OCS Study
BOEM 2018-031

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

Volume 2: Final Report Appendices

US Department of the Interior
Bureau of Ocean Energy Management
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Environmental Sensitivity and Associated Risk to Habitats and Species on the Pacific West Coast and Hawaii with Offshore Floating Wind Technologies

Volume 2: Final Report Appendices

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DISCLAIMER

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List of Abbreviations and Acronyms

ABS	American Bureau of Shipping
ACPARS	Atlantic Coast Port Access Route Study
AGG	Population Aggregation Behavior
AIS	Automated Identification System
AL	Artificial Light
API	American Petroleum Institute
AS	Accidental Spills
BB	Birds and Bats
CAS	Collisions with Above Surface Structures
CoV	coefficient of variation
CSE	Collisions with Subsurface Structures, Entanglement
EEZ	Economic Exclusion Zones
EFH	Essential Fish Habitat
EIS	Environmental Impact Statement
EMF	Electromagnetic Fields
FI	Fish and Invertebrates
FM	Feeding Method
GPS	Geographic Position System
GT	Gross Tons
HD	Habitat Disturbance/Displacement
HF	Habitat Flexibility
HYP_Min and HYP_Max	Hypothetical values
ICF	Impact-causing factor
IEC	International Electrotechnical Commission
km	Kilometers
LoU	Level Of Uncertainty
LSE	Large-scale event
m	Meters
MA	avoidance behavior
MBHab	Marine Bottom Habitat
MMS	Minerals Management Service
MODIS	Moderate Resolution Image Spectroradiometer
MT	Marine Mammals And Sea Turtles
MW	Megawatt
NCP	National Contingency Plan

NGDC/WDS	National Geophysical Data Center/World Data Service
NPP	Net Primary Productivity
NR	Night Roosting Behavior
OCS	Outer Continental Shelf
OFW	offshore floating wind
OFWESA	Offshore Floating Wind Environmental Sensitivity Analysis
PAM	Protected Area Modifier
RESA	Relative Environmental Sensitivity Analysis
S/N	Sound/Noise
SSHWS	Saffir-Simpson Hurricane Wind Scale
TSS	Traffic Separation Scheme
USFWS	U.S. Fish and Wildlife Service
VOWTAP	Virginia Offshore Wind Technology Advancement Project
VS	Vessel Strikes
WCHab	Water Column Habitat
WDPA	World Database on Protected Areas
WSC	World Shipping Council

Appendix A: ICF Definitions

A.1 Terminology, Definitions, and Ranges

Appendix A provides definitions of each impact-causing factor (ICF) included in the Offshore Floating Wind Environmental Sensitivity Analysis (OFWESA) model. Some text is repeated verbatim among different ICF sections as the same definitions can apply to multiple factors.

Table A-1. ICF Terms and Definitions

Term	Definition
Impact Magnitude	A summary attribute incorporating Impact Duration, Impact Scale, Impact Level, and Current Level of Development. It assesses the spatiotemporal extent of an ICF within a study area.
Impact Duration	Temporal scale at which the ICF would most likely occur.
Impact Scale	Spatial scale at which the ICF would most likely occur.
Impact Level	Level of impact on an individual expected if the ICF occurred.
Current Level of Development	Assessment of existing BOEM-regulated activities in a planning area or broad outer continental shelf regions of interest relative to other planning areas.

A.1.1 Impact Range

Areal range describes the distance from shore the ICF can occur. A value of zero represents the shoreline; positive integers indicate distance out to sea in kilometers (km). The depth range represents the bathymetric depth ranges at which the ICF can occur. Current offshore floating wind (OFW) turbine technology may not allow. Construction in waters excessively shallow or deep. A value of zero represents sea level. Positive integers represent depth below the sea surface in meters (m), and negative integers represent distance above sea level in m.

A.1.2 Impact Duration

The Impact Duration attribute assesses the temporal scale at which the ICF would likely occur (Table A-2). For example, a large oil spill is unlikely to occur, but if it occurs the impact might persist for several months. Therefore, this is the duration assessed with the Impact Duration attribute.

Table A-2. Impact Duration Ranks

Impact Duration Rank	Definition	Rank Score
N/A	The impact does not occur during a specific project phase.	0
Immediate	A short-term event where effects are relaxed almost immediately (minutes) (pulse effect).	1
Short-Term	A short-term event where effects are relaxed quickly (days) (pulse effect).	2
Moderate	A short-term event where effects are relaxed over a short period of time (weeks to months) (pulse effect).	3
Chronic	A sustained, long-term, or chronic event where effects are not relaxed (press effect).	4
Permanent	A permanent event that sets a new threshold for some environmental feature of a species (threshold effect).	5

A.1.3 Impact Scale

The Impact Scale attribute assesses the spatial scale at which the ICF is likely to occur. The rank reflects an approximation of worst-case spatial scale for each ICF (Table A-3).

Table A-3. Impact Scale Ranks

Impact Scale Rank	Definition	Rank Score
N/A	The impact does not occur during a specific project phase.	0
Site-Specific	A contained impact that occurs only at the location of the structure producing the ICF.	1
Small	A minimally dispersed ICF, potentially occurring over a few square kilometers.	2
Moderate	A moderately dispersed ICF, potentially occurring between 10 and 100 square kilometers.	3
Large	An ICF that may occur over hundreds of square kilometers of OCS and coastal areas.	4
Very Large	An ICF that may occur over an unlimited or unmeasurable spatial area.	5

A.1.4 Impact Level

The Impact Level attribute assesses the intensity of effect on an individual if an ICF were to occur. The rank reflects an approximation of the potential negative effect of each ICF (Table A-4).

Table A-4. Impact Level Ranks

Impact Level Rank	Definition	Rank Score
N/A	The impact does not occur during a specific project phase.	0
Nuisance	An impact-causing factor that causes a nuisance to an individual, but is unlikely to cause physiological harm. This may include but is not limited to alteration of movement, slight disruption of feeding habits, or reduction in predator avoidance capabilities.	1
Harmful	An impact-causing factor that causes harm to an individual, but is extremely unlikely to cause mortality. Or, an impact-causing factor that causes a significant disruption in navigation, feeding habits, or prey avoidance.	2
Potentially Fatal	An impact-causing factor that may cause fatality, but is more likely to wound an individual. Or, an impact-causing factor that causes a potentially fatal alteration in an individual’s navigation, feeding habits, or prey avoidance.	4
Fatal	An impact-causing factor that causes fatality to an individual or group of individuals.	5

A.1.5 Level of Development Impacts

The Level of Development attribute assesses the level of development of the same technology type that currently exists within a general OCS region (Table A-5). Regions with greater levels of OFW development have greater probabilities of receiving impacts from OFW development. This metric is intended to be of greater use in future implementations of the model if OFW development becomes prominent in the outer continental shelf (OCS).

Table A-5. Level of Development Ranks

Level of Development Rank	Definition	Rank Score
N/A	The impact does not occur during a specific project phase.	0
None	The impact does not currently occur in the broad OCS region/planning area.	1
Low	The impact currently occurs in the broad OCS region/planning area and is in the lower 50 percent of nationwide OCS development (of areas where impact occurs).	3
High	The impact currently occurs in the broad OCS region/planning area and is in the upper 50 percent of nationwide OCS development (of areas where impact occurs).	5

A.2 ICF Characterizations

A.2.1 Accidental Spills

Definition: Accidental spills are oil and chemical spills resulting from both routine operations and incidents occurring outside of normal operating procedures. Accidental spills may be associated with production accidents, transportation failures, and low-level releases from turbines or substations (MMS 2007). Additionally, accidental spills include the release of solid waste materials such as plastic containers or construction materials. Accidental spills from turbines may include, but are not limited to, lubricators (e.g., Mobil SCH 632, Optimol Synthetic A320, Mobil SHC XMP 220, polyalphaolefin/ester-based products), phenol, acetone, and polyethylene terephthalate (BOEM 2013). Accidental chemical spills from floating substations may include naphthenic mineral oil, dielectric fluid, transformer oil (motor and/or diesel), Edisol XT, and sulfuric acid.

Areal Range: *0 – 100 km*

The Areal Range minimum is assumed to be the shoreline (0 m) due to potential for accidental spills originating from vessels in harbor. The maximum areal range is based on the distance from shore in potential lease blocks centered on the maximum reported depth at which OFW construction can/has occur(red). Maximum depth at which current OFW turbine technology could operate is approximately 1,000 m. In the areas requested for lease offshore of Hawaii and California, the 1,000-m depth contour occurs approximately 40 – 50 km from shore (Progression Hawaii Offshore Wind Inc. 2015, Trident Winds 2016). Therefore, the maximum areal range of accidental spills was assumed to occur within a 50-km radius of the 1,000-m depth contour, or up to approximately 100 km from the shoreline.

Depth Range: *0 – 50 m*
Accidental spills are assumed to potentially occur at the surface or near-surface of the water column. A value of 50 m is used to define the maximum depth at which this ICF could occur. Spills are likely to originate from the turbine fuselage or construction/ maintenance vessels as opposed to anchoring devices, which could occur in deeper waters.

Impact Scale:

- Site Assessment – *Small*
- Construction – *Small*
- Operation and Maintenance - *Small*

Impact Duration:

Accidental spills fall into the Short-Term category: a short-term event for which effects are relaxed almost immediately (minutes to days) (pulse effect).
- Site Assessment – *Short-Term*
- Construction – *Short-Term*
- Operation and Maintenance – *Short-Term*

Current Level of Development: *None*

There is no existing large-scale OFW turbine farm on the OCS of the United States. Accordingly, the current level of development is set as None for all ICFs.

Mitigation: Accidental spills are most likely to originate from transportation failures and accidents, or from catastrophic large-scale events leading to structural failure of a 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. Mitigation for accidental spills relating to structural failure is based on structural engineering and site placement. During construction and operation, it is possible that emergency response may be available to address significant spills.

