to be impacted by an ICF;
- when impacted, how negatively affected is the species/habitat;
- what is the ability of the species/habitat to recover from a negative impact, and
- what existing conditions in a region may contribute to increased sensitivity of species and habitats?

The OFWESA model used for this sensitivity analysis was developed to expand upon the earlier studies to provide application directly to OFW for the U.S. OCS and coastal regions. Beyond the base models examined, additional studies specific to wind energy environmental sensitivities and risks were collected and reviewed, which served as the basis for development of the OFWESA model. Details of the model development process can be found in Appendix F.

3.3 OFWESA Model Structure

The OFWESA model assesses the environmental sensitivity of OCS lease block regions and surrounding waters to ICFs associated with OFW development and operation by applying the standard technical definition of risk, which includes both the likelihood (i.e., probability) and consequences (i.e., impacts) of incidents. An incident is defined as the interaction of an ICF with species or habitats. Impacts are defined as the detrimental consequences of incidents on species and habitats. The OFWESA model also includes concepts of existing (baseline) conditions in the ecosystem and potential mitigation practices that may reduce the sensitivity of certain species to OFW activities.

The sensitivity model developed for this project consists of five main components:

(1) sensitivity of habitats to OFW;
(2) sensitivity of species to OFW;
(3) effect of mitigation options on species sensitivity;
(4) probability of large-scale events that may lead to increased species and habitat sensitivity; and
(5) baseline conditions characterizing the present influence of anthropogenic activities on the environment at a study location.

A flow diagram for the overall model is provided as Figure 3.

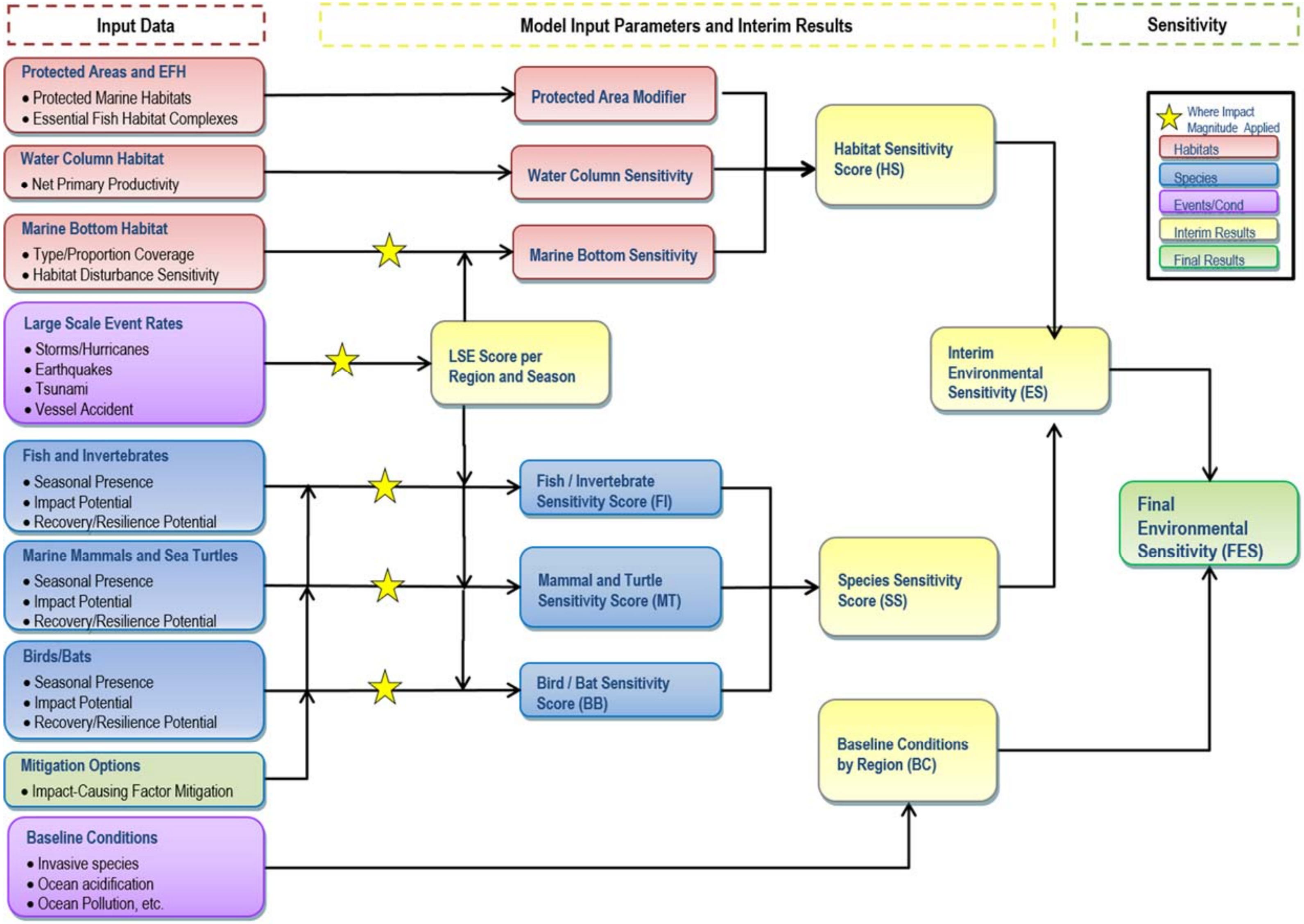

Figure 3. OFWESA model flow diagram

3.4 OFWESA Inputs and Implementation

The OFWESA model consists of a series of rank scores and normalization steps in simple multiplication, addition, and averaging calculations, as summarized below. For details on the model calculations used for each step, refer to Appendix C, Section C.3 of this report. For a detailed description of the input data that was used in the model steps, refer to Appendix D, Section D.1.

1. **Impact Magnitude –** This parameter combines impact duration, spatial scale, level of impact, and current level of development into one number that represents the magnitude of the impact for each ICF during each project phase: site assessment, construction, and operation. The impact magnitude values were applied in multiple algorithms throughout the model, indicated by the yellow stars in the model flow diagram (Figure 3).
2. **Large-Scale Event Rate Scores –** This parameter incorporates results seasonal frequencies of occurrence of hurricanes, earthquakes, tsunamis, and vessel accidents for two different magnitudes (partial and full structural failure of the wind facility) into LSE scores for each study area.
3. **Habitat Sensitivity –** This parameter is an interim result calculated by adding the water column habitat and marine bottom habitat scores together and then multiplying them by the protected area modifier. These scores were normalized to a regional minimum and maximum across all seasons for the hypothetical scenarios and scaled from 1 – 15.
4. **Species Sensitivity –** This parameter is composed of the ICF vulnerability and recovery potential scores for all species within three species groups and incorporated seasonal LSE rate scores, species presence, and the level of uncertainty for each assessment metric score.
    - 4.1. **ICF Vulnerability Scores –** These scores were part of the input data collected during the species literature review. The vulnerability to ICFs ranged from 0 (low) to 5 (high) for categories of behavior and life history traits that were assigned based on assessment metric questions that captured a species' potential for interacting with OFW ICFs (see Section 2.2.3). Researchers assigned an assessment metric rank category and a level of uncertainty (LoU) score to indicate how accurate the rank might be based on data availability, reliability, and professional opinion.
    - 4.2. **Species Presence –** These scores were part of the input data collected during the species literature review. They rated a species as fully present, migrating in or out, or absent from a study area during six periods of the year.
    - 4.3. **Species-specific Sensitivity –** Species-specific sensitivity was composed of ICF vulnerability scores modified by the ICF impact magnitude during each project phase, recovery potential scores, seasonal presence of the species, and LSE rate scores for the study area.
    - 4.4. **Species Group Sensitivity –** Species group sensitivity interim results were calculated by summing the sensitivity of each species within a group and region for each season, and dividing the summed scores by the number of species evaluated for that group in that region. This resulted in an average species group sensitivity score for each season and study area.
5. **Environmental Sensitivity –** This parameter is an interim result calculated by adding the habitat sensitivity score to the species sensitivity score for each region and season. It represents the environmental sensitivity of a study area before modifying by the baseline conditions score.
6. **Baseline Conditions –** This parameter combined metrics from several spatial datasets to capture existing anthropogenic impacts in each study area.
7. **Final Environmental Sensitivity –** This result was calculated by multiplying the environmental sensitivity by the baseline conditions score to arrive at a final environmental sensitivity score for each region and season. The season scores were also averaged together for one annual score per region.

3.5 Hypothetical Minimum and Maximum Values

A key difference between the OFWESA model and previous relative environmental sensitivity models (RESA; e.g., Niedoroda et al. 2014, Reich et al. 2014) is that the previous models compared study areas to each other to obtain relative risk results. In the OFWESA model, hypothetical minimum and maximum values were incorporated instead, so that the results would be independent of the sensitivity of other regions in the model. This means that when users add new regions to the database in the future, the results for the existing study areas will not change in response to the new information, because they are compared to independent minimum and maximum values.

The hypothetical minimum and maximum values for comparison were developed differently for each model parameter and carried through each step of the model calculations. For parameters that had an upper bound that represented a “worst case” most sensitive value, the highest possible rank or score was assigned (e.g., marine bottom habitat sensitivity, protected areas, species presence, species impact scores, and species recovery potential). For parameters that did not have a hypothetical upper bound, a measured value likely to be much larger than the value within the study area had to be obtained. To do this, two “dummy” regions were incorporated into the model to calculate the hypothetical values for the model parameters without a logical upper bound (e.g., water column sensitivity (NPP) and baseline conditions score). These hypothetical regions were the Economic Exclusion Zones (EEZ) for HI (clipped to include only the EEZ for main southeastern Hawaiian Islands) and for CA. For water column sensitivity, the maximum NPP measured in any season within the EEZ was set as the hypothetical maximum value. For baseline conditions, the all of the baseline metrics occurring within the EEZ were measured just as they were for the study areas and these measurements were used for each normalization step. (For details, see Appendix C.) Finally, LSEs were the only parameter for which neither a logical nor EEZ-related upper bound could be determined. Thus, the maximum LSE score calculated across periods and study areas was assigned. For this iteration of the model, the LSE score for the Hawaii study areas during period 5 (August – September) were the highest, so it served as the hypothetical maximum value.

For a detailed description of the development of the hypothetical minimum and maximum values, see Appendix C.

3.6 Impact Magnitude and Mitigation

Impact magnitude was a metric originally developed for the RESA model (Niedoroda et al. 2014) to objectively characterize the size, duration, and potential level of effect of each ICF. The impact magnitude attribute assessed the spatiotemporal extent of the ICF within the study area as a function of impact duration, spatial scale, impact level, and current OFW development in the region (which was considered low for this analysis). Rank scores from 1 (low) to 5 (high) were assigned for each component of the impact magnitude calculation based on the defined characteristics of each ICF (see Table 17). The components were then summed together in a weighted algorithm to derive one value representing the impact magnitude of each ICF during each project phase. The impact magnitude of each ICF/phase combination was used as a multiplier throughout the model to calculate impacts to species and habitats for the unmitigated base scenario.

For this study, identified feasible mitigation practices were represented in the OFWESA model as a modification of the unmitigated impact magnitude values (i.e., mitigation option) to reflect the application of mitigation on environmental sensitivity. Mitigation practices affect the impact potential of ICF/species or habitat relationships within a respective project phase, as described for each ICF in Section 2.3. Mitigation was applied in the model by reducing the impact scale and impact level for some of the ICFs during specific project phases, which then reduced the impact magnitude for those ICF/phase combinations accordingly. The reduced mitigated impact magnitude was used in the calculation of the mitigated scenario ICF impact scores in the analysis. For definitions of impact duration, scale, level, and supporting research justifying the mitigation options for each ICF, refer to Appendix A. The effects of applying the mitigation option on model results are discussed in Section 4.3.

In contrast to mitigation, the impact magnitude of some ICFs could be heightened from the occurrence of certain LSEs (e.g., earthquakes, tsunamis, hurricanes, and vessel accidents). This was accounted for in the model by increasing the impact scale and level for some of the ICFs during some project phases, thus increasing impact magnitude under different LSE scenarios. The large-scale event analysis was explained in Section 2.4 and in Appendix F.

The ranks assigned to each ICF/project phase combination for impact duration, scale, and level are shown in Table 17. The results of the impact magnitude calculation are color-coded from low magnitude ICFs (green) to high magnitude ICFs (red) in particular phases to help visualize the weight each ICF carried through the OFWESA model sensitivity calculations. For example, collisions above surface during the operation phase had a high impact magnitude of 3.8 (out of 5) due to the duration of the effect (chronic) as well as the likelihood for injury (high level of impact). Therefore, species with behaviors that make them vulnerable to the collisions above surface ICF will likely have higher sensitivity scores due to the influence of the large impact magnitude of the collisions above surface ICF. Alternatively, the artificial light ICF during the assessment and construction phases had a low impact magnitude of about 1.6 and species that are vulnerable to artificial light might not automatically have a high sensitivity score because their vulnerability to artificial light receives lower weight throughout the model (lower impact magnitude) than other ICF vulnerabilities. The table also describes the mitigation and LSE assumptions for each ICF and project phase as they were applied in the model (Table 17).

Table 17. Calculated Impact Magnitude Rank (Max = 5) based on Scores Assigned for Impact Duration, Scale, Level, and Current Level of Development. The unmitigated magnitude is modified by reducing or increasing the impact scale and level by one for mitigation or large-scale event influences on certain ICFs, respectively. See assumptions in table and Appendix A for details. Green=low values, red=high values.

ICF	Phase	Impact Duration	Impact Scale	Impact Level	Unmitigated Impact Magnitude	Mitigation Assumptions	Large-Scale Event Assumptions
Artificial Light	Assessment	1	2	1	1.2	Mitigation measures assumed for the construction and operation phases.	No increased impact from LSEs assumed.
	Construction	2	3	1	1.6		
	Operation	5	3	2	2.7		
Accidental Spills	Assessment	1	2	4	2.7	Mitigation assumed for all three phases.	LSE impact of hurricanes, tsunamis, earthquakes, and vessel accidents assumed during all project phases.
	Construction	1	2	4	2.7		
	Operation	1	2	4	2.7		
Collisions Above Surface	Assessment	0	0	0	0	Mitigation assumed for operation phase. ICF not applicable to assessment or construction phases.	LSE impact of hurricanes and tsunamis assumed during operation.
	Construction	0	0	0	0		
	Operation	5	1	5	3.8		
Collisions and Subsurface Entanglement	Assessment	0	0	0	0	No mitigation measures assumed.	LSE impact of hurricanes and tsunamis assumed during all project phases.
	Construction	0	0	0	0		
	Operation	5	1	2	2.3		
Electromagnetic Fields	Assessment	1	1	2	1.5	No mitigation measures assumed for operation phase. ICF not applicable to assessment or construction phases.	No increased impact from LSEs assumed.
	Construction	2	1	1	1.2		
	Operation	5	1	2	2.3		
Habitat Disturbance / Displacement	Assessment	1	2	4	2.7	No mitigation measures assumed.	LSE impact of hurricanes, tsunamis, earthquakes, and vessel accidents assumed during all project phases.
	Construction	1	2	4	2.7		
	Operation	5	2	4	3.5		
Sound / Noise	Assessment	2	1	4	2.7	Mitigation measures assumed for all three phases.	No increased impact from LSEs assumed.
	Construction	1	1	4	2.5		
	Operation	5	1	4	3.3		
Vessel Strikes	Assessment	1	1	5	3	Mitigation measures assumed for all three phases.	No increased impact from LSEs assumed.
	Construction	1	1	5	3		
	Operation	1	1	5	3		

4 Results and Analysis

The OFWESA model and associated database is intended to aid in identifying the habitats, species, regions, and seasons that are potentially more sensitive to impacts of OFW development among those included in the model. This will allow analysts and regulators to focus their studies and mitigation efforts on the environmental components most at risk. Users can also update the database to include additional regions and species of interest for an analysis of their sensitivity compared to hypothetical minimum and maximum risk conditions within the model.

Detailed outputs and results of the model used in this analysis are included in Appendix D, Section D.2 of this report, which includes results for LSEs, baseline conditions, habitat sensitivity, species sensitivity, and final environmental sensitivity. The section below represents one interpretation of the outputs and model results for the study areas in California and Hawaii. It summarizes which of the modeled species and habitats were more sensitive to each OFW ICF in each study area to provide a snapshot of environmental components of potentially greatest concern that may serve as a starting point to inform a more detailed analysis of risk and impact.