A.2.2 Artificial Light

Definition: Artificial light refers to all light emanating from the site assessment, construction, and operation of OFW turbine fields. Detrimental effects of artificial light may include increased chances of collision with turbine blades, disorientation, and skewed migratory bird pathways. 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. Artificial light can also influence diurnal vertical migration patterns of plankton in the surface waters.

Areal Range: *0 – 100 km*

The Areal Range minimum is assumed to be the shoreline (0 m) due to potential for artificial light originating from vessels in harbor or nearshore wind turbines. Since it is not possible to generalize the distance traveled by various lighting schemes in all weather conditions, the upper range for this ICF is based is based on the distance from shore in potential lease blocks centered on the maximum reported depth at which OFW construction can/has occur(red). Maximum depth at which current OFW turbine technology could operate is approximately 1,000 m. In the areas requested for lease offshore of Hawaii and California, the 1,000-m depth contour occurs approximately 40 – 50 km from shore (Progression Hawaii Offshore Wind Inc. 2015, Trident Winds 2016). Therefore, the maximum areal range of artificial light was assumed to occur within a 50-km radius of the 1,000-m depth contour, or up to approximately 100 km from the shoreline.

Depth Range: -*200 – 10 m*

Minimum depth range for artificial light represents the maximum height above the waterline at which artificial light may adversely affect biota. A height of 200 m has been selected; the hub heights of the Hywind 6 megawatt (MW) system and the WindFloat 8 MW system are both approximately 100 – 105 m above mean sea level (Principle Power 2015, Statoil 2015). The distance traveled by artificial light may extend the visible effects of the artificial light to around 200 m or more. Because the distance light travels in air will differ greatly based on the size of the wind turbine field and the atmospheric conditions, assumptions must be made regarding the potential area of impact. The maximum depth of artificial light is given as 10 m due to differing underwater light attenuation values across lease regions.

Impact Scale:

- Site Assessment – *Small*
- Construction – *Moderate*
- Operation and Maintenance - *Moderate*

Impact Duration:

- Site Assessment – *Short-Term*
- Construction – *Moderate*
- Operation and Maintenance - *Permanent*

Given the predicted life span of wind turbines (at least 20 years), artificial light is designated as a permanent impact factor during the operational phase. Turbines and floating substations require 24-hour lighting due to aviation regulations. During site assessment and construction, increases in artificial light will occur on shorter time scales.

Current Level of Development: *None*

There is no existing large-scale OFW turbine farm on the OCS of the United States. Accordingly, current level of development is set as None for all ICFs.

Mitigation: The most significant concern from artificial light emanating from turbines and substations is from chronic operational light and its impact on species behavior, particularly birds and bats. Because federal aviation regulations dictate some minimum requirements for lighting on turbines, no complete mitigation measures are available. It is thought that lighting should be set at the minimum number, minimum intensity, and minimum number of flashes ordained by federal law in order to minimize disorienting effects on birds and bats (Manville 2005). With the aim of deterring species to avoid collision, lighting can attract or disorient wildlife, but responses to lighting are still poorly understood (Arizona Game and Fish Department 2008, Johnson et al. 2007). Studies on turbine lighting have primarily been conducted on land-based turbine fields. It is still unknown how lighting intensity offshore can affect migrant and seabird species movement; whether it be viewing the wind farm as an obstacle and flying around it, becoming disoriented (i.e., have a “trapping effect”), or becoming attracted to wind farms for rest or forage (Blew et al. 2013, Hüppop et al. 2006, Johnson et al. 2007). 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 is a baseline mitigation measure (Blew et al. 2013, Gartman et al. 2016, Orr et al. 2013).

A.2.3 Collisions Above-Surface

Definition: Collisions above-surface are the detrimental effects of above-water structures on biota unaccustomed to OFW turbines on the OCS, resulting in collisions with these structures. Collisions refer exclusively to collisions of bird and bat species with rotor blades and hubs of wind turbines.

Areal Range: *12 – 50 km*

The Areal Range minimum is assumed to be 12 km from shore because potential lease blocks in Hawaii and California occur as close as 12 km to shore and collisions with turbines are not assumed to occur outside of lease block regions. The maximum areal range is based on the maximum reported depth at which floating offshore wind construction can/has occur(red). Maximum depth at which current OFW turbine technology could operate is approximately 1,000 m. In the areas requested for lease offshore of Hawaii and California, the 1,000-m depth contour occurs approximately 40 – 50 km from shore (Progression Hawaii Offshore Wind Inc. 2015, Trident Winds 2016). Therefore, the maximum areal range of collision impacts corresponds to 12 – 50 km.

Depth Range: *-200 – 0 m*
Minimum depth range for collisions represents the maximum height above the waterline at which collisions may adversely affect biota. The heights of the tip of the rotor blade of both the Hywind 6 MW system and the WindFloat 8 MW system are approximately 180 – 190 m above mean sea level (Principle Power 2015, Statoil 2015); therefore, a maximum height of 200 m is selected. No detrimental collision is assumed to occur below the water surface. However, 0 m is used as the depth maximum in the case of accidental collisions with the tower structure near the water’s surface.

Impact Scale:

- Site Assessment – *Not Applicable*
- Construction –*Not Applicable*
- Operation and Maintenance - *Site-Specific*

Impact Duration:

- Site Assessment – *Not Applicable*
- Construction – *Not Applicable*
- Operation and Maintenance - *Permanent*

Given the extremely long lifespan of wind turbines (at least 20 years), collisions are designated as a permanent impact factor during the Operation and Maintenance phase. Turbines are not considered to be spinning prior to the operation and maintenance phase and therefore no collisions above the surface occur before operation.

Current Level of Development: *None*

There is no existing large-scale OFW turbine farm on the OCS of the United States. Accordingly, current level of development is set as None for all ICFs.

Mitigation: Mitigation measures affecting artificial light can reduce above-surface collisions from birds and bats and are discussed in Section 5.2. Other deterrence mitigation measures that can be used in addition to light mitigation include 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). Future testing of electromagnetic deterrence devices is needed; however, the microwave signals, magnets, or electromagnetic waves have been recommended as potential forms of deterrence (Harris and Davis 1998, Johnson et al. 2007). 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). Current investigations into visual deterrents and their effectiveness around wind turbines may result in updated mitigation measures in the future.

A.2.4 Collisions, Entanglement Sub-Surface

Definition: Entanglement with sub-surface structures is defined as the detrimental effects of below-water structures on biota unaccustomed to OFW turbines on the OCS, resulting in entanglement with the anchoring structures or cable between turbines. In this instance, entanglements refer primarily to marine mammal interactions with the inter-array cables and mooring lines below the turbines. Collisions with the sub-surface portion of the tower structure are included here, as well. OFW turbines will use anchoring technology generally similar to that used for offshore floating oil rig platforms. Impacts of entanglement with offshore floating oil rigs are considered negligible (BOEM 2014b). However, due to the increased density of tension cables in an OFW field, entanglement is considered a potential, though minor, ICF.

Areal Range: *12 – 50 km*

The Areal Range minimum is assumed to be 12 km from shore because potential lease blocks in Hawaii and California occur as close as 12 km to shore and collisions or entanglement with turbines, inter-array cables, or mooring lines are not assumed to occur outside of lease block regions. The maximum areal range is based on the maximum reported depth at which floating offshore wind construction can/has occur(red). Maximum depth at which current OFW turbine technology could operate is approximately 1,000 m. In the areas requested for lease offshore of Hawaii and California, the 1,000-m depth contour occurs approximately 40 – 50 km from shore (Progression Hawaii Offshore Wind Inc. 2015, Trident Winds 2016). Therefore, the maximum areal range of sub-surface collision and entanglement impacts corresponds to 12 – 50 km.

Depth Range: *0 – 1,000 m*

Depth range is based on the deepest possible installation depth because mooring lines span the entire water column from surface to seafloor.

Impact Scale:

- Site Assessment - *Site-Specific*
- Construction – *Site-Specific*
- Operation and Maintenance – *Site-Specific*

Impact Duration:

- Site Assessment – *Short-Term*
- Construction – *Moderate*
- Operation and Maintenance - *Permanent*

Given the extremely long lifespan of wind turbines (at least 20 years), entanglements are designated as a permanent impact factor during operation. Entanglements may occur at any point during site assessment, construction, and operation phases.

Current Level of Development: There is no existing large-scale OFW turbine farm on the OCS of the United States. Accordingly, current level of development is set as None for all ICFs.

Mitigation: Entanglements with sub-surface tension cables are anticipated to occur infrequently. No mitigation measures (e.g., deterrent sounds) are anticipated to be required. The anchoring method for OFW turbines will be generally similar to existing technology used for offshore floating oil rig platforms, for which mitigation measures are not employed (Adaramola 2015).

A.2.5 Electromagnetic Fields

Definition: The electromagnetic fields (EMF) ICF is defined as the adverse effects of EMF on electromagnetically sensitive fish species such as elasmobranchs. Observed detrimental impacts associated with EMF include changes in prey detection, predator detection, and navigation (Normandeau et al. 2011). Although research into impacts of EMF on fish species is still in its infancy; numerous studies have found minor negative interactions between fish species and EMF (Claisse et al. 2015).

Areal Range: *0 – 50 km*

The Areal Range minimum is assumed to be the shoreline (0 m) due to the existence of nearshore transmission cables which travel to the offshore turbines. The maximum areal range is based on the maximum reported depth at which OFW construction can/has occur(red). Maximum depth at which current OFW turbine technology could operate is approximately 1,000 m. In the areas requested for lease offshore of Hawaii and California, the 1,000-m depth contour occurs approximately 40 – 50 km from shore (Progression Hawaii Offshore Wind Inc. 2015, Trident Winds 2016). Therefore, the maximum areal range of EMF impacts extends from the 1,000-m depth contour distance shoreward.

Depth Range: *0 – 1,000 m*

Depth Range is based on the deepest possible installation depth because subsea cables span the entire water column from surface to seafloor.

Impact Scale:

- Site Assessment - *Not Applicable*
- Construction –*Not Applicable*
- Operation and Maintenance - *Site-Specific*

Impact Duration:

- Site Assessment – *Not Applicable*
- Construction – *Not Applicable*
- Operation and Maintenance - *Permanent*

Given the extremely long lifespan of wind turbines and their associated subsea cables (at least 20 years), impacts from EMFs are designated as a permanent impact factor. Transmission of electricity is not anticipated to occur until the operation and maintenance phase, therefore there are no impacts in the site assessment or construction phases for EMF.

Current Level of Development: There is no existing large-scale OFW turbine farm on the OCS of the United States. Accordingly, current level of development is set as None for all ICFs.

Mitigation: As research into EMF impacts is ongoing, there are no proposed mitigation methods. 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.

A.2.6 Habitat Disturbance

Definition: Habitat disturbance refers to general benthic habitat disturbance (including sedimentation and turbidity) and habitat displacement due to infrastructure placement including anchors and cables.

Areal Range: *0 – 50 km*

The Areal Range minimum is assumed to be the shoreline (0 m) due to the existence of nearshore transmission cables. The maximum areal range is based on the maximum reported depth at which OFW construction can/has occur(red). Maximum depth at which current OFW turbine technology could operate is approximately 1,000 m. In the areas requested for lease offshore of Hawaii and California, the 1,000-m depth contour occurs approximately 40 – 50 km from shore (Progression Hawaii Offshore Wind Inc. 2015, Trident Winds 2016). Therefore, the maximum areal range of habitat disturbance/displacement impacts extends from the 1,000-m depth contour distance shoreward.

Depth Range: *0 – 1,000 m*
Habitat disturbance may occur at any depth where OFW turbines are installed or export cables traverse the seafloor towards shore.

Impact Scale:

- Site Assessment - *Site-Specific*
- Construction – *Site-Specific*
- Operation and Maintenance – *Site-Specific*

Impact Duration:

- Site Assessment – *Short-Term*
- Construction – *Moderate*
- Operation and Maintenance - *Permanent*

Given the extremely long lifespan of wind turbines (at least 20 years), habitat disturbance is designated as a permanent impact factor due to long-term displacement of habitats.

Current Level of Development: *None*

There is no existing large-scale OFW turbine farm on the OCS of the United States. Accordingly, current level of development is set as None for all ICFs.

Mitigation: Habitat disturbance of the benthos occurs during the construction of OFW fields 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 wind fields and individual turbines are anchored. In general, sensitive benthic regions should be avoided when possible, reducing potential impacts on habitats and associated species (Gartman et al. 2016).

A.2.7 Sound/Noise

Definition: The sound/noise ICF refers to the artificial sound and noise created by siting assessment, construction, installation, and operation. The main drivers of sound and noise impacts for OFW include vessel traffic noise and rotor operation. Pile driving can cause significant noise impacts, but OFW construction does not use pile driving. Underwater noise assessment is still a relatively new field, with a lack of understanding of population-level thresholds, inconsistent methods of characterization of the noise source and modeling of propagation loss, and high uncertainty of risk and effect, particularly with respect to fish and invertebrate populations (Farcas et al., 2016; Hawkins and Popper, 2017). However, noise modeling at the Hornsea 3 fixed offshore wind farm (6 MW turbines) in the United Kingdom 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 turbine are expected to generate less underwater noise than turbine foundations in contact with the seafloor, so noise effects may be of low concern during the operation and maintenance phase for OFW, particularly when compared to vessel traffic noise during the site assessment and construction phases.

Areal Range: *0 – 100 km*

The Areal Range minimum is assumed to be the shoreline (0 m) for the sound/noise impact factor. This assumption is based on the potential for noise-generating activities to occur up to the shoreline (e.g., cable installation and vessel traffic) and on the low attenuation and long-distance sound wave propagation through seawater (Rogers and Cox, 1988). Since it is not possible to generalize the distance traveled by various noises in the underwater environment due to the effects of depth, salinity, and pressure on sound propagation, the upper range for this ICF is based on the distance from shore in potential lease blocks centered on the maximum reported depth at which OFW construction can/has occur(red). Maximum depth at which current OFW turbine technology could operate is approximately 1,000 m. In the areas requested for lease offshore of Hawaii and California, the 1,000-m depth contour occurs approximately 40 – 50 km from shore (Progression Hawaii Offshore Wind Inc. 2015, Trident Winds 2016). Therefore, the maximum areal range of this ICF was assumed to occur within a 50-km radius of the 1,000-m depth contour, or up to approximately 100 km from the shoreline.

Depth Range: -*200 – 1,000 m*

The depth range of the sound/noise impact factor is deemed to be from -200 to 1,000 m to include the highest rotor height above mean sea level and the entire water column at the potential lease blocks. Because anchor placement does not result in any persistent noise disturbance aside from ship operation, only vessel traffic–related sound/noise in surface waters is considered for construction and installation. The elevated sound from rotors is accounted for in the above-water portion of the depth range and assumes that sound propagates throughout the entire water column below the lease blocks. The physics of sound propagation in both air and water are complicated and will vary greatly based on weather and water column conditions, so a more precise depth cannot be generalized.

Impact Scale:

- Site Assessment – *Small*
- Construction – *Small*
- Operation and Maintenance - *Small*

Impact Duration:

- Site Assessment – *Short-Term*
- Construction – *Short-Term*
- Operation and Maintenance - *Chronic*

Two types of sound/noise are being considered in this assessment (vessel traffic during site assessment and construction, and rotor noise during operation and maintenance phases), the greater frequency of these two is used for impact characterization. Impact frequency rotor noise is considered to be chronic: a sustained, long-term event for which effects are not significantly relaxed over time.

Current Level of Development: *None*

There is no existing large-scale OFW turbine farm on the OCS of the United States. Accordingly, current level of development is set as None for all ICFs.

Mitigation: During the construction phase, impacts from noise on species in the water column are 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 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 are available including bubble curtains, shell-in-shell systems, hydro sound dampers, and cofferdams (Bellman et al. 2015, Verfuß 2014). There are no planned mitigation measures for operational noise, which may have impacts on marine mammals, fish, and benthos (Pine et al. 2014, van Opzeeland 2014).

A.2.8 Vessel Strikes (Surface and Sub-Surface)

Definition: Vessel strikes refer to the collision of a moving site assessment, construction, or maintenance vessel with a marine mammal or turtle causing harm or mortality. Service vessel traffic during construction and operation and maintenance of renewable energy projects is expected to be relatively high based on maintenance trips described in lease applications and environmental statements for offshore wind farms. The AlphaWindEnergy lease applications for the Northwest and South Oahu sites proposed 2-4 maintenance visits per turbine per year, which for a 400-MW farm comprised of 67 6-MW turbines would involve a maximum estimate of 268 vessel trips per year (AW Hawaii Wind LLC, 2015a; 2015b). For the Hornsea 3 fixed offshore wind farm in the United Kingdom, 2,822 return trips per year are expected over 35 years of operation for the maximum design scenario, which is a 22% increase to the baseline level of vessel activity (12,755 return trips per year; Ørsted, 2018). In addition, the construction phase could involve up to 10,774 return trips (Ørsted, 2018) for installation, transport, support, dredging, and cable laying vessels. The Hornsea 3 environmental statement also summarized vessel movements expected from several proposed or approved offshore wind farms, most of which ranged between approximately 1,000 – 4,000 return trips per year. While these may be fixed turbines, it is possible that maintenance trips for floating offshore wind will be on the same order of magnitude. Thus, offshore wind development is likely to increase the chances of vessel strikes occurring with increased vessel traffic. There have been 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). Collisions with vessels greater than 80 m in length are usually either lethal or result in severe injuries (Laist et al. 2001). In addition, most ship strikes occur over or near the continental shelf. Collisions with vessels can cause major wounds on marine mammals and/or be fatal. Debilitating injuries may have negative effects on a population through impairment of reproductive output (MMS 2003).

Areal Range: *0 – 50 km*

The Areal Range minimum is assumed to be the shoreline (0 m) for the vessel strikes impact factor. This assumption is based on the potential for increased vessel traffic between the offshore turbines and the shore. The maximum areal range is based on the maximum reported depth at which OFW construction can/has occur(red). Maximum depth at which current OFW turbine technology could operate is approximately 1,000 m. In the areas requested for lease offshore of Hawaii and California, the 1,000-m depth contour occurs approximately 40 – 50 km from shore (Progression Hawaii Offshore Wind Inc. 2015, Trident Winds 2016). Therefore, the maximum areal range of vessel strike impacts extends from the 1,000-m depth contour distance shoreward.

Depth Range: *0 – 10 m*

The depth range of the vessel strike impact factor includes surface waters where vessels travel.

Impact Scale:

- Site Assessment – *Site-Specific*
- Construction – *Site-Specific*
- Operation and Maintenance - *Site-Specific*

Impact Duration:

- Site Assessment – *Short-Term*
- Construction – *Short-Term*
- Operation and Maintenance - *Chronic*

Current Level of Development: *None*

There is no existing large-scale OFW turbine farm on the OCS of the United States. Accordingly, current level of development is set as None for all ICFs.

Mitigation: Vessel strikes are a major concern regarding marine mammals. During all stages of OFW development (planning and siting, construction, operation, decommissioning), active observing and passive acoustic monitoring techniques can be used to reduce the potential for vessel strikes. However, because large OFW fields may aggregate vessel traffic outside of the operational area, there is an additional possibility of increased vessel strikes in the surrounding area. There are no mitigation plans to address this issue. 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, although vessel strikes causing injuries were still shown to occur at slower speeds.