4.1 Interpreting ICF Vulnerability Scores

Species vulnerability to each ICF is evaluated on a categorical ranking scale, with certain categories ranked as more or less vulnerable to a particular ICF relative to other categories assessed for the same metric (see Section 2.2.3 and Appendix B). The table below (Table 18) is an example scoring table from Appendix B, used during species data literature review. For each assessment metric, a species receives a rank score representing a behavior or trait category that translates to different vulnerability scores for each ICF. These ICF vulnerability scores are not a measure of actual impact on a species, nor are they comparable in magnitude between ICFs. The values should be considered as an index of relative risk.

For example, for the macro-avoidance assessment metric, if a species is categorized as “highly attracted” it will receive a vulnerability score of “5” for accidental spills (AS) and “5” for collisions above surface (CAS) for that assessment metric (Table 18). This does not mean that both accidental spills and collisions would affect the same number of birds. Instead, these scores mean that this bird exhibits attraction behaviors that make it more vulnerable to accidental spills and more vulnerable to collisions above the water’s surface because being attracted to OFW fields increases the potential for encountering these ICFs, relative to the other behavior categories like “highly avoidant”.

Table 18. Birds and Bats Macro-avoidance Assessments for Encounter Impact during All Project Phases

Ranking Score - Category	Category Description	ICF Scores							
		AS	AL	CAS	CSE	EMF	HD	S/N	VS
(5) Highly attracted.	Species has been documented as highly attracted to OFW or other open water structures.	5	5	5	--	--	5	5	--
(4) Somewhat attracted.	Species may be attracted to OFW, some evidence of slight attraction.	3	3	3	--	--	3	3	--
(3) Neither attracted nor avoidant.	Species is neither attracted to nor avoids OFW, or status is unknown.	3	3	3	--	--	0	3	--
(2) Somewhat avoidant.	Species may avoid OFW, some evidence of slight avoidance.	2	2	2	--	--	3	2	--
(1) Highly avoidant.	Species avoids OFW or other offshore construction or structures at a high rate.	0	0	0	--	--	5	0	--

All OFWESA model results, particularly the ICF vulnerability scores, should be evaluated in the context of outside knowledge about a species or study area. For instance, a marine mammal may have a high subsurface collisions/entanglement vulnerability score based on time spent in the water column and at the surface, or a sensitivity to increased anthropogenic sound that could mask the detection of underwater obstacles. However, an expert may know that the typical range occupied by the species is unlikely to overlap the exact area of a proposed OFW development, so the collision/entanglement vulnerability for that species may not overstated by the OFWESA model. Additionally, a fish or invertebrate species might have high vulnerability scores to multiple ICFs because of their location in the pelagic water column or surface waters, which overlaps the spatial extent of most of the ICFs from OFW development. However, a manager may decide that that particular species is not a priority with respect to OFW due to lack of commercial use or large population numbers leading to a high recovery potential and lower species sensitivity overall. This illustrates how the OFWESA model results may inform an analyst/expert/manager about ICFs of potential concern, but it is incumbent on the user to interpret the ICF vulnerabilities and put them into context for an individual species and study area.

Finally, the ICF vulnerability scores account for just one portion of the species sensitivity interim results calculated in the OFWESA model. Species-specific sensitivity scores are composed of ICF vulnerability scores modified by the ICF impact magnitude during each project phase, then multiplied by the recovery potential score, seasonal presence of the species, and LSE scores for the study region and season. This emphasizes that high vulnerability to a particular ICF does not equate to high impact from that ICF nor to an overall high sensitivity to OFW development.

4.2 Results of Regional Sensitivity Analysis

The following sections present results and conclusions of the regional sensitivity analyses based on the outputs of the OFWESA model. The results sections below include an examination of the regional characteristics and habitat sensitivities, the influence of the ICFs, the sensitivity of the species groups, and the application of mitigation measures in each study area.

Results presented below are based on the outputs of the first iteration of the OFWESA model. The addition of input data (e.g., more species, revised assessment question scores, new large-scale event frequencies) may affect the model outputs and lead to different conclusions, but the first iteration of the model outputs are interpreted below.

4.2.1 California

Table 19 summarizes the results of the regional analysis of environmental sensitivity for the California study area, which are explained in detail in the sections below.

Table 19. Summary of Environmental Sensitivity Analysis Results for the California Study Area.

Analysis Parameter	Results Summary
Large-Scale Events	• Highest frequency LSE: earthquakes (partial failure magnitude return rate of 1 in 8 years) and tsunamis (partial failure magnitude return rate of 1 in 13 years) • Full failure magnitude events of all types were very rare, with return rates of 1 in > 100 years • Lowest frequency LSE: vessel accidents (medium / partial failure return rate of 1 in 227 years and large / full failure return rate of 1 in 400 years)
Baseline Conditions	• Little added impact (< 3%)) from pre-existing anthropogenic influences to final regional sensitivity score • Most prevalent baseline metrics: submarine cables (7% in study area compared to hypothetical EEZ), wastewater outfalls (10%), and general pollution (14%)
Marine Bottom Vulnerability	• Marine bottom consists of 69% soft bottom deep, 27% no data, 4% soft bottom shallow, and < 0.1% hard bottom deep habitats • Summed vulnerability score of 2.96 out of 5 (59% of maximum)
Water Column Vulnerability	• Moderate water column sensitivity, with mean NPP at 28% - 41% of hypothetical maximum NPP • Mean water column NPP is lowest during December – January and highest from June – September
Protected Areas	• 69% of marine area designated as protected areas • 15 essential fish habitats in study area, compared to 21 in the larger California EEZ • Protected area modifier increased habitat sensitivity by 72%
Species Vulnerability (all ICFs combined)	• Highest BB: aerial seabirds (ashy storm petrel) • Highest MT: baleen whales (CMX humpback whale) • Highest FI: small pelagic fish (Pacific sardine)
Species Recovery Potential	• Lowest BB: aerial seabirds (ashy storm petrel) • Lowest MT: baleen whales (CMX humpback whale) • Lowest FI: demersal fish (cowcod)
Species Sensitivity	• Highest BB: aerial seabirds (ashy storm petrel) • Highest MT: baleen whales (CMX humpback whale) • Highest FI: benthic invertebrates (black abalone) • Moderate sensitivity, 31% of the maximum
Final Environmental Sensitivity	• Periods with highest score: period 1, period 5 (i.e., Dec – Jan and Aug – Sep) • FES relatively low, 15% of the hypothetical maximum of the California EEZ • Mitigated scores differed by 0.5% • Lower and upper estimate scores differed by 1.5%

4.2.1.1 LSE Results

Table 20 provides the seasonal and annual LSE frequencies used to calculate the LSE scores. These frequencies are converted into recurrence times, or the number of years between events. Recurrence times, annual frequencies, and resulting LSE scores for each study area are discussed in the following subsections.

As noted in Section 3.4 of this report, LSEs that could lead to partial or complete structural failure of an OFW turbine or field were considered for the potential to cause or increase the occurrence of the ICFs evaluated in the analysis. The LSE type with the highest annual frequency in the California study area was earthquakes of partial-failure magnitude with an annual frequency of 0.12, or one event every 8 years. The next highest annual frequency of 0.08 is for tsunamis of partial-failure magnitude, or one event every 13 years. The annual frequency of partial-failure magnitude hurricanes is 0.011, or one event every 91 years. Full-failure magnitude tsunamis were not observed in the data, for an annual frequency of zero. The annual frequency rates of earthquakes, hurricanes, tsunamis, and vessel accidents of full failure magnitude were all less than 0.01, suggesting that the largest LSEs in the study area would be infrequent (fewer than one event every 100 years). Vessel accidents of either magnitude had the lowest annual frequencies, with recurrence rates of 227 years for medium vessel/partial failure event and 400 years for large vessel/full failure event.

The LSE analysis indicates that the frequency of occurrence of a natural event or vessel accident of magnitude large enough to cause significant damage to an OFW facility in California is very low. Partial-failure magnitude events may be more frequent, with Category 6 tsunamis and Category 5 earthquakes likely to occur most often. These are expected to cause damage to some of the turbines within an OFW facility but will likely result in only a small increase in potential impacts. Seasonal differences in LSE rate were minimal for California.

Table 20. Seasonal Large-Scale Event Frequencies Used to Calculate LSE Scores and Recurrence Time of LSEs for California. P=partial structural failure, F=full structural failure. Cells are color-coded along a gradient from low frequencies (green) to high (red) across regions and seasons.

Region	Event Type	Event Magnitude	Pd 1 Freq. (Dec – Jan)	Pd 2 Freq. (Feb – Mar)	Pd 3 Freq. (Apr – May)	Pd 4 Freq. (Jun – Jul)	Pd 5 Freq. (Aug – Sep)	Pd 6 Freq. (Oct – Nov)	Annual Freq.	Recurrence Time (one event every # years)
CA	Earthquake	P – Category 5	0.0200	0.0200	0.0200	0.0200	0.0200	0.0200	0.1200	8
	Hurricane	P – Category 4	0.0002	0.0001	0.0001	0.0028	0.0067	0.0012	0.0110	91
	Tsunami	P – Category 6	0.0133	0.0133	0.0133	0.0133	0.0133	0.0133	0.0800	13
	Vessel Accident	P – Medium Vessels	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004	0.0025	400
	Earthquake	F – > Category 7	0.0013	0.0013	0.0013	0.0013	0.0013	0.0013	0.0080	125
	Hurricane	F – > Category 5	0.0001	0.0000	0.0000	0.0015	0.0036	0.0007	0.0060	167
	Tsunami	F – > Category 7.9	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	2,000
	Vessel Accident	F – Large Vessels	0.0007	0.0007	0.0007	0.0007	0.0007	0.0007	0.0044	227

4.2.1.2 ICF Vulnerability

The following sections summarize the mechanism by which each ICF may affect different species groups and sub-groups and the members of each group that are most vulnerable to the ICF in the California study area. A summary of the species groups vulnerable to each ICF in the California study area based on species behavior is presented in Table 21 below. Of the species analyzed, the degree of vulnerability was identified by comparing the ICF vulnerability score to the hypothetical maximum possible species vulnerability score as calculated in the model (see Section 3.5 for additional detail on hypothetical maximum values). For detailed tables presenting the impact scores for all species modelled in the analysis, see Appendix D, Section D.4.2.5 of this report.

As explained in Section 4.1, vulnerability of a species to an ICF should not be interpreted as certainty that an ICF will impact a species. The ICF vulnerability scores account for just one portion of the species sensitivity scores. The vulnerability scores provide an index that summarizes the behaviors or traits that would make a species more vulnerable to each ICF in the event of spatiotemporal overlap with the ICFs. They are not a measurement of impact, but they are an index of relative risk to be used in conjunction with outside information for impact assessment.

Table 21. Most Vulnerable Species to Each ICF of Those Assessed in the California Study Area.

Impact-Causing Factor	Vulnerable Species (by Species Group) *	Reason for Vulnerability
Accidental Spills	• aerial seabirds and waterbirds (Brandt's cormorant, ashy storm petrel, Scripp's murrelet, western grebe) • pinnipeds and baleen whales (California sea lion, northern fur seal, humpback whale) • pelagic fish and invertebrates (krill, Pacific sardine, Pacific bluefin)	• roost at night in large aggregations on water surface • surface associated filter feeder, has fur for thermoregulation • associate with upper water column and surface
Artificial Light	• aerial seabirds and bats (ashy storm petrel, hoary bat) • sea turtles and baleen whales (leatherback turtle, humpback whale) • pelagic fish and invertebrates (krill, Pacific sardine, Pacific bluefin)	• surface foraging on the wing and nocturnal flight activity • occupies mid to surface water column, attracted to bioluminescent prey • occupies mid to surface water column and makes daily vertical migrations may be affected by light
Collisions Above Surface	• bats and aerial seabirds (hoary bat, Brandt's cormorant, ashy storm petrel)	• feed in offshore waters at heights within rotor sweep zone and nocturnal flight activity
Collisions and Subsurface Entanglements	• toothed whales and baleen whales (harbor porpoise, killer whale)	• rely on sound for navigation, aggregate in large pods in pelagic water column
Electromagnetic Fields	• demersal fish, corals, sponges, and benthic invertebrates (e.g., cowcod, sea pen, orange puffball, black abalone)	• demersal, attracted to hard structures, sessile near submarine cables
Habitat Disturbance / Displacement	• surface and aerial seabirds (Scripps's murrelet, ashy storm petrel) • baleen and toothed whales and sea turtles (humpback whale, California sea lion, killer whale, leatherback turtle) • **corals and pelagic fish/invertebrates (sea pen, krill, Pacific sardine)**	• attracted to or avoidant of wind farms • aggregate in schools in upper and pelagic water column • benthic with limited motility and occupy sandy substrates where construction is likely
Sound / Noise	• aerial seabirds and bats (Brandt's cormorant, ashy storm petrel) • baleen and toothed whales (killer whale and humpback whale) • small and large pelagic fish (Pacific sardine)	• aggregates, night roosting in offshore waters • communicate in songs; rely on echolocation • low frequency hearing specialist
Vessel Strikes	• baleen and toothed whales and pinnipeds (California sea lions, humpback whales)	• aggregate in large groups, attracted to structures, feeds at surface, slow-moving

*Note: Species groups were evaluated independently so a species that is "most vulnerable" within its species groups does not mean it has the same degree of vulnerability as the most vulnerable species of another group, It also does not necessarily mean there will be an impact, it just indicates that species has behaviors and traits that make it more potentially vulnerable to an ICF relative to other members of its species group.

Accidental Spill Vulnerability

Bird/Bat Species Group

Brandt's cormorant, an aerial seabird, was determined to be the most vulnerable to accidental spills of the birds/bats species group included in the California study area and of all species groups included in the regional analysis. This is primarily because Brandt's cormorants roost at night in large aggregations and accidental spills will affect a greater proportion of them at once if they occur. Ashy storm petrel (aerial seabird), Scripps's murrelet (surface seabird), and Western grebe (waterbird), were also determined to be vulnerable to accidental spills. These bird species forage for prey near the surface, either on the wing by skimming their beaks in the water or by dipping necks while floating on the surface. These forage behaviors increase vulnerability to ingesting oil that accumulates at the surface or oiling feathers in contact with the surface slick.

Marine Mammals/Turtles Species Group

The California sea lion, Northern fur seal, and the Central American/Mexico distinct population segment of humpback whales were determined to be the most vulnerable to accidental spills of the marine mammals/turtles group in the California study area. In general, baleen whales were determined to be highly vulnerable to accidental spills because of their association with the surface for breathing and feeding, and the large aggregations they form. Pinniped species were also very vulnerable to accidental spills because they rely on fur for thermal regulation, which does not insulate properly when oiled.

Fish/Invertebrates Species Group

In the California study area, krill, a pelagic invertebrate, was determined to be the most vulnerable to accidental spills of the fish/invertebrates species group. The relatively higher vulnerability of krill to potential impacts from accidental spills is due to their association with the upper water column/surface throughout all life stages, highly aggregative behavior, and filter-feeding forage technique, which increases the chance for toxicity at the individual and high mortality at the population levels. Following krill, Pacific sardine and Pacific bluefin tuna were determined to be the next most vulnerable to accidental spills, due to similar surface-oriented and aggregation behaviors. The egg and larval locations near the surface of Pacific sardine and bluefin tuna will be particularly sensitive to oiling.

Artificial Light Vulnerability

Bird/Bat Species Group

Of the species included in this group in the California study area, the ashy storm petrel, an aerial seabird, and the hoary bat were both the most vulnerable to artificial light. This is likely because these species are regularly active at night for forage and migration purposes when the effects of artificial lights are more pronounced. Even though the hoary bat may be vulnerable to artificial light because its prey concentrates around light, its range may not extend far enough to encounter OFW on a regular basis, barring infrequent migrations. However, if its foraging range overlaps with future OFW development, the hoary bat is likely to be more vulnerable to artificial light impacts. Ashy storm petrel was ranked sensitive to light due to regularly foraging at night over marine waters.

Marine Mammals/Turtles Species Group

Of the species in this group included in the analysis of the California study area, the leatherback sea turtle was determined to be the most vulnerable to artificial light. This is due to their preference for bioluminescent prey (i.e., jellyfish), which suggests an evolved sensitivity to detect light, and for which they primarily forage at the surface of the water, nearer the light source. In addition, green sea turtle hatchlings have been shown to orient towards artificial light in nearshore waters, supporting the possibility of artificial light vulnerability in sea turtles (Thums et al. 2016). The Central American / Mexico distinct population segment of humpback whales, the blue whale (both baleen whales), and the Northern fur seal were determined to be the next most vulnerable to artificial light of the species assessed in this group. The high vulnerability to light for baleen whales and pinnipeds is likely because they are strongly associated with the surface and regularly inhabit surface waters where turbine lights may be visible. This positioning increases their encounter rate with the ICF; however, direct effects of artificial light on baleen whales and pinnipeds are not typically reported. Light could affect the behavior of their prey by attracting them to unusual locations, which could spatially and temporally disturb foraging. However, this is a hypothetical indirect effect. It is likely that marine mammals will not be directly affected by artificial light when analyzed under an impact assessment.