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Appendix B: Species Scoring Tables

B.1 Species Impact Parameters

The impact parameter is assessed using the same general ecological themes across all three species groups; however, each theme is implemented in a manner appropriate to each group. The ecological themes used in the assessment of impact potential are:

- **Encounter** – likelihood of overlap with ICFs (ICF) based on behaviors such as escape behavior, time spent on the water surface, and attraction/avoidance responses to light/noise/chemicals. Species more likely to encounter a given ICF are assumed to be more sensitive. Because each respective ICF overlaps with species groups in unique ways, each interaction potential is assessed.
- **Concentration (Aggregation)** – the degree to which a species aggregates in a given location. Species that aggregate into large groupings are considered to be more vulnerable to certain ICFs because a large portion of the population could be affected at once.
- **Physiology** – reflects certain physiological characteristics (e.g., fur) or sensitivities that may affect the magnitude of impact.
- **Flexibility (Feeding Specificity)** – addresses how the effects of an ICF on lower trophic levels may affect the species of interest. A species that feeds in a very specific ecological niche is more vulnerable than a species that can readily switch between various forage items.

Each species group has a unique set of impact-scoring parameters that follow these ecological themes. For each individual species assessed, the impact parameters are scored on a 0 to 5 scale with 5 indicating the greatest negative impact potential from a spill and 0 indicating no impact. Assignments of impact potential scores are based on input from previous sensitivity models, ICF and species research, and professional judgement. Each impact potential assessment metric is set on the same 0 to 5 ranking scale, but the overall influence of an assessment metric is also scaled by the impact magnitude of the associated ICF. In instances where multiple scores are possible for a given species and parameter, the most conservative (i.e., greater number) score is assigned. As the model user/researcher assigns the impact potential assessment metric rank for a species, the selection is accompanied in the model database with a written rationale for the assignment as well as all related references. These notes and references are also held within the model database for future reference. The scoring schemes for each species group are detailed in the following sections.

Species are assessed based on vulnerability to eight ICFs)

- Accidental Spills (AS);
- Artificial Light (AL);
- Collisions with Above Surface Structures (CAS);
- Collisions with Subsurface Structures, Entanglement (CSE);
- Electromagnetic Fields (EMF);
- Habitat Disturbance/Displacement (HD);
- Sound/Noise (S/N); and
- Vessel Strikes (VS).

Although the eight ICFs were selected based on impacts to the three species groups, some do not apply to certain groups and were not included in the assessment metrics for that group (Table B-1). For example, EMF is an ICF of potential concern for fish and invertebrates because some of these species can detect electric and magnetic fields for orientation, navigation, and predator/prey detection (Normandeau et al.

2011). The addition of anthropogenic EMF from submarine cables associated with wind farms may disrupt the senses required for basic function (i.e., prey detection and predator avoidance) and negatively impact survival. The EMF ICF was only included in assessment metrics for fish and invertebrates because there is little evidence in the literature that marine mammals are electrosensitive, and therefore there is no associated impact to model. In addition, because EMF produced by submarine cables decreases with distance and are buried in the seafloor, there would be no impact to birds and bats flying above the surface.

Table B-1. ICFs that are assessed for each species group. "X" indicates that an ICF was assessed

Species Group	Assessed ICFs							
	AS	AL	CAS	CSE	EMF	HD	S/N	VS
Birds / Bats	X	X	X			X	X	
Marine Mammals / Sea Turtles	X	X		X		X	X	X
Fish / Invertebrates	X	X			X	X	X	X

Different scoring equations were developed for each ICF to capture all the impacts assessed in the metrics relevant to each ICF and species group. For example, the scoring equation for accidental spills impacts on birds and bats incorporated the species-specific rankings of the following assessment metrics: night roosting behavior (NR); feeding method (FM); avoidance behavior (MA); population aggregation behavior (AGG); and habitat flexibility (HF). The ICF score of accidental oil spills for NR of the surface seabird Scripps's murrelet was 5 because this species roosts on the water surface (was ranked '5' for this assessment metric, which translates to an AS score of 5 in the NR scoring table) and would be severely impacted by an oil spill on the water's surface. Note the night roosting behavior on the water surface would make Scripps's murrelet similarly vulnerable to impacts from artificial light and sound/noise, as well (Table B-2). The impact score for accidental spills was the sum of all the individual assessment metric ICF scores divided by the maximum impact score (sum of the highest impact score for all assessment metrics). In this example for Scripps's murrelet, the accidental spill equation was:

$$AS_{BB} = (NR\ (5) + MA\ (0) + \ FM\ (5) + AGG\ (3) + HF\ (3))/25;$$

and the raw AS score was 0.64 out of a maximum possible score of 1. In the model, this value is next multiplied by the impact magnitude for accidental spills during site assessment, construction, and operation and maintenance and those answers were summed for each ICF. The accidental spill impact score for Scripps's murrelet summed for all project phases was 5.18, out of a maximum hypothetical score of 8.10.

In comparison, the equation for bald eagle, a raptor that only occasionally interacts with the water's surface for feeding but not for roosting, was:

$$AS_{BB} = (NR\ (1) + MA\ (0) + FM\ (5) + AGG\ (1) + HF\ (1))/25;$$

and the raw AS score was 0.32. The accidental spill impact score for bald eagle summed for all project phases was 2.59, out of a maximum hypothetical score of 8.10. The difference in scores between these two bird species demonstrates the variation in ICF vulnerability based on their ecological niches.

Table B-2. Birds and bats night roosting 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) Nearly always roosts on offshore marine waters	Species nearly always roosts on offshore marine waters, with exceptions during breeding season.	5	5	--	--	--	--	5	--
(4) Roosts on shallow marine water nearshore or in nearshore habitats	Species actively roosts on shallow marine waters or nearshore habitats like marshes or mudflats.	3	1	--	--	--	--	1	--
(3) Spends minimal time roosting on marine waters	Species actively roosts on land but may spend a small amount of time roosting on marine waters.	1	2	--	--	--	--	2	--
(2) Never roosts on water	Species does not roost on marine waters in Study area.	0	0	--	--	--	--	0	--

Table B-3 provides a list of the different assessment metrics used to evaluate the four ecological themes (encounter, concentration, physiology, and flexibility) for each species group. Most of the remaining tables in this appendix contain scoring schemes designed to reflect generalized potential impacts from each individual ICF on each species. Finally, tables are provided for the impact scoring equations for each ICF and species grouping.

Table B-3. Impact parameters and metrics assessed for each species group

Species Group	Impact Parameter	Assessment Metric
Marine Mammals / Sea Turtles (MT)	Encounter	- Habitat Use (HU) - Macro-Avoidance/Attraction (MA) - Feeding Method (FM)
	Concentration	- Aggregation (AGG)
	Physiology	- Sensitive Features (SNF) - Sound Sensitivity (SS)
	Flexibility	- Habitat Flexibility
Birds / Bats (BB)	Encounter	- Time in Rotor Sweep Zone - Nocturnal Flight Activity - Diurnal Flight Activity - Macro-Avoidance/Attraction - Night Roosting - Feeding Method
	Concentration	- Aggregation
	Physiology	- Light Sensitivity
	Flexibility	- Habitat Flexibility
Fish / Invertebrates (FI)	Encounter	- Egg Location - Larval Location - Juvenile/Adult Location - Macro-Avoidance/Attraction - Movements - Feeding Method
	Concentration	- Aggregation
	Physiology	- Predator Detection - Prey Detection - Navigation/Migration - Sound Sensitivity
	Flexibility	- Habitat Flexibility

B.2 Marine Mammals / Sea Turtles Scoring Tables

B.2.1 MT – Encounter – Habitat Use (HU)

Table B-4. Marine mammal and sea turtle habitat use 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) Entire life history spent in marine habitats (water column) and species actively utilizes sediment habitat	Species uses pelagic water column and marine sediment as main habitat.	3	3	--	5	--	5	5	2
(4) Entire life history spent in marine habitats (water column) (no sediment use)	Species uses pelagic water column as main habitat. Water surface is used for breathing or occasional excursions only.	3	3	--	5	--	4	5	3
(3) All or large portion of time spent on water surface	Species maintains contact with water surface and/or uppermost water column (top few meters) for most of its daily activity.	5	5	--	4	--	3	5	5
(2) All or large portion of time spent on shoreline	Species actively utilizes shoreline, intertidal, and nearshore subtidal habitats for most of its daily activity.	4	1	--	2	--	2	1	1
(1) Life history not entirely dependent on marine/shoreline habitats	A portion of species life history is not dependent on marine habitats. May spend extensive amount of time inland.	1	1	--	1	--	1	1	1

The preferred habitat of a species directly associates that species with different parts of the water column and seabed. Each respective ICF affects different parts of the water column and seabed uniquely. Therefore, a species' preferred habitat may increase or decrease the likelihood of impact with a given impact factor. Greater scores are assigned to HU categories that increase encounter rates with given ICFs.

B.2.2 MT – Encounter – Macro-Avoidance / Attraction (MA)

Table B-5. Marine mammal and sea turtle macro-avoidance / attraction 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	5
(4) Somewhat attracted.	Species may be attracted to OFW, some evidence of slight attraction.	3	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	3
(2) Somewhat avoidant.	Species may avoid OFW, some evidence of slight avoidance.	2	2	--	2	--	3	2	2
(1) Highly avoidant.	Species avoids OFW or other offshore construction or structures at a high rate.	0	0	--	0	--	5	0	0

While research exploring the avoidance habits of marine mammals and turtles to OFW is still in its infancy, it remains an important concept to consider within the model. Species that have been found to actively avoid OFW are less likely to be negatively impacted by accidental spills, artificial light, subsea entanglements, and sound/noise. In contrast, species that actively avoid OFW are more adversely affected by habitat disturbance/displacement. This Assessment Metric has been derived directly from Adams et al. (2016) as designed for bird impacts.