Fish/Invertebrates Species Group

Of the fish and invertebrates included in the analysis for the California study area, pelagic species were the most vulnerable of the fish and invertebrate sub-groups to artificial light. This included krill, Pacific sardine, and Pacific bluefin tuna, which have the greatest potential exposure to offshore surface waters within the aerial range of the artificial light ICF. These species may change their diel vertical migrations or avoidance/attraction behavior in response to light from OFW development, leading to habitat displacement and possible changes in prey availability or predator risk.

Collisions Above Surface Vulnerability

Bird/Bat Species Group

Hoary bat was the most vulnerable to collisions of the species included in the model from the California study area. Although hoary bats are generally terrestrial, they have been observed flying between the California coast and various islands offshore. They are also almost exclusively active at night, foraging for insects that are attracted to lights or turbine structures, behavior that has made them one of the most commonly killed bats at terrestrial wind facilities. Brandt’s cormorant and ashy storm petrel, both aerial seabirds, are the next most vulnerable bird or bat species in the California study area. Both species feed on the wing in offshore waters at heights within the rotor sweep zone and could lose maneuverability and collide with turbine structures as they focus on prey movements.

Subsurface Collisions / Entanglement Vulnerability

Marine Mammal/Turtle Species Group

Of the mammal and turtle species included in the California study area, the species exhibiting behaviors that suggest high vulnerability to subsurface collisions and entanglement were two toothed whale species, harbor porpoise, and killer whale. Both harbor porpoises and killer whales rely on sound for navigation (which can be masked or distracted by other targets), aggregate in large groups or pods, and primarily occupy the pelagic water column. These characteristics increase the likelihood of a collision or entanglement with subsea cables or mooring lines if noise from OFW operation masks auditory cues for direction. Occupying the pelagic habitat increases their potential encounter likelihood with cables and mooring lines. However, in determining impact, spatial distribution of the species should be considered in relation to the location of the underwater structures.

Habitat Disturbance / Displacement Vulnerability

Bird/Bat Species Group

The bird or bat species most vulnerable to habitat disturbance or displacement in the California study area were Scripps’s murrelet and ashy storm petrel. Both species are seabirds and very common in offshore marine waters. In addition, both are very active at night and sensitive to artificial light, which can distract or disorient birds during nocturnal foraging movements, reducing the amount of effective forage habitat. These species differ in their reactionary behavior towards the OFW facilities, with Scripps's murrelets are likely being attracted, while the ashy storm petrels are likely avoidant. Both reactions lead habitat displacement and force alterations in the movement patterns of these species. Changes in flight path towards or around an OFW facility can reduce available energy resources on long migrations or frequent foraging trips.

Marine Mammal/Turtle Species Group

The California distinct population segment of humpback whale was the species of this group in the California study area most vulnerable to habitat disturbance or displacement. Humpback whales are frequently at the surface during feeding and breathing activities and may avoid OFW facility areas, which could interfere with foraging habitats or be a barrier during migrations. California sea lion and killer whales would also be highly vulnerable to habitat disturbance or displacement. California sea lions are very surface oriented and aggregate in large groups, which increases the risk of many animals being disturbed by the presence of the OFW facility. Killer whales also often use surface waters during hunting and may avoid the OFW facility, which will likely displace some animals by reducing forage habitat or acting as a barrier they need to swim around to avoid.

Fish/Invertebrate Species Group

In the California study area, orange sea pen was the most vulnerable species of this group to habitat disturbance or displacement. Because orange sea pens are benthic, have very limited motility, and prefer sandy substrates, where facilities are likely to be sited. The benthic footprints of OFW facility activities, including the installation of anchors and submarine cables, would result in complete bottom habitat disturbance or loss. Krill and Pacific sardine were the next most vulnerable to habitat disturbance or displacement as these species aggregate in large schools in the upper and pelagic water column (i.e., the location of the main turbine structures). In addition, these species had high attraction scores and are likely going to aggregate near the turbine structures, not only increasing their risk to be impacted by other ICFs and predators, but also potentially drawing them away from more suitable natural habitats.

Electromagnetic Field Vulnerability

Fish/Invertebrate Species Group

Of the species in this group representing the California study area, cowcod was the most vulnerable to EMF. Cowcod had a high EMF vulnerability score because it is demersal, attracted to hard structures, and may be sensitive to EMF (based on the sensitivity of other rockfish species). The second most vulnerable species were two benthic invertebrate species, orange puffball sponge and orange sea pen. Both species are sessile or attached to the seafloor and would be located near submarine cables. However, information on the electrosensitivity of most species is limited with observed direct impacts of EMF almost nonexistent (Normandeau et al. 2011). Thus, these species exhibit behaviors and traits that make them more vulnerable to EMF in the event of exposure, but the direct effects of EMF are currently not known.

Sound / Noise Vulnerability

Bird/Bat Species Group

In the California study area, Brandt's cormorant and ashy storm petrel, both aerial seabirds, were the bird and bat species most vulnerable to noise. Both of these species form medium to large groups when foraging on the wing or night roosting in offshore waters. Sound and noise from turbines varies with wind speed and could disturb and displace birds that previously used those habitats. In addition, because these species tend to form aggregations offshore, a substantial proportion of the population can be displaced at once when turbines are producing more noise.

Marine Mammal/Turtle Species Group

Killer whale, a toothed whale, and CMX DPS humpback whale, a baleen whale, were the most vulnerable to sound species of this group from the California study area. Humpback whales are sensitive to OFW noise because they communicate in low-frequency songs that can be heard by conspecifics from long distances and persistent, low-frequency operational noise from turbines may cause masking and limit communication. The increased noise may cause avoidance behavior in marine mammals, reducing forage habitat in the California region. Killer whales are also highly vulnerable to anthropogenic noise because they rely on echolocation for navigation and communication, which could potentially be masked by noise generated by turbines. In addition, if seismic surveys are employed during site assessment and characterization, direct injury from sound and noise could occur.

Fish/Invertebrate Species Group

Pacific sardine, a small pelagic fish, were the most vulnerable to OFW noise of the species included in the California study area. Although information on the hearing abilities of many fish species is lacking, Pacific sardines are a member of the Clupeidae family and have been determined to be a hearing specialist. Because of this increased hearing ability, Pacific sardine in the region may be injured or displaced by the continuous operational noises generated by the turbines. In addition, Pacific sardine school in massive aggregations and therefore many fish could be exposed at once, which could alter food web dynamics in the area if injury or avoidance occurs.

Vessel Strike Vulnerability

Marine Mammal/Turtle Species Group

Of the species of this group chosen to represent the California study area, California sea lions and the humpback whales (CMX DPS) were the most vulnerable to project-related vessel strikes. California sea lions are a common pinniped species in California, typically associated with coastal surface waters and also frequently observed aggregating in large groups around offshore oil platforms, which increases their exposure to vessels in harbors and development areas (e.g., 12 fatalities between 2005-2009 reported due to boat collisions; NOAA 2011). Vessel strikes are one of the leading known causes of humpback whale deaths. Because they feed at the surface, sometimes in large groups, and are slow to move out of the way of vessels, humpback whales in the project area would be very vulnerable to vessel strikes.

Fish/Invertebrate Species Group

None of the fish and invertebrate species included in the California study area would be at risk for vessel strikes. Species that may be vulnerable include large, slow-swimming individuals like sturgeon, shark, or sunfish.

4.2.1.3 Recovery Potential

For this analysis, a recovery potential score was assigned for each species. The recovery potential score assesses how quickly a species population would be able to recover in the event of a population-level impact and used in the determination of species sensitivity as described in Section 2.2.3 and Section 3.4 of this report. The recovery potential for different species in the California study area are described below. For a detailed description of how recovery potential was determined for each species, see scoring tables in Appendix B.

Bird/Bat Species Group

Two seabirds, ashy storm petrel and Scripps’s murrelet had the lowest recovery potential of the bird and bat species included in the California study area. Both species have low population levels, with ashy storm petrel listed as endangered and Scripps’s murrelet listed as vulnerable. Both species also have very limited ranges within the northern Pacific region, which increases the proportion of the entire population affected and limits overall recoverability if they should be impacted by the OFW development in the area.

Marine Mammal/Turtle Species Group

The humpback whale that occurs in California (CMX DPS) was the species with the lowest recovery potential of those included in the California study area. Recovery potential is low for humpback whales because they are listed as endangered, have very late adult maturation ages, and long gestation periods. In addition, humpback whales are foraging while in the study area and surrounding waters and any displacement of these whales could impact their ability to effectively forage to sustain activity levels and reproductive capacity.

Fish/Invertebrate Species Group

Cowcod and black abalone were the species of this group included in the California study area with the lowest potential for recovery. The low potential for both species is a result of low population levels and relatively small population ranges. Black abalone were listed as endangered in 2009 because of population reductions caused by overfishing and a wasting disease. Cowcod are a species of concern, with low populations due to overfishing and capture as bycatch.

4.2.1.4 Baseline Conditions

Baseline conditions within the study area were assessed to characterize existing anthropogenic impacts in the study area. Generally, areas with more existing human development, activities, and impacts are already under stress and may experience increased impact from the addition of OFW. In addition, any potential interactions between new OFW development and existing anthropogenic influences should be evaluated during a cumulative effects analysis. In this analysis, the number of anthropogenic features in the California study area was identified and compared against the average number of features per square kilometer within the California EEZ. The average number of features within the entire California EEZ was used as a cut-off point for determining whether there were relatively high or low amounts of a particular baseline metric within the study area (i.e., above or below hypothetical average per square kilometer) compared to the proportion of the EEZ that the study area comprised. The California study area was 11,429 km^2, or 2% of the California EEZ area (i.e., hypothetical measurement area, 577,319 km^2). Therefore, a baseline metric in the study area that measured substantially more than 2% of the measurement in the EEZ area was considered a high amount for that particular baseline metric.

The baseline metrics that were most prevalent in the California study area were submarine cables, wastewater outfalls, and general pollution which were 6.6%, 9.5%, and 13.8% of the measurements in the larger EEZ, representing concentrations higher than the regional average at proportions much greater than 2%.

When considering all baseline condition datasets together, the raw baseline conditions score (which adds the normalized scores for each metric together) for the study area was only 2.8% of the maximum score for the California EEZ. The habitat and species within the study area may be most frequently exposed to wastewater outfalls and pollution, and the relatively high concentration of submarine cables may add to the cumulative impacts of new OFW development in the California study area.

4.2.1.5 Habitat Sensitivity

As noted in Section 3.4, the habitat sensitivity for each study area is a function of the marine bottom habitat sensitivity, the water column habitat sensitivity, and the protected area.

Marine Bottom Habitat Sensitivity

The majority (69%) of marine bottom habitat within the California study area is categorized as deep soft bottom habitat, which is considered in the analysis to be moderately vulnerable due to consisting of adaptable communities on relatively unstable, mobile substrate. Shallow soft bottom habitat accounted for 4% of marine bottom habitat and is considered less vulnerable due to faster recovery rates assumed in shallower waters. Approximately 27% of the bottom habitat of the California study area is of unknown type, which is conservatively considered to be a habitat of mid-range sensitivity to account for sensitive habitats that might be there. There was only a small amount of hard bottom deep habitat in the study area (<0.1%), which is a more vulnerable habitat type because it generally supports more stable communities with longer recovery times.

Each of these habitats—deep soft bottom, no data, shallow soft bottom, and deep hard bottom—contribute to the summed vulnerability score of 2.96 (out of 5) in California, which is 59% of the maximum possible vulnerability score for marine bottom habitat. None of the highly vulnerable bottom habitat types (corals, seagrass, kelp) were present in the bottom habitat dataset used for the analysis, and hard bottom habitat made up a very small proportion of the study area. Therefore, it should be possible to mitigate bottom habitat impacts in the California study area with appropriate macro- and micro-siting of OFW facilities. There was a large proportion of unknown habitat type in the dataset, so additional data may yield different results, but in this analysis the marine bottom habitat in the California study area was found to be moderately vulnerable to OFW habitat disturbance.

Water Column Habitat Sensitivity

For this analysis, water column habitat with high net primary productivity (NPP) is assumed to be more vulnerable to potential OFW impacts, as higher-productivity waters are associated with greater species richness and abundance (Ware and Thomson 2005). Within the California study area, the mean water column NPP is lowest during December – January and the NPP is highest from June – September. This high productivity for the open ocean is driven by nutrient-rich upwelling in the central California region and coincides with the summer/early fall season when many fish species spawn and feeding grounds are likely to be busy. The water column vulnerability ranged from 28% - 41% of the hypothetical maximum depending on the time of year, indicating that the California study area consists of moderately sensitive water column habitat compared to the California EEZ (see Section 3.5 for details on the application of hypothetical values in the analysis).

Protected Areas and Essential Fish Habitat

Identified protected areas are used in the analysis because the proportion of a study area designated as protected areas serves as an indicator of the presence of sensitive species or habitats in the study area and can influence the habitat sensitivity score as noted in Section 3.4. Within the California study area, 69% of the marine waters are designated as protected areas. In addition, there are 15 essential fish habitat (EFH) designations in the study area. Based on the proportion of protected marine areas and the number of essential fish habitat designations, the habitat sensitivity of the California study area was increased by 72% to account for potentially sensitive resources near the study area.

4.2.1.6 Summary of Species Sensitivity

The species sensitivity score for each species is a combination of the summed vulnerability scores for each ICF, the species recovery score, species seasonal presence, and LSE rate for the study area. The following sections summarize the species sensitivity of each species group included in the analysis of the California study area.

Bird/Bat Species

Of the bird and bat species in the California study area, ashy storm petrel had the highest species sensitivity score. Classified as an aerial seabird, most ashy storm petrel feeding is done offshore and at night, when they feed almost exclusively at the surface either on the wing or while sitting on the surface, which makes them potentially vulnerable to all of the ICFs included in this study (Wildscreen Arkive 2010; Hamer et al. 2014). In addition, because they have a limited range, small population size, and are listed as endangered, their potential for recovery from impacts is low (Wildscreen Arkive 2010). Scripps's murrelet also had a high species sensitivity score and would likely be most sensitive to the OFW facility during their breeding dispersal period, when they swim and forage offshore as they rear flightless young (US FWS 2012; Audubon 2017).

Species with mid-range sensitivity scores included the bald eagle, western grebe, and Brandt's cormorant. Western grebe, a waterbird, and Brandt's cormorant, an aerial seabird, both had high impact scores and high recovery potential, which indicates that although impacts from the OFW facility may be high, population are healthy enough to withstand some minor losses. Because bald eagles are primarily land based or coastal and will have very limited interaction with offshore wind, they had a low vulnerability score. However, bald eagles had a low recovery potential because of low reproductive capacity and highly demanding nestlings (CADFW 2017).

In the California study area, birds and bats with the lowest species sensitivity scores were the Western snowy plover, in the shorebirds/wading birds sub-group, and hoary bat. Because western snowy plovers generally nest on land and forage in nearshore areas, their potential to interact with the OFW facility would only occur during seasonal migrations to and from coastal nesting areas (Iverson et al. 1996; Burger et al. 2011). Similarly, hoary bats roost in inland, vegetated areas and would likely only encounter OFW facilities during seasonal movements (Cryan and Brown 2007). Overall, the low impact and sensitivity scores of land-associated bird and bat species, such as the hoary bat and bald eagles, suggests that these species will be minimally affected by OFW facilities. However, hoary bat fatalities at inland wind energy facilities are frequent and could be due to attraction towards turbines as a result of their similar appearance to large trees or to increased prey near turbine lights. Therefore, the distance of OFW from shore should be considered when evaluating the potential for effects on this species (Ellison 2012).

Marine Mammal/Turtle Species

In the California study area, Central American/Mexico DPS (CMX) humpback whales had the highest impact score, recovery score (i.e., lowest recovery potential), and species sensitivity score of all mammals and turtles included in the model. Humpback whales had the highest or the second highest score for most individual ICFs, as well. CMX humpback whales use marine waters near the California study area for foraging on krill. They are most abundant in waters off the West Coast from the spring through the fall, as many migrate south to overwinter; however, observations and tag detections of humpback whales in this region have occurred during winter periods as well (Calambokidis et al. 2015). Vessel strikes are a major cause of mortality for humpback whales and baleen whales, in general, as they tend not to move out of the way of ships out of curiosity or lack of time to respond to the threat (Rockwood et al. 2017). Another reason that CMX humpback whales were determined to be sensitive in the model is because they are listed as endangered and mature at older ages than the other marine mammal species evaluated in this model (NOAA Fisheries 2016a). Killer whales had a high species sensitivity score based on its year-round presence in the study area and low recovery potential. Killer whales had a low vulnerability score when all ICF impact scores were summed, but were highly vulnerable to collisions or entanglements, habitat disturbance, and sound and noise impacts. The species sensitivity score for this species illustrate how long-lived, slow-maturing species are at higher risk of population-level impacts.