B.2.3 MT – Encounter – Feeding Method (FM)

Table B-6. Marine mammal and sea turtle feeding method 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) Feeds at surface.	Species feeds at the water surface and/or uppermost water column (top few meters).	5	5	--	--	--	5	5	--
(4) Filter feeder (water column).	Species utilizes filter-feeding strategies to extract plankton from water column.	3	3	--	--	--	3	3	--
(3) Forages in benthic sediments.	Species extracts infauna from or grazes algae/seaweed on benthic substrates.	1	1	--	--	--	1	1	--
(2) Pelagic piscivore.	Species is a pelagic piscivore or pelagic scavenger.	1	1	--	--	--	3	3	--

The feeding method employed by a species directly informs both where in the water column a species will be foraging as well as what OFW ICFs may directly impact that species' feeding methods. Species feeding directly at the surface or within the water column are more detrimentally impacted by habitat disturbance/displacement than those species primarily occupying benthic habitats because the turbines occupy the uppermost water column. Accidental spills, artificial light, and sound/noise are most likely to negatively impact species that feed at the surface due to increased encounter rate from proximity to the turbines. 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 or anchor tethers), there is inadequate research to distinguish differences among feeding methods and correlations with entanglements.

B.2.4 MT – Concentration – Aggregation (AGG)

Table B-7. Marine mammal and sea turtle aggregation assessments for concentration impact during all project phases

Ranking Score - Category	Category Description	ICF Scores							
		AS	AL	CAS	CSE	EMF	HD	S/N	VS
(5) Forms persistent large aggregations in Study area	While in Study area, species forms persistent large colonies or aggregations.	5	--	--	5	--	--	5	5
(4) Forms persistent small aggregations or seasonal/ transient aggregations in Study area	While in Study area, species forms persistent small aggregations or seasonal (usually breeding- or feeding-related) colonies or aggregations. Large colonies/aggregations do not persist throughout the year.	3	--	--	3	--	--	3	3
(3) Solitary or mostly solitary in Study area	While in Study area, species is solitary, or forms very small transient groups.	1	--	--	1	--	--	1	1

Species that form large aggregations are more likely to be significantly impacted by accidental spills (Niedoroda et al. 2014), entanglements, sound/noise, and vessel strikes because these events can displace, injure, or kill a substantial proportion of the population all at once (Jensen and Silber 2003). Species that are more solitary are less likely to have population level impacts from OFW.

B.2.5 MT – Physiology – Sensitive Features (SNF)

Table B-8. Marine mammals and sea turtles sensitive feature assessments for physiology impact during all project phases

Ranking Score - Category	Category Description	ICF Scores							
		AS	AL	CAS	CSE	EMF	HD	S/N	VS
(5) Uses fur for thermoregulation	Species uses fur as a primary mean of thermoregulation.	5	--	--	--	--	--	--	--
(4) Does not use fur for thermoregulation	Species does not use fur as a primary mean of thermoregulation.	0	--	--	--	--	--	--	--
(3) Echolocation or sound reliance	Species uses echolocation or is otherwise reliant on sound for feeding, communication, or travel.	--	--	--	5	--	--	5	--
(2) No echolocation or sound reliance	Species does not use echolocation or other sounds for feeding, communication, or travel.	--	--	--	0	--	--	0	--

The physiology of a species may affect how that species is impacted by OFW. Fur-bearing marine mammals have been shown to be more significantly impacted by oil and chemical spills than those that do not use fur for thermal regulation (Hansen 1985). Species that utilize echolocation or other sounds for feeding, communication, or travel are more likely to be vulnerable to sound/noise effects and may have increased potential for entanglements when 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 obstacles in time to avoid them (Wilson et al., 2007).

B.2.6 MT – Physiology – Sound Sensitivity (SS)

Table B-9. Marine mammals and sea turtles sound sensitivity assessments for physiology impact during Operation and Maintenance phase only

Ranking Score - Category	Category Description	ICF Scores							
		AS	AL	CAS	CSE	EMF	HD	S/N	VS
(5) Low-frequency cetacean	Baleen whales, assumed to have a generalized hearing range of 7 Hz to 35 kHz	--	--	--	--	--	--	5	--
(4) Mid-frequency cetacean	Dolphins, toothed whales, beaked whales, bottlenose whales, assumed to have a generalized hearing range of 150 Hz to 160 kHz	--	--	--	--	--	--	3	--
(3) High-frequency cetacean	True porpoises, *Kogia*, river dolphins, cephalorhynchid, and hourglass and Peale's dolphins, assumed to have a generalized hearing range of 275 Hz to 160 kHz	--	--	--	--	--	--	1	--
(2) Phocid pinniped	True seals, assumed to have a generalized hearing range of 50 Hz to 86 kHz	--	--	--	--	--	--	5	--
(1) Otariid pinniped	Sea lions and fur seals, assumed to have a generalized hearing range of 60 Hz to 39 kHz	--	--	--	--	--	--	5	--
(0) Sea turtle	Sea turtles, assumed to have a generalized hearing range of 100 to 800 Hz, with an upper limit of 2 kHz	--	--	--	--	--	--	3	--

Hearing ranges from Popper et al., (2014) and NMFS (2016).

Sound sensitivity varies between species, and can dictate how impacted a species will be to underwater anthropogenic noise. Artificial noise created by increased vessel traffic and turbines in OFW areas may lead to avoidance behaviors or mask biologically important noises, potentially reducing breeding and foraging abilities of some species (Thomsen et al. 2006). Species that can hear lower frequency sounds below 100 Hz, like baleen whales and pinnipeds, are likely to be more vulnerable to OFW noise because turbines emit low frequency noise over the life of the project and may mask communication; however, noise impact assessment involves a lot of uncertainty (Farcas et al., 2016).

B.2.7 MT – Habitat Flexibility – Habitat Flexibility (HF)

Table B-10. Marine mammal and sea turtle habitat flexibility assessments for trophic impact during Operation and Maintenance phase only

Ranking Score - Category	Category Description	ICF Scores							
		AS	AL	CAS	CSE	EMF	HD	S/N	VS
(5) Highly specialized (narrow)	Species has very habitat- and prey-specific requirements and little flexibility in foraging range, foraging behavior, habitat selection, or diet.	5	--	--	--	--	5	--	--
(4) Moderately adaptable	Species shoes some grade of behavior between highly specialized and generalist.	3	--	--	--	--	3	--	--
(3) Generalist	Species uses a wide range of foraging habitats over a large area. Species is an opportunistic forager and has the ability to switch among prey types based on availability.	1	--	--	--	--	1	--	--

Marine mammals and sea turtles exhibit varying degrees of habitat flexibility. Some species depend on specific prey in specific locations, while others have high habitat flexibility and are generalists. Species with highly specialized habitat and prey needs are more likely to be negatively impacted by OFW than generalist species. This metric has been directly adapted from Adams et al. 2016.

B.2.8 MT – Scoring Equations

Table B-11. Marine mammal and sea turtle impact potential scoring equations for each ICF

ICF	Scoring Equation
AS	$AS_{MMT} = (HU + MA + FM + AGG + SNF + HF)/30$
AL	$AL_{MMT} = (HU + MA + FM)/15$
CAS	--
CSE	$CSE_{MMT} = (HU\ + MA + AGG + SNF)/20$
EMF	--
HD	$HD_{MMT} = (HU + MA + FM + HF)/20$
S/N	$SN_{MMT} = (FM + HU + MA + AGG + SNF + SS)/30$
VS	$VS_{MMT} = (HU + MA + AGG\ )/15$

B.3 Birds / Bats Scoring Tables

B.3.1 BB – Encounter – Rotor Sweep Zone (RSZ)

Table B-12. Birds and bats percent of time in rotor sweep zone assessments for encounter impact during Operation and Maintenance phase only

Ranking Score - Category	Category Description	ICF Scores							
		AS	AL	CAS	CSE	EMF	HD	S/N	VS
(5) >20 Percent	Species frequently travels at height of turbine blades	--	5	5	--	--	--	5	--
(4) 5-20 Percent	Species infrequently travels at height of turbine blades	--	4	3	--	--	--	4	--
(3) <5 Percent	Species rarely or never travels at height of turbine blades	--	1	1	--	--	--	1	--
(2) ~0 Percent	All or large portion of time spent on shoreline	--	1	0	--	--	--	1	--

The amount of time a bird spends flying at the same height as the sweeping zone of the turbine blades will influence its probability of collision. This assessment metric has been modified from Adams et al. (2016) to also include impacts related to Artificial Light and Sound/Noise. Bird species that frequently migrate or forage over water at heights between 0 and 200 m will be the most at risk for collision or disturbance from artificial light and noise. Alternatively, if a bird species spends all or most of its time onshore, there would be no risk of collision with rotor sweep; however, there still may be slight disturbance from artificial light and noise onshore. Due to the large variability in percentage of time spent in the RSZ, data uncertainty is likely high for this metric for all species assessed.

B.3.2 BB – Encounter – Nocturnal Flight Activity (NFA)

Table B-13. Birds and bats nocturnal flight activity assessments for encounter impact during Operation and Maintenance phase only

Ranking Score - Category	Category Description	ICF Scores							
		AS	AL	CAS	CSE	EMF	HD	S/N	VS
(5) 0-20 Percent	A very low percentage of time spent flying/migrating during night hours.	--	1	1	--	--	--	--	--
(4) 21-40 Percent	A low percentage of time spent flying/migrating during night hours.	--	2	2	--	--	--	--	--
(3) 41-60 Percent	A moderate percentage of time spent flying/migrating during night hours.	--	3	3	--	--	--	--	--
(2) 61-80 Percent	A high percentage of time spent flying/migrating during night hours.	--	4	4	--	--	--	--	--
(1) 81-100 Percent	A very high percentage of time spent flying/migrating during night hours.	--	5	5	--	--	--	--	--

The amount of time that a species spends in flight during nighttime hours has been associated with its collision vulnerability (see review in Adams et al. 2016). This assessment metric has been modified from Adams et al. (2016) to also include impacts related to Artificial Light. Collisions caused by reduced visibility at night and navigational confusion induced by artificial lights on turbines will most severely impact bird species that frequently travel at night.