Mid-range sensitive species included the blue whale, California sea lion, and harbor porpoise. California sea lions had high impact and recovery scores, but are only fully present in the study area for half of the year, which lowered their sensitivity score. California sea lions would be most likely to occur near the California study area during the non-breeding season (October – March), as breeding occurs farther south (Reidman et al. 2017). California sea lion were most vulnerable to accidental spills and vessel strikes because they form large aggregations, are surface oriented, rely on fur for thermoregulation, and have been observed near offshore manmade structures (NOAA Fisheries 2015; Orr et al. 2016). Both blue whales and harbor porpoises had mid-range scores for most individual ICFs, with blue whales most vulnerable to artificial light because of their association with the surface and harbor porpoises most vulnerable to collisions or entanglement because of their use of echolocation rather than visual cues for navigation and association with mid-water column (Teilmann and Carstensen 2013; National Geographic 2017; NOAA Fisheries 2017a).

Of the mammal and turtle species in the analysis for the California study area, leatherback turtles and northern fur seals had the lowest species sensitivity scores. Although leatherback turtles had a relatively high impact score, their high population recovery potential and low species presence in the study area contributed to the low species sensitivity score. The high recovery potential was based on the worldwide distribution and opportunistic forage behavior of leatherback turtles (USFWS 2015). Leatherback turtles were assumed to occur in low abundances offshore of the California coast for most of the year; however, increases in observed abundance occur annually from July-September, coinciding with large seasonal aggregations of jellyfish, their preferred prey (NOAA Fisheries 2012). Northern fur seal had the lowest score for many of the ICFs, based on generalist range and forage behaviors, onshore breeding and pupping, low rate of vessel mortality, and generalist hearing abilities (Benoit-Bird et al. 2013; NOAA Fisheries 2014; Gelatt et al. 2015). In general, because pinnipeds are primarily associated with the surface waters to forage and thermoregulate via thick coats of fur, they would be particularly sensitive to accidental spills (Liwanag 2010; NOAA Fisheries 2015; Smithsonian's National Zoo and Conservation Biology Institute 2017).

Fish/Invertebrate Species

Of the fish and invertebrate species in the California study area, black abalone and cowcod had the highest species sensitivity scores. Both black abalone and cowcod had moderate to low summed impact scores and low potential for recovery (i.e., high recovery score). Although cowcod have been observed to be attracted to man-made structures and hard bottom habitat, noise from turbines could deter fish from utilizing the new habitat as some rockfish species rely on sound for communication (Love and York 2006; NOAA NMFS 2009; Popper and Hawkins 2016). In addition, because both species are benthic or demersal, they would have greater exposure to EMF and potential impacts if magno- or electro-senses are used in navigation and predator/prey detection (Normandeau et al. 2011). Both black abalone and cowcod also had the lowest recovery potential based on current low population abundances. Black abalone, once abundant in the California region, is now listed as endangered due to aggressive overharvest and a wasting disease called withering syndrome (NOAA Fisheries 2016b). Cowcod is currently listed as a species of concern by NMFS, with low populations a result of overfishing and catch as bycatch (NOAA NMFS 2009). These species are representative of other bottom-associated fish and invertebrate species with small populations that would be at similar risk to habitat disturbance, sound/noise, and potential EMF ICFs.

Fish and invertebrate species with mid-range sensitivity scores included krill, orange puffball sponge, Pacific bluefin tuna, and orange sea pen. Orange puffball sponge and orange sea pens are slow-growing, benthic, filter-feeding invertebrates that will have limited interaction with the offshore wind turbine components within the water column. Because they are both benthic and attached to the seafloor, they would be primarily vulnerable to EMF and habitat disturbance impacts (Fuller et al. 2008; SIMON 2017). Pacific bluefin tuna and krill are pelagic species that had high vulnerability scores because they aggregate in large groups, are associated with the surface and upper water column, and are attracted to floating hard structure in the marine environment. The high vulnerability scores were mediated by high recovery potential.

The south-central California steelhead and Pacific sardine had the lowest species sensitivity scores of the fish and invertebrates considered in the California study area. Steelhead had low impact scores for all individual ICFs and the lowest summed impact score of species included in the California study area. In contrast, Pacific sardine scored highly for most of the individual ICFs and had the highest summed impact score, but its high impact score was offset by a high recovery potential. Steelhead spawn in freshwater and spend juvenile and adult life stages in the ocean. At the ocean-going adult stage, they are very agile in swimming abilities, have a wide range, and forage on whatever is readily available, suggesting they can avoid OFW installations due to habitat flexibility (Quinn 2006). Pacific sardine had high impact scores for many of the ICFs because of its likelihood to be attracted to the OFW structures. The turbines may act as a fish attraction device for small pelagic fish like Pacific sardine, which increases the chance for this species to be affected by various ICFs like accidental spills, sound/noise, and artificial light (Dempster and Kingsford 2004). The opposite situation may occur as well, as these fish are considered hearing specialists and therefore, may be displaced from habitat or injured due to sound disturbances (Thompson et al. 2006). The similar low species sensitivity scores and vastly different impact scores for these two species is in part a result of the high recovery potential for Pacific sardine and the moderate to low recovery potential for steelhead. Pacific sardine are common throughout the Pacific Ocean and are considered of least concern in terms of population status (NOAA Fisheries 1998; Iwanoto and Eschmeyer 2010). South-central California Steelhead are listed as threatened and have critical habitat designations along the California coast and therefore have a reduced recovery potential which increases species sensitivity (NOAA Fisheries 2017b).

4.2.1.7 Final Environmental Sensitivity of the California Study Area

The final environmental sensitivity scores for the California study area combine the data for the habitat and regional characteristics with the information derived from the literature review of species impact and recovery potential. Specifically, habitat sensitivity and species sensitivity scores for each region are summed and then multiplied by the baseline conditions modifier to obtain the final environmental sensitivity score for the study area. These values are influenced by the impact magnitude of LSEs and the unmitigated and mitigated ICFs in the model calculations, to result in one score that represents the potential overall sensitivity of the study area to OFW development.

The unmitigated final environmental sensitivity (FES) scores for the California study area were highest during periods 1 and 5 (December – January and August – September, respectively). Period 1 corresponds to higher NPP and thus greater water column sensitivity, increasing the habitat sensitivity in the area. Period 5 corresponds to hurricane season when the frequency of storms severe enough to cause partial and full failure of OFW structures is approximately 2 – 6 times higher than in the other periods, thus increasing impact magnitude and vulnerability to ICFs. In general, however, the scores between seasons did not vary greatly primarily because seasonal differences in LSE rate in California were minimal.

The final environmental sensitivity of the study area is relatively low, at 16% of the hypothetical maximum sensitivity possible. Factors affecting this result include:

- A relatively low score for baseline conditions (i.e., the California study area is not heavily affected by anthropogenic activities on average).
- The majority of marine bottom habitat was categorized as deep soft bottom with moderate vulnerability and only a small amount of more vulnerable hard bottom deep habitat present.
- Moderately sensitive water column habitat.
- Moderate species sensitivity, 31% of the hypothetical maximum sensitive species score.

4.2.2 Hawaii North

Table 22 summarizes the results of the regional analysis of environmental sensitivity for the Hawaii North study area, which are explained in detail in the sections below.

Table 22. Summary of Environmental Sensitivity Analysis Results for the Hawaii North Study Area.

Analysis Parameter	Results Summary
Large-Scale Events	• Highest frequency LSE: earthquakes (partial failure magnitude return rate of 1 in 2 years) and tsunamis (partial failure magnitude return rate of 1 in 7 years) • Full failure magnitude events of all types were very rare, with return rates of 1 in > 100 years, except for full-failure magnitude hurricanes which had a return rate of 1 in 9 years • Lowest frequency LSE: vessel accidents (medium / partial failure return rate of 1 in 1,190 years and large / full failure return rate of 1 in 1,563 years)
Baseline Conditions	• Moderate added impact (17%)) from pre-existing anthropogenic influences to final regional sensitivity score • Most prevalent baseline metrics: danger and restricted zones (67% in study area compared to hypothetical EEZ), coastal energy facilities (28%), and light pollution (21%)
Marine Bottom Vulnerability	• Marine bottom consists of 57% soft bottom deep, 14% no data, 10% volcanic deep, 10% hard bottom deep, 5% coral/sponges, and 3% soft bottom shallow habitats • Summed vulnerability score of 3.03 out of 5 (61% of maximum) = moderate-high vulnerability
Water Column Vulnerability	• Moderate water column sensitivity, with mean NPP at 35% - 52% of hypothetical maximum NPP • Mean water column NPP is lowest during August – September, which corresponds to the height of hurricane season, and highest from February - March
Protected Areas	• 4% of marine area designated as protected areas • 7 essential fish habitats in study area, same as in the larger Hawaii EEZ • Protected area modifier increased habitat sensitivity by 52%
Species Vulnerability (all ICFs combined)	• Highest BB: aerial seabirds (wedge-tailed shearwater) • Highest MT: toothed whales (pantropical spotted dolphin and bottlenose dolphin) • Highest FI: large pelagic fish (bigeye tuna)
Species Recovery Potential	• Lowest BB: aerial seabirds (Hawaiian petrel) • Lowest MT: toothed whales (false killer whale) • Lowest FI: corals/sponges (massive black sponge)
Species Sensitivity	• Highest BB: shorebirds and aerial seabirds (Hawaiian stilt, Hawaiian petrel) • Highest MT: toothed whales (false killer whale) • Highest FI: corals/sponges (pink coral) • Moderate sensitivity, 40% of the maximum
Final Environmental Sensitivity	• Periods with highest score: period 5 (i.e., Aug – Sep) • FES relatively low, 21% of the hypothetical maximum of the Hawaii EEZ • Mitigated scores differed by 1.0% • Lower and upper estimate scores differed by 2.5%

4.2.2.1 LSE Results

Table 23 provides the seasonal and annual LSE frequencies used to calculate the LSE scores. These frequencies are converted to recurrence times, or the number of years between events, which is calculated as one divided by the annual frequency. Recurrence times, annual frequencies, and resulting LSE scores for each study area are discussed below.

Due to their proximity, both the Hawaii North and Hawaii South study areas were evaluated together for the LSE analysis. The LSE type with the highest annual frequency in Hawaii was earthquakes of partial-failure magnitude with an annual frequency of 0.53, or one event every 2 years. The next highest annual frequency of 0.15 is for tsunamis of partial-failure magnitude, or one event every 7 years. The annual frequency of full- and partial-failure magnitude hurricanes were 0.108 and 0.095, or one event every 9 and 11 years, respectively. The annual frequency rates of full-failure earthquakes and tsunamis, and vessel accidents both magnitudes were all less than or equal to 0.01, suggesting that the highest impact LSEs in the study area would be infrequent (fewer than one event every 100 years). Vessel accidents of either magnitude had the lowest annual frequencies, with recurrence rates of 1,190 years for medium vessel/partial failure event and 1,563 years for large vessel/full failure event.

The LSE analysis indicates that the frequency of occurrence of a natural event or vessel accident of magnitude large enough to cause significant damage to an OFW facility in Hawaii is very low, except for Category 5 hurricanes that could potentially cause a full failure. Hurricanes of this magnitude are the third most frequent event, with Category 6 tsunamis and Category 5 earthquakes likely to occur most often. These are expected to cause damage to some of the turbines within an OFW facility, but will likely result in only a small increase in potential impacts. Seasonal differences in LSE rate were pronounced for Hawaii, with hurricane frequency increasing by 87-91% between the lowest frequency (February – May) and highest frequency (August – September) seasons. LSEs, specifically high magnitude hurricanes, have the potential to increase the occurrence of ICFs in Hawaii.

Table 23. Seasonal Large-Scale Event Frequencies Used to Calculate LSE Scores and Recurrence Time of LSEs for Hawaii. P=partial structural failure, F=full structural failure. Cells are color-coded along a gradient from low frequencies (green) to high (red) across regions and seasons.

Region	Event Type	Event Magnitude	Pd 1 Freq. (Dec – Jan)	Pd 2 Freq. (Feb – Mar)	Pd 3 Freq. (Apr – May)	Pd 4 Freq. (Jun – Jul)	Pd 5 Freq. (Aug – Sep)	Pd 6 Freq. (Oct – Nov)	Annual Freq.	Recurrence Time (one event every # years)
HI	Earthquake	P – Category 5	0.0883	0.0883	0.0883	0.0883	0.0883	0.0883	0.5300	2
	Hurricane	P – Category 4	0.0021	0.0005	0.0005	0.0239	0.0576	0.0104	0.0950	11
	Tsunami	P – Category 6	0.0250	0.0250	0.0250	0.0250	0.0250	0.0250	0.1500	7
	Vessel Accident	P – Medium Vessels	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0008	1,190
	Earthquake	F – > Category 7	0.0017	0.0017	0.0017	0.0017	0.0017	0.0017	0.0100	100
	Hurricane	F – > Category 5	0.0024	0.0006	0.0006	0.0271	0.0655	0.0118	0.1080	9
	Tsunami	F – > Category 7.9	0.0012	0.0012	0.0012	0.0012	0.0012	0.0012	0.0070	143
	Vessel Accident	F – Large Vessels	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0006	1,563

4.2.2.2 ICF Vulnerability

For this analysis, species sensitivity was evaluated for both Hawaii North and Hawaii South using the same selected species and species input data, because the study areas were too close to each other geographically to meaningfully differentiate species data compiled during the literature review.

The following sections summarize the mechanism by which each ICF may affect different species groups and sub-groups and the members of each group that are most vulnerable to the ICF in the Hawaii North and Hawaii South study areas. A summary of the species groups vulnerable to each ICF in these study areas based on species behaviors is presented in Table 24 below. Of the species analyzed, the degree of vulnerability was identified by comparing the ICF vulnerability score to the hypothetical maximum possible species vulnerability score as calculated in the model (see Section 3.5 for additional detail on hypothetical maximum values). For detailed tables presenting the impact scores for all species modelled in the analysis, see Appendix D, Section D.4.2.5 of this report.

As explained in Section 4.1, vulnerability of a species to an ICF should not be interpreted as certainty that an ICF will impact a species. The ICF vulnerability scores account for just one portion of the species sensitivity scores. The vulnerability scores provide an index that summarizes the behaviors or traits that would make a species more vulnerable to each ICF in the event of spatiotemporal overlap with the ICFs. They are not a measurement of impact, but they are an index of relative risk to be used in conjunction with outside information for impact assessment.

Table 24. Most Vulnerable Species to Each ICF of Those Assessed in the Hawaii North and Hawaii South Study Areas.

Impact-Causing Factor	Vulnerable Species (by Species Group)*	Reason for Vulnerability
Accidental Spills	• aerial and surface seabirds (wedge-tailed shearwater, laysan albatross, Hawaiian petrel) • baleen whales (humpback and fin whales) • pelagic fish (bigeye tuna, mackerel scad)	• frequent flight within rotor sweep zone, offshore surfaced foraging, offshore night roosting • high association with mid-surface water column for feeding and breathing • attraction to artificial structures
Artificial Light	• aerial and surface seabirds (wedge-tailed shearwater, laysan albatross) • pinnipeds (Hawaiian monk seal) • pelagic fish and invertebrates (pink coral, bigeye tuna)	• aggregate in large flocks on surface waters offshore • rely on fur for thermoregulation • neustonic egg and larval stages; filter feeders
Collisions Above Surface	• aerial seabirds (wedge-tailed shearwater, Hawaiian petrel, great frigatebird)	• feed in offshore waters at heights within rotor sweep zone
Collisions and Subsurface Entanglements	• toothed whales (bottlenose and pantropical spotted dolphins)	• use echolocation, aggregate in large pods and primarily occupy mid-pelagic water column
Electromagnetic Fields	• benthic invertebrates (Hawaiian spiny lobster, massive black sponge)	• use electromagnetic senses in navigation and orientation • benthic and close to cables
Habitat Disturbance	• surface and aerial seabirds (Hawaiian petrel, laysan albatross) • baleen whales and sea turtles (fin whale, green turtle) • benthic and pelagic fish and invertebrates (massive black sponge, pink coral, box jellyfish, bigeye tuna)	• attracted to artificial light or avoidant of wind farms affecting habitat use and movement patterns • aggregate in upper and pelagic water column for feeding and breathing • benthic with limited motility and prefer sandy substrates or aggregates in large groups
Sound / Noise	• aerial and surface seabirds (wedge-tailed shearwaters, laysan albatross) • baleen and toothed whales (humpback whale, pantropical spotted dolphin, false killer whales) • pelagic fish (bigeye tuna)	• form large groups when foraging in offshore waters • communicate in songs; rely on echolocation • hearing generalists, may avoid sound generated from turbines but attracted to offshore structures for foraging
Vessel Strikes	• toothed whales (bottlenose and pantropical spotted dolphins)	• aggregate in large groups, primarily occupy surface to mid-pelagic waters

*Note: Species groups were evaluated independently so a species that is “most vulnerable” within its species groups does not mean it has the same degree of vulnerability as the most vulnerable species of another group, It also does not necessarily mean there will be an impact, it just indicates that species has behaviors and traits that make it more potentially vulnerable to an ICF relative to other members of its species group.

Accidental Spill Vulnerability

Bird/Bat Species Group

Wedge-tailed shearwater and laysan albatross, an aerial and surface seabird, respectively, were the most vulnerable to accidental spills of the bird and bat species included in the analysis of the Hawaii study areas. These species are highly vulnerable because they aggregate in large flocks and roost on the surface waters offshore, potentially endangering large portions of the population if an accidental spill were to occur. In addition, because oil accumulates in slicks on the surface and both species feed from the surface; with wedge-tailed shearwaters skimming water, and laysan albatross floating on the surface plunging its head in to seize prey, regular foraging in the project area could lead to ingesting oil, starvation, oiled feathers, or displacement.

Marine Mammal/Turtle Species Group

Of the marine mammals and sea turtles included in the Hawaii study area, the Hawaiian monk seal was the most vulnerable to accidental spills. Pinniped species are particularly vulnerable to accidental spills because they frequent the surface and rely on fur for thermal regulation, which does not insulate properly when oiled.

Fish/Invertebrate Species Group

The fish and invertebrate species most vulnerable to accidental spills of those included in the Hawaii study areas was pink coral. Pink coral is a benthic, sedentary coral species with eggs that float to the surface and larvae in the upper water column. Because oil typically accumulates on the surface and in the upper water column, any overlap between an accidental spill and the young life stages of this species would have large negative impacts. In addition, pink coral are filter feeders and unable to relocate in the event of an oil spill, therefore they would likely ingest any sinking oil suspended in the water column. Bigeye tuna was the next most vulnerable species, primarily due to neustonic egg and larval stages and the attraction to offshore structure by juvenile and adult fish, potentially increasing their chance of encountering an accidental spill.

Artificial Light Vulnerability

Bird/Bat Species Group

Wedge-tailed shearwaters, an aerial seabird, were the most vulnerable to the artificial light ICF of the species considered in the Hawaii study areas. Wedge-tailed shearwaters are very sensitive to artificial light and are frequently killed, injured, or disoriented by lighthouses and boats. Their vulnerability score for this ICF is due to frequent flight within the rotor sweep zone, offshore surface foraging, and offshore night roosting, which increases the encounter rate of artificial light from the turbines. Laysan albatross, a surface seabird, and Hawaiian petrel, an aerial seabird, were the next most vulnerable species. Both species are highly active at night, migrating to and from offshore forage locations, thus sensitive to light in the environment.

Marine Mammal/Turtle Species Group

Two baleen whales, humpback (Hawaiian distinct population segment (HI DPS)) and fin whales, were the species of this group most vulnerable to artificial light of those included in the Hawaii study areas. Both baleen whale species feed at the surface by gulping and filtering water. Because of the association with the surface, their encounter likelihood with artificial light is increased; however, direct effects of artificial light on baleen whales are not typically reported. Light could affect the behavior of their prey by attracting them to unusual locations, which could spatially and temporally disturb foraging, but this is a hypothetical indirect effect. It is likely that marine mammals will not be directly affected by artificial light.

Fish/Invertebrate Species Group

Of the fish and invertebrate species included in the Hawaii study areas, bigeye tuna was the most vulnerable to artificial light impacts. Bigeye tuna are vulnerable to this ICF because of their high association to surface waters throughout different life stages, which increases encounter rate and could skew photosensitive responses (e.g., diel vertical migration of ichthyoplankton). Mackerel scad, a small pelagic fish, also had a high artificial light vulnerability score, primarily due to all life stages present in the upper water column and some evidence of attraction to artificial structures.

Collisions Above Surface Vulnerability

Bird/Bat Species Group

Wedge-tailed shearwater, Hawaiian petrel, and great frigatebird were the most vulnerable species of those included in this group for the Hawaii study areas. All three species are aerial seabirds that primarily feed during the day but fly predominantly at heights that are within the rotor sweep zone or at the surface. They are also known to be very sensitive to artificial light and could be distracted by lights on the turbines and collide with the structures.

Subsurface Collisions / Entanglement Vulnerability

Marine Mammal/Turtle Species Group

Of the marine mammal and turtle species included in the Hawaii study areas, the species exhibiting behaviors that suggest high vulnerability to subsurface collisions and entanglement were bottlenose and pantropical spotted dolphin, two toothed whale species. Both species rely on sound for navigation (which can be masked or distracted by other targets), aggregate in large groups or pods, and primarily inhabit the mid-pelagic water column, which increases their potential to encounter cables and mooring lines and underwater structures. However, in determining impact, spatial distribution of the species should be considered in relation to the location of the underwater structures.

Habitat Disturbance / Displacement Vulnerability

Bird/Bat Species Group

The bird or bat species most vulnerable to habitat disturbance or displacement from OFW were all seabirds. Hawaiian petrel was considered the most vulnerable to habitat disturbance because of their high sensitivity and attraction to artificial light, which limits their ability to safely forage and migrate in areas with offshore structures. Laysan albatross and wedge-tailed shearwater also scored highly vulnerable and are thought to be avoidant of offshore structures, which limits habitat offshore and may act as a barrier between forage and nesting or roosting habitats.

Marine Mammal/Turtle Species Group

The fin whale was the species of this group most vulnerable to habitat disturbance or displacement in the Hawaii study areas. Fin whales frequently inhabit the upper water column for breathing and feeding activities and may avoid OFW facilities because of the noise generated during operation. If avoidance occurs, whales that previously used those habitats for foraging or transit will be displaced. The green turtle was also highly vulnerable to habitat disturbance as it spends most of its time in the upper water column. Sea turtles may be somewhat attracted to the turbine structures, which could alter prior habitat use patterns.

Fish/Invertebrate Species Group

Of the species of this group included in the Hawaii study areas, massive black sponge was the most vulnerable to habitat disturbance or displacement. Because massive black sponges are slow, often sessile, benthic organisms, all benthic components of the OFW facility may result in the habitat disturbance or loss for this species. In addition, the loss of some reef and sponge habitat in the OFW facility area could result in increased use and stress of nearby areas, which would disturb additional organisms. Pink coral also received a high vulnerability score for habitat disturbance and as another sessile, benthic invertebrate, would be affected similarly. Two pelagic species, box jellyfish and bigeye tuna had high habitat disturbance vulnerability scores, explained by their tendency to form large aggregations and congregate near structure in the water column.

Electromagnetic Feld Vulnerability

Fish/Invertebrate Species Group

The species of this group most vulnerable to EMF in the Hawaii study areas was the Hawaiian spiny lobster. Because Hawaiian spiny lobsters are demersal and use electromagnetic senses in navigation and orientation, they exhibit behaviors and traits that make them theoretically vulnerable to cable EMFs; however, there have been no observations of direct effects of EMF on spiny lobsters (Normandeau et al. 2011; Woodruff et al. 2013). Currently, research on direct impacts of cable EMFs is very limited, but the potential for impact exists and may be revealed in future research. The second most vulnerable species is the massive black sponge. Like the Hawaiian spiny lobster, massive black sponges are benthic and would be located close to the cables, increasing potential exposure and any resulting impacts if they are shown to be affected by EMF. However, there is currently no data on EMF effects on corals/sponge life stages.

Sound / Noise Vulnerability

Bird/Bat Species Group

Wedge-tailed shearwaters, an aerial seabird, and laysan albatross, a surface seabird, were the bird and bat species most vulnerable to noise from OFW of those selected for the Hawaii study areas. Both species form large aggregations and forage to feed young in offshore waters that may overlap with the study areas. These species may be displaced and disturbed during foraging trips by the noise generated by the turbines. Displaced birds could need to travel greater distances to get around the OFW facility, increasing energetic demand and reducing forage efficiency, which could have negative impacts on the overall fitness of the local birds.

Marine Mammal/Turtle Species Group

Marine mammals and turtles most vulnerable to OFW sound and noise are those that rely on communication with conspecifics and have wide hearing ranges that overlap OFW operational and vessel traffic noise. Of the marine mammals and turtles included in the study to represent the Hawaii study areas, HI DPS humpback whales, pantropical spotted dolphin, and false killer whales were the most vulnerable to noise generated by OFW. Pantropical spotted dolphin and false killer whale are aggregating toothed whale species that use echolocation and various click noises for navigation and communication. Because these species rely on sound, increased underwater noise from turbines could mask their communications and lead to avoidance behavior and displace large groups of toothed whale species in the area. Humpback whale is a baleen whale that relies on sounds for communication and produces songs that are meant to be heard from great distances at low-frequencies that fall within the range produced by OFW.

Fish/Invertebrate Species Group

Bigeye tuna were the species of this group most vulnerable to anthropogenic noise in the Hawaii study areas. Bigeye tuna are considered hearing generalists (i.e., mid-range vulnerability to sound) and may avoid the sound generated by turbines. Because they typically school in large groups, many fish would be affected if avoidance occurs. However, tuna tend to be attracted to offshore structures for increased forage opportunities in which case louder ambient noise around OFW facilities may mask important sounds and reduce forage efficiency.

Vessel Strike Habitat Vulnerability

Marine Mammal/Turtle Species Group

Of the species of this group selected for the Hawaii study areas, bottlenose and pantropical spotted dolphins, two toothed whale species, were the most vulnerable to vessel strikes. Both species aggregate in large groups and primarily occupy surface to mid-pelagic waters, frequently in the range of vessel bows. With vessel occurrence in the study area expected to increase, these behaviors could lead to increased vessel strikes among these species.

Fish/Invertebrate Species Group

None of the specific fish and invertebrate species included in the analysis for the Hawaii study areas would be at risk for vessel strikes. Other species that were not included in the analysis, but may be vulnerable include sturgeon, shark, or sunfish.

4.2.2.3 Recovery Potential

For this analysis, a recovery potential score was assigned for each species. The recovery potential score assesses how quickly a species population would be able to recover in the event of a population-level impact and was used in the determination of species sensitivity as described in Section 2.2.3 and Section 3.4 of this report. The recovery potential for different species in the Hawaii study areas are described below. For a detailed description of how recovery potential was determined for each species, see scoring tables in Appendix B.

Bird/Bat Species Group

The species of this group with the lowest potential for recovery included in the analysis of the Hawaiian study areas were the Hawaiian stilt, laysan albatross, and Hawaiian petrel. Both the Hawaiian stilt and petrel are endemic to the Hawaiian Islands and listed as endangered. The small range and population sizes of these species makes them highly sensitive to possible increases in morality that could be caused by the presence of an OFW facility. Laysan albatross almost exclusively breed on the Hawaiian Islands and are listed as near threatened and considered a bird of conservation concern. In addition to endemic ranges and low populations, the young of these three species are fully dependent on the adults, who migrate between nests to offshore foraging colonies frequently in order to feed young, increasing their encounter risk.

Marine Mammal/Turtle Species Group

The false killer whale and the pantropical spotted dolphin (toothed whale species), and the fin whale (a baleen whale) had the lowest recovery potential of the species included in the analysis in the Hawaii study areas. All three whale species have very late ages of maturation and relatively long gestation and nursing periods, which limit the speed of recovery if population-level effects occur. In addition, both the false killer whale and the fin whale are listed as endangered, with very low population levels. The pantropical spotted dolphin is listed under the Marine Mammal Protection Act as a depleted stock.

Fish/Invertebrate Species Group

Of the fish and invertebrate species included in the Hawaii study areas, the species with the lowest potential for recovery were Hawaiian grouper, massive black sponge, and pink coral. Massive black sponge and pink coral are slow-growing, sessile, benthic invertebrates with endemic or localized distributions around the Hawaiian Islands. Because these species are sessile and unable to relocate, disturbance to habitat during construction actives would result in mortality of the organism, with reestablishment depending on nearby populations and likely to be very slow. Hawaiian groupers are endemic to the Hawaiian Islands and listed as near threatened with low population levels due to overfishing.

4.2.2.4 Baseline Conditions

Following the methods outlined for the California study area (as described in Section 4.2.1.4), baseline conditions within the study area were assessed to characterize existing anthropogenic impacts in the study area. The Hawaii North study area was 12,302 km^2, or 1.2% of the Hawaii EEZ area (i.e., hypothetical measurement area, 1,016,943 km^2). Therefore, a baseline metric in the study area that measured substantially more than 1.2% of the measurement in the EEZ area was considered a high amount for that particular baseline metric.

Invasive species, ocean disposal sites, submarine cables, and wastewater outfalls measurements were moderately high and were 6.9%, 10.9%, 13.4%, and 18.0%, of the totals in the EEZ respectively. Baseline metrics of light pollution (21.6%) and coastal energy facilities (27.8%) were very high compared to the measurements for those baseline metrics in the EEZ. The baseline metric with the greatest percent of measurement in the Hawaii North study area was danger and restricted zones, of which 66.5% of all these zones in the EEZ occurred in the study area.

When considering all baseline condition datasets together, the raw baseline conditions score (which adds the normalized scores for each metric together) for the Hawaii North study area is only 16.7% of the maximum score for the Hawaii EEZ. The habitat and species within the study area may be most exposed to activities occurring within the danger and restricted zones, or by the very prevalent light pollution and coastal energy facilities in the study area. Light pollution is a particular problem for migratory seabirds, which should be considered in cumulative effects analyses of OFW development.

4.2.2.5 Habitat Sensitivity

As noted in Section 3.4, the habitat sensitivity for each study area is a function of the marine bottom habitat sensitivity, the water column habitat sensitivity, and the protected area.

Marine Bottom Habitat Sensitivity

The majority (57%) of marine bottom habitat within the Hawaii North study area is categorized as deep soft bottom habitat, which is considered in the analysis to be moderately vulnerable due to consisting of adaptable communities on relatively unstable, mobile substrate. Shallow soft bottom habitat comprised 3% and is considered less vulnerable due to faster recovery rates assumed in shallower waters. Approximately 14% of the bottom habitat of the Hawaii North study area is of unknown type, which is conservatively considered to be a habitat of mid-range sensitivity to account for sensitive habitats that could be there. There was a small amount of hard bottom shallow habitat in the study area (1%) and a moderate amount of hard bottom deep habitat (10%) which are more vulnerable habitat types because they generally support more stable communities with longer recovery times, with deeper areas more sensitive than shallow. Ten percent of the bottom habitat was identified as deep volcanic material, assumed to have a low vulnerability rank of 1. About 5% of the Hawaii North study area contained coral/sponge habitat, assumed to have the highest vulnerability due to sensitivity to changes in the environment and slow recovery times.

Each of the above habitats contributed to the summed bottom habitat vulnerability score of 3.03 (out of 5) in Hawaii North, which is 61% of the maximum possible vulnerability score for marine bottom habitat. Most of the bottom habitat consisted of low to moderately vulnerable habitat types, with only about 16% consisting of more vulnerable hard bottom and coral/sponge habitat. Thus, it should be possible to mitigate bottom habitat impacts with appropriate macro- and micro-siting of OFW facilities to avoid the most vulnerable habitat types. Overall, the Hawaii North study area was found to be moderately vulnerable to OFW marine bottom habitat disturbance.

Water Column Habitat Sensitivity

For this analysis, water column habitat with high NPP is assumed to be more vulnerable to potential OFW impacts, as higher-productivity waters are associated with greater species richness and abundance (Ware and Thomson 2005). Within the Hawaii North study area, the mean water column NPP is lowest during August – September, which corresponds to the height of hurricane season. Meanwhile, the NPP is highest from February – March, corresponding to the end of winter/wet season in Hawaii. The water column vulnerability ranged from 35% - 52% of the hypothetical maximum depending on the time of year (see Section 3.5 for details on the application of hypothetical values in the analysis), indicating that the Hawaii North study area consists of moderately sensitive water column habitat compared to the Hawaii EEZ seasonal maximum NPP.