B.3.3 BB – Encounter – Diurnal Flight Activity (DFA)

Table B-14. Birds and bats diurnal flight activity assessments for encounter impact during Operation and Maintenance phase only

Ranking Score - Category	Category Description	ICF Scores							
		AS	AL	CAS	CSE	EMF	HD	S/N	VS
(5) 0-20 Percent	A very low percentage of time spent flying/migrating during daylight hours.	--	--	1	--	--	--	--	--
(4) 21-40 Percent	A low percentage of time spent flying/migrating during daylight hours.	--	--	2	--	--	--	--	--
(3) 41-60 Percent	A moderate percentage of time spent flying/migrating during daylight hours.	--	--	3	--	--	--	--	--
(2) 61-80 Percent	A high percentage of time spent flying/migrating during daylight hours.	--	--	4	--	--	--	--	--
(1) 81-100 Percent	A very high percentage of time spent flying/migrating during daylight hours.	--	--	5	--	--	--	--	--

The amount of time that a species spends in flight during daylight hours has been associated with its collision vulnerability (see review in Adams et al. 2016). This assessment metric has been derived directly from Adams et al. (2016). When calculating the CAS metric, DFA contributes 50% as much to the final score compared with NFA as it is assumed species avoidance capabilities are greater during the daylight.

B.3.4 BB – Encounter – Macro-Avoidance / Attraction (MA)

Table B-15. 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	--

Numerous studies in recent years have increased our knowledge of seabird avoidance of OFW (see review in Adams et al. 2016). Species that have been found to actively avoid OFW are less likely to be negatively impacted by collisions with rotors. In contrast, species that actively avoid OFW are more adversely affected by habitat disturbance/displacement. This assessment metric has been derived directly from Adams et al. (2016).

B.3.5 BB – Encounter – Night Roosting (NR)

Table B-16. Birds and bats night roosting 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) Nearly always roosts on offshore marine waters	Species nearly always roosts on offshore marine waters, with exceptions during breeding season.	5	5	--	--	--	--	5	--
(4) Roosts on shallow marine water nearshore or in nearshore habitats	Species actively roosts on shallow marine waters or nearshore habitats like marshes or mudflats.	3	1	--	--	--	--	1	--
(3) Spends minimal time roosting on marine waters	Species actively roosts on land but may spend a small amount of time roosting on marine waters.	1	2	--	--	--	--	2	--
(2) Never roosts on marine waters	Species does not roost on marine waters.	0	0	--	--	--	--	0	--

Species that roost at night on marine waters are more likely to be negatively impacted by accidental spills, artificial lighting, and sound/noise. Surface slicks from accidental spills are more likely to impact species that roost on the water surface, especially in large groups, due to greater chance of encounter. Likewise, the negative impact of artificial light and sound/noise will be particularly emphasized for those species that roost at night near turbines due to increased exposure.

B.3.6 BB – Encounter – Feeding Method (FM)

Table B-17. Birds and bat feeding method 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) Feeds from surface waters (< 10 m deep)	Species feeds at the water surface and/or uppermost water column (top 10 meters).	5	5	--	--	--	5	5	--
(4) Dives below surface to feed from deeper portions of the water column (> 10 m deep)	Species dives below the surface to feed from deeper portions of the water column or benthos.	3	4	--	--	--	4	4	--
(3) Forages in intertidal sediments	Species extracts infauna from intertidal sediments (disturbs substrate).	1	1	--	--	--	1	1	--
(2) Does not forage from estuarine or marine habitat	Species feeds primarily over land or from freshwater sources.	0	0	--	--	--	0	0	--

The feeding method employed by a species directly informs both where on the surface or in the water column a species will be foraging as well as what OFW ICFs may directly impact that species’ feeding methods. Species feeding directly at the surface or diving below the surface to feed on benthos are more detrimentally impacted by habitat disturbance than those species primarily feeding in intertidal areas or over land. Accidental spills and artificial light are most likely to negatively impact species that feed on surface waters offshore by increasing the encounter rate.

B.3.7 BB – Concentration – Aggregation (AGG)

Table B-18. Birds and bat aggregation assessments for concentration impact during all project phases

Ranking Score - Category	Category Description	ICF Scores							
		AS	AL	CAS	CSE	EMF	HD	S/N	VS
(5) Forms persistent large aggregations in Study area	While in Study area, species maintains large flocks or colonies.	5	5	5	--	--	--	5	--
(4) Forms persistent small aggregations or seasonal/ transient aggregations in Study area	While in Study area, species forms persistent small flocks or seasonal (usually breeding- or feeding-related) colonies. Large flocks/colonies do not persist year-round.	3	3	3	--	--	--	3	--
(3) Solitary or mostly solitary in Study area	While in Study area, species is solitary, or forms very small transient groups.	1	1	1	--	--	--	1	--

Species that form large aggregations offshore are more likely to be significantly impacted by accidental spills (Niedoroda et al. 2014), artificial light, collisions, and sound/noise because these events can displace, injure, or kill a substantial proportion of the population at once. Species that are more solitary are less likely to have population level impacts from OFW. For instance, communication is likely more important in large aggregations and communication cues, like predator alarm calls, may be masked by turbine noise.

B.3.8 BB – Physiology – Light Sensitivity (LS)

Table B-19. Bird and bat sensitive feature assessments for physiology impact during Operation and Maintenance phase only

Ranking Score - Category	Category Description	ICF Scores							
		AS	AL	CAS	CSE	EMF	HD	S/N	VS
(5) Species forages for bioluminescent prey or makes nocturnal migrations over marine water using celestial patterns	While in Study area, species forages for bioluminescent prey and/or makes nocturnal flights (for foraging or breeding purposes) over marine waters using celestial patterns to navigate.	--	5	5	--	--	5	--	--
(4) Species makes nocturnal migrations but use of celestial patterns is unknown, or bioluminescent prey only small part of diet	While in Study area, species makes nocturnal flights (for foraging or breeding purposes) but use of celestial patterns for navigation is unknown -or the proportion of the species diet which consists of bioluminescent prey is low or unknown.	--	3	3	--	--	3	--	--
(3) Does not make major migrations or consume bioluminescent prey	While in Study area, species does not make nocturnal flights or forage for bioluminescent prey.	--	0	0	--	--	0	--	--

Species that rely on light cues for foraging or navigation are more likely to be impacted by artificial light, collision, and habitat disturbance. Attraction to artificial light has been documented in bird species that forage for bioluminescent prey or that use celestial patterns during nocturnal migrations (Montevecchi 2006). Bird species that are attracted to signaling lights on turbines have increased risk of collision and often get lost or disoriented during migrations.

B.3.9 BB – Habitat Flexibility – Habitat Flexibility (HF)

Table B-20. Birds and bats habitat flexibility assessments for trophic impact during Operation and Maintenance phase only

Ranking Score - Category	Category Description	ICF Scores							
		AS	AL	CAS	CSE	EMF	HD	S/N	VS
(5) Highly specialized (narrow)	Species has very habitat- and prey-specific requirements and little flexibility in foraging range, foraging behavior, habitat selection, or diet.	5	--	--	--	--	5	--	--
(4) Moderately adaptable	Species shoes some grade of behavior between highly specialized and generalist.	3	--	--	--	--	3	--	--
(3) Generalist	Species uses a wide range of foraging habitats over a large area. Species is an opportunistic forager and has the ability to switch among prey types based on availability.	1	--	--	--	--	1	--	--

Seabirds exhibit varying degrees of habitat flexibility. Some species depend on specific prey in specific locations, while others have high habitat flexibility and are generalists. Species with highly specialized habitat and prey needs are more likely to be negatively impacted by OFW than generalist species. This metric has been directly adapted from Adams et al. (2016).

B.3.10 BB – Scoring Equations

Table B-21. Birds and bats impact potential scoring equations for each ICF

ICF	Scoring Equation
AS	$AS_{BB} = (NR + MA + FM + AGG + HF)/25$
AL	$AL_{BB} = (RSZ + NFA + NR + MA + FM + AGG + LS)/35$
CAS	$CAS_{BB} = ((\frac{(2 * NFA) + DFA}{3}) + RSZ + MA + AGG + LS)/25$
CSE	--
EMF	--
HD	$HD_{BB} = (FM + HF + MA + LS)/20$
S/N	$SN_{BB} = (RSZ + MA + NR + FM + AGG)/25$
VS	--

B.4 Fish / Invertebrates Scoring Tables

B.4.1 FI – Encounter – Egg Location (EL)

Table B-22. Fish and invertebrate egg location 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) Neustonic	Eggs are primarily neustonic or often in the surface waters, occupying the top 50 m (i.e., wave mixing zone).	5	--	--	--	--	1	--	--
(4) Estuarine/brackish	Eggs occupy estuarine waters or river mouths.	1	--	--	--	--	1	--	--
(3) Epipelagic	Eggs are buoyant and occupy the upper water column, but primarily below the mixing zone (~50–200 m).	3	--	--	--	--	1	--	--
(2) Pelagic	Eggs are neutrally buoyant and occupy the mid-water column (below 200 m).	0	--	--	--	--	0	--	--
(1) Demersal or semi-demersal	Eggs are semi-demersal, demersal, or adhered to benthic substrates in subtidal habitats.	0	--	--	--	--	3	--	--
(0) In freshwater or life stage not applicable	Species does not have an external egg life stage, or eggs occupy freshwater environments.	0	--	--	--	--	0	--	--

The habitat location of fish and invertebrate egg deposition directly associates that species with different parts of the water column and seabed. Each respective ICF affects different parts of the water column and seabed uniquely, accidental spills from OFW are most likely to originate as surface spills and would therefore most prominently impact neustonic eggs (BOEM 2012). Therefore, a species preferred habitat may increase or decrease the likelihood of impact with a given impact factor.