Protected Areas and Essential Fish Habitat

Identified protected areas are used in this analysis because the proportion of a study area designated as protected areas serves as an indicator of the presence of sensitive species or habitats in the study area. The protected area modifier has the potential to double the habitat sensitivity calculated by the OFWESA model. Within the Hawaii North study area, only 4% of the marine waters are designated as protected areas. In addition, there are just 7 EFH designations in the region, which equals the maximum number of EFH designations in the larger Hawaii EEZ. Based on the proportion of protected marine areas and the number of essential fish habitat designations, the habitat sensitivity of the Hawaii North study area was increased 52% to account for potentially sensitive resources near the study area.

4.2.2.6 Summary of Species Sensitivity

The species sensitivity score for each species is a combination of the summed ICF vulnerability scores, the species recovery score, species seasonal presence, and LSE rate for the study area. For this analysis, species sensitivity was assessed for both Hawaii North and Hawaii South using the same selected species and input data because the study areas are too close together to meaningfully differentiate data compiled during the literature review. Thus, the species sensitivity results presented below pertain to both Hawaii North and Hawaii South.

4.2.2.6.1 Bird/Bat Species

Of the bird and bat species included in the analysis of the Hawaii study areas, the Hawaiian petrel and wedge-tailed shearwater, both pelagic seabirds with aerial diving behavior, had high summed ICF vulnerability and species sensitivity scores. In general, seabirds spend a large amount of time over deep, offshore waters, foraging from surface waters either on the wing or as they sit on the surface. Both species had high impact scores for the accidental spill, collisions with above surface structures, and habitat disturbance/displacement ICFs, which suggests aerial seabirds in general would be a group potentially highly sensitive to OFW development, due largely to encounter likelihood based on flight behavior.

In addition, there is evidence of potential attraction to wind turbines for some aerial seabird species. Hawaiian petrels are known to have difficulty avoiding man-made structures and often confuse artificial lights with stars, which are used for nocturnal navigation, and end up circling the lights until exhausted sets in and they drop to the ground (Birdlife International 2016; NPS 2017). Although there have been no direct observations of the behavior of wedge-tailed shearwaters towards turbines, observations of other shearwater species indicate an attraction to man-made structures, such as oil platforms, because of the increase in forage fish near the base of these structures (Ronconi et al. 2014; Adams et al. 2016). It is the attraction to structures, confusion by artificial light, and frequent flying over offshore waters that were identified as key contributors to the sensitivity of aerial seabirds to OFW development.

Hawaiian petrel also had the lowest population recovery potential. Hawaiian petrel is endemic to and exclusively breed on the Hawaiian Islands and are listed as endangered (USFWS 2017). Wedge-tailed shearwaters had a lower recovery score and therefore have a higher potential for recovery if disturbance occurs. However, both species nest on land and forage for young, relying on offshore marine waters as foraging areas to feed young and produce successful fledglings (Whittow 1997; NPS 2017).

The Hawaiian stilt, a wading shorebird, had the highest average species sensitivity score, based primarily on a very low recovery potential and year-round presence in the study area. They had a mid-range summed ICF vulnerability score, as they are primarily a land bird with very limited presence offshore, and a very high low recovery potential because they are endemic to the Hawaiian Islands and listed as endangered (USFWS 2012). The combination of moderate impact score with a low recovery potential and high seasonal presence resulted in a high species sensitivity result.

Laysan albatross, a surface seabird, had a mid-range species sensitivity score because of high scores for vulnerability to the individual ICFs, mid-range recovery potential, and limited presence in the study area throughout the year. They were most vulnerable to potential impacts from artificial light, habitat disturbance or displacement, and sound/noise because of high nocturnal flight activity, surface foraging, and avoidance behavior (Fernandex and Anderson 2000; Adams et al. 2016).

Alternatively, the bird and bat species in the Hawaii study areas with the lowest species sensitivity scores were the Hawaiian hoary bat, Hawaiian coot, and great frigatebird. The Hawaiian hoary bat is more closely associated with land than with offshore or open water habitats, as they roost in vegetation and primarily forage over land (Koob 2012). Although Hawaiian hoary bats are listed as endangered and are endemic to the Hawaiian Islands, their behaviors indicate low encounter rates or infrequent interactions with offshore wind. If it is determined that Hawaiian hoary bats regularly fly through the study area, their sensitivity to OFW impacts would increase.

Hawaiian coots were categorized as waterbirds and generally gather in large flocks in shallow brackish waterways (Pacific Rim Conservation 2013). Although they have been observed to make long distance flights between the Hawaiian Islands at low heights, these migrations only occur when wetland habitat floods or are destroyed (Nodak Outdoors 2009). Similar to Hawaiian hoary bat, Hawaiian coots are also endemic to the Hawaiian Islands and listed as endangered, indicating low recovery potential if impacted by OFW ICFs at the population level; however, their habitat use and range do not indicate much overlap with OFW development areas.

Great frigatebirds roost on land on main Hawaiian Islands or on offshore islets in large colonies (DNR 2005). They feed in offshore marine waters on the wing and although they may encounter OFW facilities, their high population recovery potential resulted in their low species sensitivity score. Great frigatebirds do have the potential for impacts from ICFs due to their high vulnerability and likely spatiotemporal overlap, but their recovery potential reduces overall sensitivity. The scores for these species illustrate the importance of interpreting species sensitivity results in the context of their spatiotemporal overlap with

OFW ICFs, which are conservative estimates of interaction, as well as all parameters within the species sensitivity equation.

4.2.2.6.2 Marine Mammal/Turtle Species

Of the marine mammal and turtle species included in the analysis of the Hawaii study areas, false killer whale, pantropical spotted dolphin, and bottlenose dolphin had the highest species sensitivity scores. All three species were toothed whales with wide habitat ranges and foraging behaviors. The pantropical spotted dolphin and bottlenose dolphin had the same vulnerability scores for all individual ICFs and had the highest vulnerability scores of species in the Hawaii study areas for collisions and entanglement and vessel strikes, which is related to the aggregating behavior of these species and a reliance on sound for navigation (NOAA Fisheries 2015; NOAA Fisheries 2017c).

Although the vulnerability scores of the pantropical spotted dolphin and bottlenose dolphin were higher than that of the false killer whale, the low population recovery potential of the false killer whale increased its species sensitivity score. The low recovery potential is due to the increased foraging that occurs during pregnancy and nursing (a risky time for injury), endangered conservation status, late age of maturity, and long intervals between calving (NOAA Fisheries 2017d).

In addition to the two toothed whale species, the HI DPS humpback whales had a high summed ICF impact score as they were highly vulnerable to most of the individual ICFs. This suggests that other baleen whale species within the Hawaii study areas may also be highly sensitive to OFW. The HI DPS humpback whales are only present in or around the Hawaiian study area as they overwinter; other baleen whales with similar behaviors and year-round presence may receive a higher sensitivity score.

Species with mid-range species sensitivity scores included Hawaiian monk seal and fin whale. Hawaiian monk seals had the lowest summed ICF vulnerability score of all species included in the Hawaii study areas. As solitary generalist foragers that spend more time close to shore, Hawaiian monk seals were minimally vulnerable to most of the individual ICFs (NOAA Fisheries 2017e). However, Hawaiian monk seals are more vulnerable to accidental spills because they are coastal and rely on fur for thermoregulation, which loses its insulative functionality with even small amounts of oiling (Helm et al. 2015). They are also endemic to Hawaii and endangered, resulting in a low-moderate recovery potential score that increased their overall sensitivity score relative to their low ICF vulnerability scores.

Fin whales had low to moderate vulnerability to all individual ICFs, except habitat disturbance or displacement. Fin whales are particularly vulnerable to habitat disturbance or displacement because they are very sensitive to sound and may exhibit some avoidance behaviors towards the OFW facility due to the increased noise from vessel traffic and turbine operation (Kooyman 1973; Croll et al. 2001; NOAA NMFS 2005). Although both the Hawaiian monk seal and fin whale had low to moderate summed impact scores, both species are listed as endangered and therefore had low recovery potential (NOAA Fisheries 2017e, 2017f), resulting in a more moderate sensitivity score.

In the Hawaii study areas, HI DPS humpback whales and green turtles had the lowest species sensitivity score of the marine mammals and turtles included in the analysis. Although HI DPS humpback whales had a high summed ICF impact score and were highly vulnerable to most of the individual ICFs, their low species sensitivity score was due to their absence from the study area for half of the year. HI DPS humpback whales overwinter in warmer southern waters and migrate north to cooler waters for increased foraging opportunities in the spring (NOAA Fisheries 2017f). The marine waters near the Hawaiian Islands are known calving grounds for nursing female humpback whales (NOAA Fisheries 2017f). While with calves, humpback whales do not forage and tend to stay near the surface of the water, making them vulnerable to accidental spill, artificial light, and vessel strike ICFs.

Green turtles had low or mid-range vulnerability scores for all the ICFs, which contributed to its low sensitivity score. They are generalist foragers and primarily forage from the mid-water column, rather than from the surface where they would be more vulnerable to accidental spills or vessel strikes (NOAA Fisheries 2017g). Although they scored relatively low for ICF impacts, green turtles are listed as threatened and have a very late age of maturity, which reduce their population recovery potential from any major impact. These species illustrate the importance of seasonal presence/absence and habitat use (i.e., time spent at surface or deeper waters) for increasing encounter risk.

4.2.2.6.3 Fish/Invertebrate Species

Of the fish and invertebrate species evaluated in the analysis of the Hawaii study areas, midway/pink coral and massive black sponge had the highest species sensitivity scores. Both species are sessile/attached filter-feeders in the deep sea, which makes them, like other benthic organisms that are not able to move away from an ICF, vulnerable to accidental spills, EMF, and bottom habitat disturbances. In addition, these species had the lowest population recovery potential because they are slow-growing and have greatly reduced population ranges throughout the Hawaiian Islands compared to their historical ranges (Bruckner 2009; Sara 2017). Any deep-sea coral and sponge populations affected during construction of the OFW facility would likely not recover for decades and thus could be very sensitive to OFW development that occurs within their habitat range. This highlights the importance of benthic habitat surveys and careful siting of facilities.

Hawaiian grouper also had a high species sensitivity score based on a moderate ICF vulnerability score, low recovery potential, and year-round presence at the study area. Because Hawaiian grouper is a demersal fish and attracted to hard bottom habitat, they are most vulnerable to EMF from OFW power cables; however, the impacts of EMF on fish are not well understood and are likely to involve minor behavioral disturbances rather than direct adverse effects (Love et al., 2017). Recovery potential of Hawaiian grouper was considered to be very low as they are endemic to Hawaii and are listed as near threatened due to overfishing (Heemstra and Randall 1993).

Hawaiian spiny lobster, ‘O‘opu naniha, and bigeye tuna had mid-range species sensitivity scores. Bigeye tuna had the highest summed ICF vulnerability score and one of the highest population recovery potential scores of the fish and invertebrate species included in the Hawaii study areas. Larger pelagic species, such as bigeye tuna, have been observed to be attracted to man-made structure because of the aggregations of small pelagic fish, which are a primary prey source (NOAA Fisheries 2017h). These fish are good examples of how some species that may be vulnerable to particular ICFs, may not actually be very sensitive to OFW development due to their ability to recover, acting as a counterpoint to their vulnerability in this analysis.

Hawaiian spiny lobster had low vulnerability scores for all individual ICFs, except EMF because of the demersal behavior and evidence of electromagnetic senses found in other spiny lobster species (Normandeau et al. 2011; Woodruff et al. 2013; Maui Ocean Center 2017). ‘O‘opu naniha are only present in the marine environment during their larval life stage, where they are most vulnerable to artificial light produced by the turbines, which could affect diurnal vertical migrations (HI DLNR 2005). ‘O‘opu naniha are endemic to the Hawaiian Islands, with population sizes unknown, but likely declining due to habitat loss, pollution, and invasive predators (HI DLNR 2005).

The Hawaii fish species included in the analysis of the Hawaii study areas with the lowest species sensitivity scores were mackerel scad and box jellyfish. Mackeral scad are very mobile, have a very wide range, are generalist foragers, occupy the mid- to upper water column, and may be attracted to offshore structures (NOAA Fisheries 2017i). It is well known that small pelagic fish, such as mackerel scad, are attracted to structures in the ocean as algae, phytoplankton, and zooplankton aggregate around these objects as well (Dempster and Kingsford 2004). Because of their attraction to offshore structures and association with mid-water column, Mackeral scad had one of the highest summed ICF vulnerability scores, but this was moderated by their very high recovery potential, stable population sizes, and varied seasonal presence.

Box jellyfish had moderate summed ICF vulnerability scores and a very high recovery potential score. Moderate vulnerability to accidental spills, artificial light, and habitat disturbance is due to their surface association, large aggregations, and attraction to offshore structure (Richardson et al. 2009; Keesing et al. 2016). They are an early-maturing, high-fecundity species and it is anticipated that any population-level impacts would be negligible and recovered from quickly.

4.2.2.7 Final Environmental Sensitivity of Hawaii North Study Area

The FES scores for the Hawaii North study area combine the data for the habitat and regional characteristics with the information derived from the literature review of species impact and recovery potential. Specifically, habitat sensitivity and species sensitivity scores for each region are summed and then multiplied by the baseline conditions modifier to obtain the FES score for each region. These values are influenced by the impact magnitude of LSEs and the unmitigated and mitigated ICFs throughout the model calculations, to result in one value that represents the potential overall sensitivity of the study area to OFW development.

The FES scores for the Hawaii North study area were highest during period 5 (August – September). Period 5 corresponds with hurricane season when the frequency of storms severe enough to cause partial and full failure of OFW structures is approximately 58%-99% higher than in the other periods, thus increasing impact magnitude and vulnerability. In general, the scores between seasons varied primarily because of the seasonal variation in LSE rates in Hawaii.

The final environmental sensitivity of the study area is relatively low, at 21% of the hypothetical maximum sensitivity possible. Factors affecting this result include:

- The study area is moderately affected by anthropogenic activities on average (e.g., danger and restricted zones or prevalent light pollution and coastal energy facilities in area).
- The majority of marine bottom habitat was categorized as deep soft bottom with moderate vulnerability and a smaller amount of more vulnerable hard bottom deep and coral/sponge habitat (highest vulnerability bottom habitat types with slow recovery times) was present.
- Moderately sensitive water column habitat.
- Moderate species sensitivity (40% of the hypothetical maximum sensitive species score).

4.2.3 Hawaii South

Table 25 summarizes the results of the regional analysis of environmental sensitivity for the Hawaii South study area, which are explained in detail in the sections below.

Table 25. Summary of Environmental Sensitivity Analysis Results for the Hawaii South Study Area.

Analysis Parameter	Results Summary
Large-Scale Events	• Highest frequency LSE: earthquakes (partial failure magnitude return rate of 1 in 2 years) and tsunamis (partial failure magnitude return rate of 1 in 7 years) • Full failure magnitude events of all types were very rare, with return rates of 1 in > 100 years, except for full-failure magnitude hurricanes which had a return rate of 1 in 9 years • Lowest frequency LSE: vessel accidents (medium / partial failure return rate of 1 in 1,190 years and large / full failure return rate of 1 in 1,563 years)
Baseline Conditions	• Moderate-high added impact (23%) from pre-existing anthropogenic influences to final regional sensitivity score • Most prevalent baseline metrics: wastewater outfalls (66% in study area compared to hypothetical EEZ), light pollution (50%), ocean disposal sites (46%), and coastal energy facilities (33%)
Marine Bottom Vulnerability	• Marine bottom consists of 60% soft bottom deep, 15% volcanic deep, 13% coral/sponges, 6% soft bottom shallow, 3% no data, 3% hard bottom deep, and 1% hard bottom shallow habitats • Summed vulnerability score of 2.96 out of 5 (59% of maximum) = moderate-high vulnerability
Water Column Vulnerability	• Moderate water column sensitivity, with mean NPP at 30% - 45% of hypothetical maximum NPP • Mean water column NPP is lowest during August – September, which corresponds to the height of hurricane season, and highest from February – March
Protected Areas	• 13% of marine area designated as protected areas • 5 essential fish habitats in study area, the same as in the larger Hawaii EEZ • Protected area modifier increased habitat sensitivity by 57%
Species Summed Impact Score (all ICFs combined)	• Highest BB: aerial seabirds (wedge-tailed shearwater) • Highest MT: toothed whales (pantropical spotted dolphin and bottlenose dolphin) • Highest FI: large pelagic fish (bigeye tuna)
Species Recovery Potential	• Lowest BB: aerial seabirds (Hawaiian petrel) • Lowest MT: toothed whales (false killer whale) • Lowest FI: corals/sponges (massive black sponge)
Species Sensitivity	• Highest BB: shorebirds and aerial seabirds (Hawaiian stilt, Hawaiian petrel) • Highest MT: toothed whales (false killer whale) • Highest FI: corals/sponges (pink coral) • Moderate sensitivity, 40% of the maximum
Final Environmental Sensitivity	• Periods with highest score: period 5 (i.e., Aug – Sep) • FES relatively low, 23% of the hypothetical maximum of the Hawaii EEZ • Mitigated scores differed by 1.1% • Lower and upper estimate scores differed by 2.8%

4.2.3.1 LSE Results, ICF Vulnerability, and Recovery Potential

For this analysis, LSEs, ICF vulnerability scores, and species recovery potential were evaluated for both Hawaii North and Hawaii South using the same selected species and input data, since the study areas were too geographically close to meaningfully differentiate data compiled during the literature review and analysis. Thus, refer to Sections 4.2.2.1, 4.2.2.2, and 4.2.2.3 for the LSE results, ICF vulnerability scores, and species recovery potential results that pertain to both Hawaii North and Hawaii South.