B.4.2 FI – Encounter – Larval Location (LL)

Table B-23. Fish and invertebrate larval location 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) Neustonic	Larvae are primarily neustonic or often in the surface waters, occupying the top 50 m (i.e., wave mixing zone).	5	5	--	--	1	1	--	--
(4) Estuarine/brackish	Larvae occupy estuarine waters or river mouths.	1	0	--	--	1	1	--	--
(3) Epipelagic	Larvae occupy the upper water column, but primarily below the mixing zone (~50–200 m).	3	3	--	--	0	1	--	--
(2) Pelagic	Larvae mainly occupy the mid-water column (below 200 m).	0	0	--	--	0	0	--	--
(1) Demersal or semi-demersal	Larvae are semi-demersal, demersal, or benthic in subtidal habitats.	0	0	--	--	3	3	--	--
(0) In freshwater or life stage not applicable	Species does not have a larval life stage, or larvae occupy freshwater environments.	0	0	--	--	0	0	--	--

The preferred habitat of a species larval stage directly associates that species with different parts of the water column and seabed. Each respective ICF affects different parts of the water column and seabed uniquely, therefore a species' preferred habitat may increase or decrease the likelihood of impact with a given impact factor. Accidental spills from OFW are most likely to originate as surface spills and would therefore most prominently impact neustonic larvae (BOEM 2012). Some larval fish species undergo daily vertical migrations that are typically cued by photosensitive responses to day and night. Artificial light from turbines could confuse these migratory responses and lead to migrations that occur outside of the optimal window for that species (Gibson et al. 2001). In addition, because EMF produced by submarine cables decreases with distance, only larval fish that directly utilize demersal habitats are likely to be impacted (Normandeau et al. 2011).

B.4.3 FI – Encounter – Juvenile / Adult Location (JAL)

Table B-24. Fish and invertebrate juvenile\adult location 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) Neustonic	Juveniles/adults are neustonic.	5	5	--	--	1	1	--	--
(4) Estuarine/brackish	Juveniles/adults occupy estuarine waters or river mouths.	1	0	--	--	1	1	--	--
(3) Epipelagic	Juveniles/adults mainly occupy the upper water column (0–200 m).	3	3	--	--	0	1	--	--
(2) Pelagic	Juveniles/adults mainly occupy the mid-water column (below 200 m).	0	0	--	--	0	0	--	--
(1) Demersal or semi-demersal	Juveniles/adults are semi-demersal, demersal, or benthic in subtidal habitats.	0	0	--	--	5	3	--	--
(0) In freshwater	Juveniles/adults exclusively occupy freshwater environments.	0	0	--	--	0	0	--	--

The preferred habitat of a species’ adult stage directly associates that species with different parts of the water column and seabed. Each respective ICF affects different parts of the water column and seabed uniquely; therefore, a species’ preferred habitat may increase or decrease the likelihood of impact with a given impact factor. Accidental spills from OFW are most likely to originate as surface spills and would therefore most prominently impact neustonic fish (BOEM 2012). Neustonic fish species are also more likely to be negatively impacted from surface originating artificial light. EMF will most prominently impact demersal fish species as marine cables will be laid on the seafloor.

B.4.4 FI – Encounter – Macro-Avoidance / Attraction (MA)

Table B-25. Fish and invertebrate macro-avoidance/attraction 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	--
(4) Somewhat attracted.	Species may be attracted to OFW, some evidence of slight attraction.	3	3	--	--	--	3	3	--
(3) Neither attracted nor avoidant.	Species is neither attracted to nor avoids OFW, or status is unknown.	3	3	--	--	--	0	3	--
(2) Somewhat avoidant.	Species may avoid OFW, some evidence of slight avoidance.	2	2	--	--	--	3	2	--
(1) Highly avoidant.	Species avoids OFW or other offshore construction or structures at a high rate.	0	0	--	--	--	5	0	--

The introduction of floating turbines in offshore areas would change open-water habitat from non-structure oriented to a structure oriented system. Pelagic fish species that associate with structure will be more attracted to OFW than demersal or avoidant species. Fish species that are attracted to the turbines are more likely to be significantly impacted by accidental spills, artificial light, and sound/noise. In addition, turbines may attract increase predator concentration and reduce the amount of safe habitat for some species. Species that are highly avoidant to artificial structure are less likely to be impacted by accidental spills, artificial light or sound/noise but would lose habitat and be displaced from the OFW areas.

B.4.5 FI – Encounter – Movement (MV)

Table B-26. Fish and invertebrate movement 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) Drifting/planktonic	Species is incapable, or minimally capable, of directed swimming, and drifts with ocean currents.	4	5	--	--	--	--	--	--
(4) Stationary	Species is stationary on the seafloor.	5	0	--	--	--	--	--	--
(3) Slow moving	Species swims slowly or moves only small distances.	3	3	--	--	--	--	--	--
(2) Fast moving or large home range	Species is fast-swimming, or has a large home range.	1	1	--	--	--	--	--	--

A species' ability, or lack of ability to move directly affects that species' ability to avoid an ICF. Immobile (stationary) species are incapable of avoiding ICFs. Likewise, those species that are planktonic are more likely to spend increased amounts of time in contact with ICFs at the surface. Fast-moving species or species with large home ranges will be less impacted because they can avoid impacted areas.

B.4.6 FI – Encounter – Feeding Method (FM)

Table B-27. Fish and invertebrate feeding method 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) Surface/pelagic filter feeding planktivore	Species utilizes filter-feeding strategies to extract plankton from the upper water column (e.g., whale shark, sunfish)	5	5	--	--	1	5	--	--
(4) Sessile filter feeder	Species utilizes filter-feeding strategies to extract plankton from the water (e.g., mollusks, coral)	5	0	--	--	3	3	--	--
(3) Pelagic non-filter feeder	Feeds on plankton, fish, and invertebrates from within water column (e.g., jellyfish, herring).	3	3	--	--	1	2	--	--
(2) Non-filter feeding benthic planktivore, piscivore, or scavenger	Species feeds in deeper water near the seafloor (e.g., crabs, flatfish).	1	0	--	--	5	3	--	--

Where and how a fish or invertebrate species feeds may increase or decrease the likelihood of impact with a given impact factor. Filter feeding planktivores are most likely to come into contact with accidental spill and artificial light ICFs, while species that forage in benthic sediments are more likely to be impacted by habitat disturbance and EMF.

B.4.7 FI – Concentration – Aggregation (AGG)

Table B-28. Fish and invertebrate aggregation assessments for concentration impact during all project phases

Ranking Score - Category	Category Description	ICF Scores							
		AS	AL	CAS	CSE	EMF	HD	S/N	VS
(5) Forms persistent large aggregations in Study area	While in Study area, species maintains large schools or aggregations.	5	5	--	--	--	5	5	--
(4) Forms persistent small aggregations or seasonal/ transient aggregations in Study area	While in Study area, species forms persistent small aggregations/schools or seasonal (usually breeding- or feeding-related) aggregations/schools. Large aggregations/schools do not persist throughout the year.	3	3	--	--	--	3	3	--
(3) Solitary or mostly solitary in Study area	While in Study area, species is solitary, or forms very small transient groups.	1	1	--	--	--	1	1	--

Species that form large aggregations are both more likely to be impacted individually and at a population scale by accidental spills (Niedoroda et al. 2014), artificial light, habitat disturbance/displacement, and sound/noise, due to a greater number of individuals impacted at the same time. Species that are more solitary are less likely to have population level impacts from OFW.

B.4.8 FI – Physiology – Predatory Detection (PDR)

Table B-29. Fish and invertebrate predator detection assessments for physiology impact during Operation and Maintenance phase only

Ranking Score - Category	Category Description	ICF Scores							
		AS	AL	CAS	CSE	EMF	HD	S/N	VS
(5) Reduced Predator Detection	Species has been documented as being negatively impacted by EMF to avoid predators.	--	--	--	--	5	--	--	--
(4) No Data - Predator Detection	No data is available noting reduced predator avoidance capabilities due to EMF. However, species uses mechanisms for predator avoidance similar to those of species that have been documented as having negative impacts from EMF.	--	--	--	--	3	--	--	--
(3) No Negative Impact - Predator Detection	Species has been identified as not negatively impacted by EMF regarding predator detection, OR no data is available noting reduced predator avoidance capabilities due to EMF and species does not use mechanisms for predator avoidance similar to those of species that have been documented as having negative impacts from EMF.	--	--	--	--	0	--	--	--

Some fish species, including elasmobranchs, 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).

B.4.9 FI – Physiology – Prey Detection (PRY)

Table B-30. Fish and invertebrates prey detection assessments for physiology impact during Operation and Maintenance phase only

Ranking Score - Category	Category Description	ICF Scores							
		AS	AL	CAS	CSE	EMF	HD	S/N	VS
(5) Reduced Prey Detection	Species has been documented as being negatively impacted by EMF to locate and/or catch prey.	--	--	--	--	5	--	--	--
(4) No Data - Prey Detection	No data is available noting reduced prey detection capabilities due to EMF. However, species uses mechanisms for prey detection similar to those of species that have been documented as having negative impacts from EMF.	--	--	--	--	3	--	--	--
(3) No Negative Impact - Prey Detection	Species has been identified as not negatively impacted by EMF regarding prey detection, OR no data is available noting reduced prey detection capabilities due to EMF and species does not use mechanisms for prey detection similar to those of species that have been documented as having negative impacts from EMF.	--	--	--	--	0	--	--	--

Some fish species, including elasmobranchs, 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).