4.2.3.2 Baseline Conditions

Following the methods outlined for the California study area (as described in Section 4.2.1.4), baseline conditions within the study area were assessed to characterize existing anthropogenic impacts in the study area. The Hawaii South study area was 15,849 km^2, or 1.6% of the Hawaii EEZ area (i.e., hypothetical measurement area, 1,016,943 km^2). Therefore, a baseline metric in the study area that measured substantially more than 1.6% of the measurement in the EEZ area was considered a high amount for that particular baseline metric.

Danger and restricted zones, submarine cables, and invasive species metrics in the study area were moderately high compared to the measurements in the EEZ (6.6%, 8.9%, 15.0%, respectively). Baseline metrics for coastal energy facilities (33.3%) and ocean disposal sites (45.5%) were very high compared to the measurements for those baseline metrics in the EEZ. The baseline metrics with the greatest percent of measurements in the Hawaii South study area were light pollution and wastewater outfalls, of which 50.2% and 65.8% of all these baseline metrics in the EEZ occurred in the study area.

When considering all baseline condition datasets together, the raw baseline conditions score (which adds the normalized scores for each metric together) for the Hawaii South study area is 23.0% of the maximum score for the Hawaii EEZ. The habitat and species within the study area are likely to be most frequently exposed to light pollution and wastewater outfalls, as these baseline metrics are highly concentrated in the study area. Light pollution is a particular problem for migratory seabirds, which should be considered in cumulative effects analyses of OFW development.

4.2.3.3 Habitat Sensitivity

As noted in Section 3.4, the habitat sensitivity for each study area is a function of the marine bottom habitat sensitivity, the water column habitat sensitivity, and the protected area.

Marine Bottom Habitat Sensitivity

The majority (60%) of marine bottom habitat within the Hawaii South study area is categorized as deep soft bottom habitat, which is assigned a moderate vulnerability rank of 3 out of 5 due to consisting of adaptable communities on relatively unstable, mobile substrate. Shallow soft bottom habitat accounted for 6% of the study area and was assigned a lower vulnerability rank of 2 due to faster recovery rates assumed in shallower waters. Approximately 3% of the bottom habitat of the Hawaii South study area is of unknown type, which is conservatively assumed to be a habitat of mid-range sensitivity rank (3 out of 5) to account for sensitive habitats that could be there. There were small amounts of hard bottom shallow (1%) and deep (3%) habitat in the study area, which are more vulnerable habitat types (sensitivity ranks of 3.5 and 4.5 out of 5, respectively) because they generally support less resilient organisms with longer recovery times. Fifteen percent of the bottom habitat was identified as deep volcanic material, assumed to have a low vulnerability rank of 1. About 13% of the Hawaii South study area contained coral/sponge habitat, assumed to have the highest vulnerability due to sensitivity to changes in the environment and slow recovery times.

Each of the above habitats contributed to the summed vulnerability score of 2.96 in Hawaii South, which is 59% of the maximum possible vulnerability score of 5 for marine bottom habitat. Most of the bottom habitat consisted of low to moderately vulnerable habitat types, with only about 17% consisting of more vulnerable hard bottom and coral/sponge habitat. Thus, it should be possible to mitigate bottom habitat impacts with appropriate macro- and micro-siting of OFW facilities to avoid the most sensitive habitat types. Overall, the Hawaii South study area was found to be moderately vulnerable to OFW habitat disturbance.

Water Column Habitat Sensitivity

For this analysis, water column habitat with high NPP is assumed to be more vulnerable to potential OFW impacts, as higher-productivity waters are associated with greater species richness and abundance (Ware and Thomson 2005). Within the Hawaii South study area, the mean water column NPP is lowest during August – September, which corresponds to the height of hurricane season. Meanwhile, the NPP is highest from February – March, corresponding to the end of winter/wet season in Hawaii. The water column vulnerability ranged from 30% - 45% of the hypothetical maximum depending on the time of year (see Section 3.5 for details on the application of hypothetical values in the analysis), indicating that the Hawaii South study area consists of moderately sensitive water column habitat compared to the Hawaii EEZ seasonal maximum NPP.

Protected Areas and Essential Fish Habitat

Within the Hawaii South study area, 13% of the marine waters are designated as protected areas. In addition, there are just 7 EFH designations in the region, which equals the maximum number of EFH designations in the larger Hawaii EEZ. Based on the proportion of protected marine areas and the number of essential fish habitat designations, the habitat sensitivity of the Hawaii South study area was increased 57% to account for potentially sensitive resources near the study area.

4.2.3.4 Summary of Species Sensitivity

The species sensitivity score for each species is a combination of summed ICF vulnerability scores, the species recovery score, species seasonal presence, and LSE rate for the study area. For this analysis, species sensitivity was assessed for both Hawaii North and Hawaii South using the same selected species and input data because the study areas are too close together to meaningfully differentiate data compiled during the literature review. Thus, refer to Section 4.2.2.6 for the species ICF vulnerability and recovery information that pertains to both Hawaii North and Hawaii South.

4.2.3.5 Final Environmental Sensitivity of Hawaii South Site

The FES scores for the Hawaii South study area combine the data for the habitat and regional characteristics with the information derived from the literature review of species impact and recovery potential. Specifically, habitat sensitivity and species sensitivity scores for each region are summed and then multiplied by the baseline conditions modifier to obtain the FES score for each region. These values are influenced by the impact magnitude of LSEs and the unmitigated and mitigated ICFs throughout the model calculations, to result in one value that represents the potential overall sensitivity of the study area to OFW development.

The FES scores for the Hawaii South study area were highest during period 5 (August – September). As with the Hawaii North Study area, period 5 corresponds to hurricane season when the frequency of storms severe enough to cause partial and full failure of OFW structures is approximately 58%-99% higher than in the other periods, thus increasing impact magnitude and vulnerability. In general, scores between seasons varied primarily because of the seasonal variation in LSE rates in Hawaii.

The final environmental sensitivity of the study area is relatively low, at 23% of the hypothetical maximum sensitivity of the regional Hawaii EEZ. Factors affecting this result include:

- The study area is moderately affected by anthropogenic activities on average (e.g., light pollution and wastewater outfalls).
- Most of the marine bottom habitat was categorized as deep soft bottom with moderate vulnerability. A relatively large (17%) amount was characterized as coral/sponge or hard bottom habitat, which are more highly vulnerable habitat types due to stable community structures with slow recovery times.
- Moderately sensitive water column habitat.
- Moderate species sensitivity (40% of the hypothetical maximum sensitive species score).

4.3 Mitigation Effects on Model Results

As noted in Section 3.6 and described in addition detail in Appendix A, the effect of identified mitigation measures was applied to the impact magnitudes of each ICF on the species included in the analysis, and the maximum possible mitigated and unmitigated summed ICF vulnerability scores for each species group were compared. Although the calculation of the FES score for all three study areas in the analysis was not appreciably lower after using mitigated impact magnitude values, mitigation did have a more noticeable effect on the hypothetical maximum possible calculated ICF vulnerability scores on species groups as presented in Table 26 below.

Table 26. Effect of Mitigation on the Maximum Possible ICF Vulnerability Scores for Species Groups (% reduction in summed vulnerability score using mitigated impact magnitude values)

	Hypothetical Maximum Impact Score Reduction for Species Groups		
Mitigated ICF	**Birds and Bats**	**Marine Mammals and Sea Turtles**	**Fish and Invertebrates**
Artificial Light	16%	16%	16%
Accidental Spills	26%	26%	26%
Collisions Above Surface	13%	n/a	n/a
Sound and Noise	24%	24%	24%
Vessel Strikes	n/a	17%	17%
Summed Impact Score (across all ICFs)	18%	17%	15%

For all three species groups, the application of mitigation reduced the maximum possible vulnerability scores calculated for accidental spills by 26% and sound and noise by 24%. Applying mitigation also reduced the vulnerability score of artificial light on all species groups by 16%. For fish/invertebrates and marine mammals/turtles, the vulnerability score of vessel strikes decreases by 17% after mitigation was applied. For birds/bats, the vulnerability score of collisions above the surface decreases by 13% with mitigation. When vulnerability scores for all ICFs are added together, the maximum possible summed vulnerability score for birds/bats decreases by 18%, for fish/invertebrates by 17%, and for marine mammals/turtles by 15% with mitigation applied in the model. As described in more detail in Section 3.6, mitigation does not apply to scores for subsurface entanglement, electromagnetic fields, or habitat disturbance ICFs due to model assumptions.

For this analysis, the impact magnitude of each ICF is calculated based on impact duration, impact scale, impact level, and current level of development for each project phase (see Section 3.6). In the OFWESA model, mitigation was applied as an overarching reduction in the impact scale and impact level of particular ICFs during particular project phases, which reduced the calculated impact magnitude for that ICF and phase. This analysis did not evaluate or measure the feasibility or effectiveness of any specific mitigation type. In this context, the mitigation scenario was used to approximate which species groups or ICFs could be potentially aided by mitigation efforts. This depends, largely, on which ICFs a species group is vulnerable to.

In the table above, the summed vulnerability score of birds/bats was reduced more than the summed vulnerability score of mammals/turtles and fish/invertebrates, indicating that a higher percentage of the birds/bat maximum possible score could potentially be reduced through mitigation. In other words, the magnitude of impact is reduced for more ICFs to which birds/bats may be vulnerable under the mitigation scenario. In addition, certain ICFs show a smaller percent reduction than others (e.g., 13% collisions above surface vs. 26% accidental spills) because the ICF are only relevant during particular project phases. Collisions above surface scores were reduced by a smaller amount because that ICF was characterized as only occurring during operation, while accidental spills can occur in any phase, so mitigation could potentially improve the maximum possible scores for accidental spills to a larger degree.

5 Species and ICF Knowledge Gaps

As part of the literature review conducted for species sensitivity, a level of uncertainty (LoU) score was assigned to each assessment metric ranked for each species. This LoU score is intended to reflect the perceived quality of support available in the literature that is used to justify the rank assigned to a species for each assessment metric. The species-specific ranks, which are on a scale from 0 (lowest vulnerability/impact) to 5 (highest vulnerability/impact), are assigned for each assessment metric and translated to a score for each ICF through the species scoring tables designed for the model (see Appendix B). There are different numbers of assessment metrics ranked for each species group in the model: 12 for marine mammals/turtles, 14 for birds/bats, and 17 for fish/invertebrates.

Each metric is assigned one of three LoU ranks during the literature review: low, mid-range, and high. A high LoU was assigned when there was no data found in the literature at all, or data for a proxy species was used to derive information. A mid-range LoU was assigned when there was only one source of information found to answer the question, or more than one source was found with conflicting or unclear results. A rank of low LoU means that there was one readily-available and reliable source of information found, or two or more sources that supported the same answer. See Appendix B.6 for more information on LoU scoring.

5.1 Overall Species Group Level of Uncertainty

Potential knowledge gaps regarding OFW ICF effects were summarized by evaluating the proportion of questions that were assigned "high" uncertainty LoU scores within each species group (Table 27). For the bird/bat and marine mammal/turtle species groups, the percentage of assessment metrics ranked with a high LoU was 6.6% and 6.0%, respectively. The fish/invertebrate species group had a much higher proportion of assessment metrics ranked with high uncertainty at 17.3%. Overall, 11% of the assessment metrics ranked for all species groups received a high LoU.

Birds/bats had the highest proportion of assessment metrics ranked as mid-range LoU, at 30.1%. The species group with the highest proportion of low uncertainty assessment metrics was marine mammals/turtles, at 82.1%. A high proportion of low uncertainty scores for marine mammals/turtles is not surprising since many species have been the focus of public concern and environmental regulation.

Table 27. Percent of Total Assessment Metrics Assigned to Each Level of Uncertainty (LoU) Category within Each Species Group. Cells are color-coded along a gradient of low (green) to high (red) percent of high LoU rankings.

Species Group	# of Species Assessed	Total # of Metrics Assessed	% Low LoU	% Mid LoU	% High LoU
Birds / Bats	14	196	63.3	30.1	6.6
Fish / Invertebrates	16	272	59.9	22.8	17.3
Marine Mammals / Turtles	14	168	82.1	11.9	6.0
TOTAL	44	636	66.8	22.2	11.0

5.2 Species Level of Uncertainty for Individual Assessment Metrics

A similar analysis was performed to evaluate the proportion of species within each species group that received high LoU scores for each assessment metric to identify the species characteristics and behaviors about which the least is known and more research may be valuable. A review of trends in the LoU scores may also be used to draw conclusions about the general state of known around ICF-species interactions.

5.2.1 Birds/Bats LoU

The proportion of bird/bat species receiving different Lou ranks is presented in Table 28 below. For birds/bats, the assessment metrics with the highest proportion of high LoU answers were adult survival rate, macro-avoidance/attraction, percent of time flying within the rotor sweep zone, and percent of time flying at night. These metrics represent life history characteristics and behaviors that are not well known for many seabirds that spend much of their time offshore or that fly primarily at night (Wilson et al. 2010; Bailey et al. 2014). Macro-avoidance, nocturnal flight activity, and rotor sweep zone flights are part of bird/bat encounter risk and contribute primarily to their vulnerability to the ICF of collisions above the surface.

Table 28. Percent of Bird and Bat Species Receiving Ranks of Each Level of Uncertainty (LoU) Category within Each Assessment Metric Type. Cells are color-coded along a gradient of low (green) to high (red) percent of high LoU rankings.

Assessment Metric	% Low LoU	% Mid LoU	% High LoU
BB - Concentration - Aggregation (AGG)	92.9	7.1	0.0
BB - Encounter - Diurnal Flight Activity (DFA)	35.7	64.3	0.0
BB - Encounter - Feeding Method (FM)	100.0	0.0	0.0
BB - Encounter - Macro-Avoidance / Attraction (MA)	21.4	57.1	21.4
BB - Encounter - Nocturnal Flight Activity (NFA)	28.6	57.1	14.3
BB - Encounter - Night Roosting (NR)	92.9	7.1	0.0
BB - Encounter - Rotor Sweep Zone (RSZ)	35.7	42.9	21.4
BB - Flexibility - Habitat Flexibility (HF)	85.7	14.3	0.0

Assessment Metric	% Low LoU	% Mid LoU	% High LoU
BB - Physiology - Light Sensitivity (LS)	42.9	57.1	0.0
BB - Recovery - Breeding Score	71.4	21.4	7.1
BB - Recovery - Population Status	92.9	7.1	0.0
BB - Recovery - Range in Study Area	100.0	0.0	0.0
BB - Recovery - Reproductive Potential	78.6	21.4	0.0
BB - Recovery - Adult Survival Rates	7.1	64.3	28.6

5.2.2 Fish and Invertebrates LoU

The proportion of fish and invertebrate species receiving different LoU ranks is presented in Table 29 below. Fish and invertebrates had several assessment metrics with a high proportion of high LoU rankings. Most of these metrics pertained to physiology: navigation, predator detection, prey detection, and sound sensitivity. The first three metrics dealt directly with fish/invertebrate vulnerability to electromagnetic fields (EMF). This is an area of active research about which much is still unclear or unstudied. The general consensus is that EMF may be a concern for some species but the exposure thresholds and impacts have not yet been determined. Sound sensitivity deals directly with a fish or invertebrate's vulnerability to sound and noise impacts, based on the size, position, and type of swim bladder. This is another knowledge gap where it is understood that fish and invertebrates can detect and respond to noise, but it is still unclear what the exposure thresholds or impacts of low-frequency operational noise from OFW might be over time.

An encounter-related assessment metric with a moderately high proportion of high uncertainty rankings was macro-avoidance/attraction. The uncertainty here stems primarily from the fact that some species may be attracted to OFW providing structure in the water column but they also might avoid OFW due to sound or other impacts, and it is not entirely clear how some species will respond. Finally, a few assessment metrics pertaining to fish and invertebrate recovery potential and moderate-to-high proportions of high uncertainty rankings, including population status, reproductive potential, and adult survival rates. This uncertainty is likely related to the invertebrates studied (krill, corals, sponges) about which some key life history parameters have not been fully characterized.

Table 29. Percent of Fish and Invertebrate Species Receiving Ranks of Each Level of Uncertainty (LoU) Category within Each Assessment Metric Type. Cells are color-coded along a gradient of low (green) to high (red) percent of high LoU rankings.

Assessment Metric	% Low LoU	% Mid LoU	% High LoU
FI - Concentration - Aggregation (AGG)	75.0	25.0	0.0
FI - Encounter - Egg Location (EL)	81.3	18.8	0.0
FI - Encounter - Feeding Method (FM)	87.5	12.5	0.0
FI - Encounter - Juvenile / Adult Location (JAL)	87.5	12.5	0.0
FI - Encounter - Larval Location (LL)	81.3	18.8	0.0
FI - Encounter - Macro-Avoidance / Attraction (MA)	43.8	37.5	18.8
FI - Encounter - Movement (MV)	87.5	12.5	0.0
FI - Flexibility - Habitat Flexibility (HF)	87.5	12.5	0.0
FI - Physiology - Navigation / Migration (NAV)	6.3	50.0	43.8

Assessment Metric	% Low LoU	% Mid LoU	% High LoU
FI - Physiology - Predator Detection (PDR)	0.0	43.8	56.3
FI - Physiology - Prey Detection (PRY)	6.3	50.0	43.8
FI - Physiology - Strike Risk (SR)	93.8	6.3	0.0
FI - Physiology - Sound Sensitivity (SS)	12.5	31.3	56.3
FI - Recovery - Population Status	68.8	25.0	6.3
FI - Recovery - Range in Study Area	93.8	6.3	0.0
FI - Recovery - Reproductive Potential	81.3	12.5	6.3
FI - Recovery - Adult Survival Rates	25.0	12.5	62.5

5.2.3 Marine Mammals and Turtles LoU

The proportion of marine mammal and turtle species receiving different Lou ranks is presented in Table 30 below. Marine mammals and turtles had the fewest assessment metrics ranked as high LoU. Assessment metrics for all species except for macro-avoidance/attraction and adult survival rates received LoU rankings of either low or mid-range. Adult survival rates had moderately high proportion of high LoU rankings (14.3%) while macro-avoidance/attraction had the highest proportion of high LoU rankings (57.1%).

Table 30. Percent of Species Receiving Ranks of Each Level of Uncertainty (LoU) Category Within Each Assessment Metric Type. For the assessment metrics, BB = bird / bat, FI = fish / invertebrate, and MT = marine mammal / turtle species group questions. Cells are color-coded along a gradient of low (green) to high (red) percent of high LoU rankings.

Assessment Metric	% Low LoU	% Mid LoU	% High LoU
MT - Concentration - Aggregation (AGG)	85.7	14.3	0.0
MT - Encounter - Feeding Method (FM)	92.9	7.1	0.0
MT - Encounter - Habitat Use (HU)	100.0	0.0	0.0
MT - Encounter - Macro-Avoidance / Attraction (MA)	0.0	42.9	57.1
MT - Flexibility - Habitat Flexibility (HF)	100.0	0.0	0.0
MT - Physiology - Sensitive Features (SNF)	100.0	0.0	0.0
MT - Physiology - Sound Sensitivity (SS)	92.9	7.1	0.0
MT - Recovery - Breeding Score	78.6	21.4	0.0
MT - Recovery - Population Status	100.0	0.0	0.0
MT - Recovery - Range in Study Area	92.9	7.1	0.0
MT - Recovery - Reproductive Potential	100.0	0.0	0.0
MT - Recovery - Adult Survival Rates	42.9	42.9	14.3

Documentation of adult survival rates were difficult to find for across species groups, representing a substantial knowledge gap for many species. Macro-avoidance/attraction had high LoU rankings for many species because little definitive information was found for some regarding their behavior around offshore structures (like OFW or oil and gas rigs), or the information found was conflicting, indicating a species may avoid OFW due to noise but also be attracted to OFW if it's acting as a fish aggregating device, concentrating prey. In general, studies linking behavioral responses to changes in vital rates and longer-term population impacts are lacking and represent a large knowledge gap (Bailey et al. 2014).

6 Summary of Conclusions

In light of an increase in alternative energy initiatives and the viability of power generation by offshore wind farms, it is important to understand environmental implications and the general knowledge gaps that should be addressed prior to OFW development. This study consisted of a review of existing sensitivity analyses, a summary of OFW technology and a definition of its major ICFs, incorporation of LSE frequencies and impacts, a detailed geospatial analysis of various habitat characteristics, and a thorough literature review for 44 fish, invertebrate, mammal, turtle, bird, and bat species in one California and two Hawaii study areas to assess the sensitivity of habitats and species to large-scale OFW development.

6.1 ICF Characterization and Magnitude

Eight ICFs of OFW development were defined and determined to be potential stressors to habitats and species. The impact magnitude of each ICF was based on the impact duration, spatial scale, and level of impact, and used to objectively characterize the spatiotemporal extent and potential severity interaction with each ICF. Of the ICFs included in the model, ICFs that occurred during the operation phase would have the longest impact duration due to the expected lifespan of an OFW development. The ICF with the highest impact scale was artificial light during construction and operation, due to its potential spatial reach. Vessel strikes during all three phases of development were considered to have the highest impact level (i.e., could do the most damage upon interaction). Vessel strikes can be fatal for large marine mammals, such as humpback whales, and an increase in vessel traffic would increase the potential and frequency of strikes. In addition, collisions with above-water structures during operation were considered to have high impact level because of the increased risk for birds near the turbines to be struck by the rotors.

These ICF characterization metrics were combined into weighted average impact magnitude values that represented the potential severity of an ICF and influenced species and habitat sensitivity scores. The ICFs with the highest impact magnitudes (≥ 3 on a scale from 1 – 5) included collisions above surface during operation, habitat disturbance/displacement during operation, sound/noise during operation, and vessel strikes during all three project phases. A mitigation scenario was developed by reducing the impact scale or impact level of particular ICFs during specific project phases based on mitigation options defined during literature review.

6.2 Large Scale Events Analysis

The regular occurrence of LSEs could cause or increase the occurrence of: accidental spills of oil and/or chemicals from wind turbine generators; bird collisions with above-surface facility structures; entanglement by fish and other marine organisms with sub-surface structures, and habitat disturbance/displacement. Effects of LSEs were incorporated into the analysis by increasing the impact scale and impact level for each relevant ICF and project phase. Results indicated that natural LSEs increasing the impacts of OFW, such as hurricanes, earthquakes, and tsunamis, may be of greater concern in the Hawaii study areas, due to more frequent recurrence times (one partial structural failure magnitude event every 2-11 years depending on type). Full failure magnitude hurricanes were fairly frequent for Hawaii as well, particularly during the August-September period, with a recurrence time of one event every 9 years. Meanwhile the frequency estimated for vessel accidents was extremely unlikely, on the order of one event every 1,100+ years. For California the frequency of occurrence of any full-failure magnitude LSE was very unlikely. Of partial-failure magnitude events, earthquakes and tsunamis were the most frequent, with recurrence times of one event every 8 and 13 years, respectively. Vessel accidents were somewhat more likely for the California study area than for Hawaii, with recurrence times on the order of one event every 227-400 years, but these results suggest that LSE s may have a greater influence on potential impacts when planning within the Hawaii EEZ.

6.3 Habitat Receptor Sensitivity

The habitat sensitivity portion of the analysis illustrates how study areas with a wide range of habitat characteristics can be evaluated in the context of a regional hypothetical maximum score for comparison. For example, even though the mean NPP of the water column in California was objectively much higher than the mean NPP of Hawaii (therefore suggesting California waters would be more vulnerable to impact than Hawaii), when the means are compared to their respective regional maximum, the water column vulnerability of California and Hawaii was similar. Water column vulnerability varied over the year in both study areas but was moderate overall.

Marine bottom habitat vulnerability was assessed based on short-term impact and long-term recovery potential of generalized bottom habitat types. Anthropogenic or mobile, soft-sediment habitats with resilient, opportunistic communities received lower vulnerability scores while habitats with more stable communities and slow recovery times (e.g., corals/sponges, deep hard bottom habitat) received higher vulnerability scores. Bottom habitat in Hawaii North consisted primarily of low vulnerability soft bottom deep habitat, with a moderate proportion of higher vulnerability habitats (15% hard bottom deep and coral/sponges). Bottom habitat in Hawaii South were similar. The California study area consisted of a higher proportion of less vulnerable soft bottom deep habitat and almost no potentially vulnerable habitat types (< 0.1%); however, the proportion of “unknown” bottom type in this area was relatively high (27%). The habitat sensitivity analysis highlighted the need for detailed bottom habitat spatial data in the appropriate evaluation of sensitivity due to the relatively high proportions of “unknown” bottom habitat in the best spatial datasets identified.

Due to the prevalence of less vulnerable soft bottom sediment habitats in all three study areas, the overall habitat sensitivity scores were relatively low, with annual average scores of 4.6, 5.2, and 5.4 out of a maximum of 15 for California, Hawaii South, and Hawaii North, respectively. These scores indicate that habitat sensitivity is about one third as sensitive as it possibly could be as calculated in the OFWESA model; this suggests that these areas are amenable to OFW development and with careful micro-siting could potentially avoid habitat disturbance impacts.

6.4 Species Receptor Sensitivity

Species group vulnerability to various ICFs were determined using assessment metrics to evaluate major ecological themes (including encounter likelihood), species aggregation, sensitive physiology, and habitat flexibility, as well as recovery potential based on population size, range, conservation status, and reproductive potential. For each individual species, assessment metrics were scored on a categorical ranking scale based on behaviors or life history characteristics informed by extensive literature review. ICF vulnerability scores are not a measure of actual impact to a species, nor are they comparable in magnitude between ICFs. The values should be considered as an index of relative risk. The ICF vulnerability scores account for only one portion of the species sensitivity interim results calculated by the model. Species-specific sensitivity scores were composed of ICF vulnerability scores modified by the ICF impact magnitude during each project phase, then multiplied by the recovery potential, seasonal presence, and LSE scores. This emphasizes that high vulnerability to a particular ICF does not equate to high impact from that ICF nor to an overall high sensitivity to OFW development.

The species scoring method developed for the OFWESA model provided an informed assessment of vulnerability to and recovery from various ICFs. Level of uncertainty ranks assigned to each vulnerability assessment metric enabled a quantitative account of uncertainty in the data, highlighting the behaviors and traits of species and their interactions with ICFs that have knowledge gaps in the literature. The fish/invertebrate group had higher uncertainty surrounding their assessment metrics than other groups, particularly for questions regarding electromagnetic fields, sound sensitivity, macro-avoidance/attraction, and adult survival rates. The bird/bat group had high uncertainty for questions regarding flight time within rotor sweep zone, macro-avoidance/attraction, and adult survival rates. There were the fewest high uncertainty assessment metrics for the marine mammals/turtles group, with most surrounding questions of macro-avoidance/attraction. This highlights the lack of basic life history trait information for some species groups, along with a need to understand movement patterns and avoidance/attraction to OFW structure

The results of the species sensitivity portion of the model suggest that pelagic seabirds that spend most of their time in the air exhibit behaviors that make them the most vulnerable to potential OFW impacts. Aerial seabirds spend most of their lives at sea, foraging and roosting offshore. This life history strategy puts them at increased risk for habitat disturbance and accidental spills encounters as they rely on surface waters for feeding. Many aerial bird species also forage at night, which increases the potential for the navigation lights on the turbines to cause confusion or collision during on-the-wing feeding. The least vulnerable bird/bat species tended to be those that spent some or most of their time on shore, such as hoary bats and plovers. These species would have minimal interactions with offshore wind farms, likely only during annual seasonal migrations or rarer offshore foraging trips. This illustrates how the OFWESA model results may inform an analyst/expert/manager about ICFs of potential concern, but it is incumbent to the user to interpret the ICF vulnerabilities and put them into context for an individual species and study area.

In both the California and Hawaii study areas, humpback whales had the highest ICF vulnerability scores of the marine mammals/turtles group and may be highly vulnerable to all individual ICFs associated with OFW development. Previous research has found vessel strikes to be a major cause of mortality for humpback whales, who approach vessels out of curiosity or lack enough time to react and avoid oncoming vessels (Rockwood et al. 2017). Operational noises from turbines could also interfere with or mask the songs of baleen whales, such as humpback or blue whales that rely on the long-distance sound propagation of low frequency songs to communicate (Madsen et al. 2006). Although they had low species sensitivity scores, pinnipeds were considered vulnerable to accidental spills because of the effect a chemical spill would have on the fur they use for thermoregulation.

For fish and invertebrates, species potentially attracted to OFW structures incurred highest vulnerability scores due to increasing encounter risk for ICFs. Krill, forage fish (Pacific sardine and mackerel scad), and tuna (bigeye and Pacific bluefin) are well known to be attracted to structure within the water column and may be attracted to turbine structures, increasing potential for injury or mortality in the event of a chemical spill. Although research on EMF impacts on fish species is in its infancy, demersal and benthic species, such as cowcod, and Hawaiian spiny lobster, have a potential for impacts based on their habitat use near submarine cables. Overall, slow, long-lived sponge and coral species in both study areas would be the most vulnerable species to habitat disturbance during construction.

Many of the species analyzed had low recovery potential based on their status as endemic species, low population levels, or both. Due to Hawaii’s location as an isolated island in the middle of the Pacific Ocean, it has an abundance of endemic species with lower recovery potential due to their isolated and unique population status, including Hawaiian petrel, Hawaiian stilt, and Hawaiian monk seal. Other species with low recovery potential are long-lived with late maturation and/or slow growth, like some of the baleen and toothed whales and the deep-sea corals and sponges. Should OFW development increase mortality or reduce reproduction on a large scale, these species would take a longer time to recover or repopulate an area.

6.5 Baseline Conditions

This report also analyzed the baseline conditions in each region to summarize environmental stress on an area due to pre-existing anthropogenic activities, and to allow identification of prevalent activities in for potential inclusion in a cumulative effects analysis. The baseline conditions score served as a modifier in the model that could effectively double the environmental sensitivity of a study area. Prevalent activities in the Hawaii North study area included danger and restricted zones, coastal energy facilities, and light pollution, which contributed a low to moderate amount of impact to the study area’s FES score. The Hawaii South study area contained relatively large amounts of wastewater outfalls, light pollution, ocean disposal sites, and coastal energy facilities that contributed a moderate amount of increased impact to the FES. Prevalent activities in California included submarine cables, wastewater outfalls, and general pollution and did not contribute meaningfully to the FES for the region.

6.6 Final Environmental Sensitivity

The FES scores were consistently higher in both Hawaii study areas than in the California study area. Differences in the final sensitivity scores between seasons and regions are a cumulative result of higher baseline condition scores, greater LSE effects, and higher habitat and species sensitivity scores derived for the Hawaii areas. However, it is important to evaluate the differences in sensitivity with regards to the regional hypothetical maximum values, to put the sensitivity scores into practical context within the regional EEZ. The FES scores ranged from 16% (California) to 23% (Hawaii South) of the hypothetical maximum FES, indicating relatively low environmental sensitivity on the broad study area scale.

6.7 Closing Remarks

Since floating turbines are a relatively new technology, uncertainty exists regarding precisely how OFW development may affect the habitats or particular species and populations in a development area. The variety of environmental parameters analyzed in this report provide a snapshot of the components of potential concern in these study areas.

Additionally, once OFW turbines are more readily utilized and impacts to species and habitats can be directly assessed, the OFWESA model approach could be applied retroactively to an offshore wind development area to compare the predicted sensitivity of resources to real-world impacts. In the absence of direct observations, the OFWESA model analysis approach provides a knowledgeable starting point for potential OFW-specific stressor-receptor interactions. It combines several disparate data types (e.g., spatial data, event frequencies, literature review) in a meaningful, comparable way by analyzing categorical information in a quantitative manner. The various input data, assessment criteria, and assumptions are transparently described to aid in interpretation and provide objective, repeatable results. Finally, the OFWESA model assumptions can be updated as new information becomes available, and the framework can be expanded to apply to any region in the OCS with appropriate input data available.

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