B.4.10 FI – Physiology – Navigation / Migration (NAV)

Table B-31. Fish and invertebrate navigation and migration assessments for physiology impact during Operation and Maintenance phase only

Ranking Score - Category	Category Description	ICF Scores							
		AS	AL	CAS	CSE	EMF	HD	S/N	VS
5- Reduced Navigation/Migration	Species has been documented as being negatively impacted by EMF to navigate and/or migrate.	--	--	--	--	5	--	--	--
4- No Data – Navigation/Migration	No data is available noting reduced navigation/migration capabilities due to EMF. However, species uses mechanisms for navigation/migration similar to those of species that have been documented as having negative impacts from EMF.	--	--	--	--	3	--	--	--
3- No Negative Impact - Navigation/Migration	Species has been identified as not negatively impacted by EMF regarding navigation/migration, OR no data is available noting reduced navigation/migration capabilities due to EMF and species does not use mechanisms for navigation/migration similar to those of species that have been documented as having negative impacts from EMF.	--	--	--	--	0	--	--	--

Some fish species, including elasmobranchs, 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).

B.4.11 FI – Physiology – Strike Risk (SR)

Table B-32. Fish and invertebrate vessel strike risk assessments for physiology impact during all project phases

Ranking Score - Category	Category Description	ICF Scores							
		AS	AL	CAS	CSE	EMF	HD	S/N	VS
(5) At risk of vessel strikes	Large, slow-moving, or surface-dwelling species with documented occurrences of vessel strikes.	--	--	--	--	--	--	--	5
(4) Little to no vessel interactions or effects	Small, agile, deep-dwelling species or others with populations unlikely to be majorly affected by contact with vessels.	--	--	--	--	--	--	--	0

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 and sharks and the increased vessel traffic associated with OFW could impact these species when present in the study areas (Brown and Murphy 2010; Towner et al. 2012).

B.4.12 FI – Physiology – Sound Sensitivity (SS)

Table B-33. Fish and invertebrate sound sensitivity assessments for physiology impact during Operation and Maintenance phase only

Ranking Score - Category	Category Description	ICF Scores							
		AS	AL	CAS	CSE	EMF	HD	S/N	VS
(5) Hearing specialist	Fish with a swim bladder and specialized structures mechanically linking it to the ear (e.g., carp, catfish, herrings, some drums and croakers)	--	--	--	--	--	--	5	--
(4) Hearing generalist	Fish that do perceive noise but not as strongly as a hearing specialist, swim bladders filled with air but are not connected to inner ear (e.g., cod, eel, some drums and croakers)	--	--	--	--	--	--	3	--
(3) Hearing non-specialist, or hearing unknown	Fish with swim bladders that contain little air and do not play a role in hearing (e.g., salmon, some tuna); or fish with no swim bladders (e.g., flatfish, sharks, rays); or invertebrates with little known about their hearing abilities.	--	--	--	--	--	--	0	--

Fish and invertebrates experience sound as particle motion as well as pressure, and hearing sensitivity is difficult to determine and likely varies greatly between species (Hawkins and Popper 2017). Fish have been divided into groups of potential hearing abilities based on their anatomy. Fishes with swim bladders involved in hearing, such as cod, will be more sensitive to anthropogenic noises than fish that do not have swim bladders, like flatfish (Wahlberg and Westerberg 2005; Popper et al. 2014). Most crustacean species lack swim bladders and are considered less sensitive to sound, though they have shown sensitivity to sound transmitted through substrate; resolution of information on invertebrates and sound is coarse (Edmonds et al. 2016; Hawkins and Popper 2017) Continuous noise from vessels and turbines can cause avoidance behavior that can interfere with feeding and breeding, alter schooling behaviors and migration patterns, and mask important environmental auditory cues (CBD 2012; Barber 2017).

B.4.13 FI – Habitat Flexibility – Habitat Flexibility (HF)

Table B-34. Fish and invertebrate habitat flexibility assessments for trophic impact during Operation and Maintenance phase only

Ranking Score - Category	Category Description	ICF Scores							
		AS	AL	CAS	CSE	EMF	HD	S/N	VS
(5) Highly specialized (narrow)	Species has very habitat- and prey-specific requirements and little flexibility in foraging range, foraging behavior, habitat selection, or diet.	5	--	--	--	--	5	--	--
(4) Moderately adaptable	Species shoes some grade of behavior between highly specialized and generalist.	3	--	--	--	--	3	--	--
(3) Generalist	Species uses a wide range of foraging habitats over a large area. Species is an opportunistic forager and has the ability to switch among prey types based on availability.	1	--	--	--	--	1	--	--

Fish and invertebrate species exhibit varying degrees of habitat flexibility. Some species depend on specific prey in specific locations, while others have high habitat flexibility and are generalists. Species with highly specialized habitat and prey needs are more likely to be negatively impacted by OFW than generalist species.

B.4.14 – Scoring Equations

Table B-35. Fish and invertebrate impact potential scoring equations for each ICF

ICF	Scoring Equation
AS	$AS_{FI} = (EL + LL + JAL + MA + MV + FM + AGG + HF)/40$
AL	$AL_{FI} = (LL + JAL + FM + AGG + MA + MV)/30$
CAS	--
CSE	--
EMF	$EMF_{FI} = (\left(\frac{(PDR + PRY + NAV)}{3}\right) + FM + LL + JAL)/20$ *If PDR+PRY+NAV=0, no impact
HD	$HD_{FI} = (AGG + EL + LL + JAL + FM + MA + HF)/35$
S/N	$SN_{FI} = (SS + MA + AGG)/15$
VS	$SR_{FI} = (SR)/5$

B.5 Species Recovery Parameters

The recovery potential score assesses how quickly a species population would be able to recover in the event of an incident. This is an important counterpoint to the impact-scoring, as certain species may suffer a large impact from a given ICF, but are less vulnerable overall if they can recover quickly due to large population numbers and high fecundity rates (e.g., euphausiids). In contrast, the loss of just a few individuals from a depleted, late-maturity/low fecundity species could result in a substantial long-term impact to a population (e.g., certain whale species).

Five parameters are used for recovery potential. These three parameters are applied to all three species groups:

1. **Conservation/population status** – species with greatly reduced breeding population numbers are compromised in their ability to recover from an impact. This parameter uses special conservation status as a proxy for population status. Species designated as endangered or threatened in the study area are of particular regulatory and conservation concern and could be jeopardized by OFW construction and operation. Conversely, non-listed species with "healthy" population levels are likely the most capable of recovering from an OFW impact.
2. **Reproductive potential** – the reproductive capacity of individuals of a species is a key contributor to population recovery. If individuals have low reproductive capacity, the population would likely be slow to recover from adverse impacts, even if population levels are relatively high. Species with low fecundity rates and late maturation exhibit reduced recovery potential relative to other species, and are therefore considered to be more vulnerable. Species exhibiting relatively high reproductive capacity are inherently more capable of population recovery from adverse OFW impacts and are considered to be less vulnerable.
3. **Range when in study area** – the geographic range inhabited by a species is related to the proportion of a population that may be adversely affected by OFW in the study area. A species endemic to a study area is considered to be at relatively greater risk than a species with a global distribution. The geographic range of a species is also related to the population's relative ability to recolonize an area after significant adverse effects; however, this parameter only addresses recolonization potential in broad terms, as assessing population connectivity is beyond the scope of this project. This parameter is assessed only for the time period in which the species is present within a study area. For example, during the summer, most of the population of California sea lions is found in Southern California and Baja, so the species is given a score of 4 for the range parameter, despite the fact that it is found in across a broader range during fall and winter seasons.
4. **Adult survival rate** – the survival rate of adult individuals is a key contributor to population recovery as it is indicative of life history characteristics. Species with higher survival rates experience lower natural mortality (M) than those species with lower adult survival rates. Species with high adult survival rates often have slow growth rates, low fecundity, and expend large amounts of energy on rearing of offspring; these species are referred to K-selection species in traditional ecological literature. Species with low adult survival rates and the opposite life history characteristics are referred to as *r*-selection species. An increase in the mortality rate (e.g., due to impacts from OFW) of K-selection species is likely to have a greater negative impact on the species population than an increase in mortality rate of *r*-selection species due to associated life history characteristics that would slow K-selection species population recovery (e.g., slow growth, low fecundity). This metric is derived from Adams et al. 2016.
5. **Breeding score (Mammals/Sea Turtles and Birds/Bats only)** – because adverse impacts that affect adult breeders that forage to feed their young have disproportionate effects on intrinsic

population growth, the potential population vulnerability for a bird/bat/mammal/sea turtle that is foraging to feed its young is exacerbated for multiple reasons. Because very few species of fish or invertebrates actively rear their young, this metric is not assessed for the fish/invertebrate species group.

The scoring schemes for each of these parameters are listed in Table A-36. In instances where multiple scores are possible for a given species and parameter, the most conservative (i.e., greater number) score is assigned.

Table B-36. Recovery scoring scheme

Recovery Score	Category	Description
CONSERVATION / POPULATION STATUS		
5	Federally or state listed as endangered	Federally- or state-listed as endangered in Study area.
4	Federally or state listed as threatened	Federally- or state-listed as threatened in Study area.
3	Candidate species; or species with very low population levels relative to historic	Candidate species for listing under the Endangered Species Act; or a species with very low population levels relative to historic (e.g., categorized as Vulnerable or higher on the IUCN Red List; NMFS “Species of Concern,” or NatureServe state rank of Vulnerable of higher).
2	Low population levels relative to historic, or a population level in noted decline	Species is not listed, but the population in Study area is low compared to historic levels (e.g., categorized as Near-Threatened on the IUCN Red List), or species remains abundant with a population in marked decline.
1	Healthy population levels relative to historic	Species is not listed, and the population in Study area is “healthy” or relatively near historic levels (e.g., categorized as Least Concern on the IUCN Red List).
REPRODUCTIVE POTENTIAL		
5	Low reproductive capacity – Low fecundity/late maturing	Species has low reproductive capacity, with low fecundity (less than about 100 offspring per year) and a late age of sexual maturation (greater than about 4 years).
4	Low reproductive capacity – Low fecundity/early maturing	Species has low reproductive capacity, with low fecundity (less than about 100 offspring per year) and an early age of sexual maturation (less than about 4 years).
3	Moderate reproductive capacity	Species reproductive capacity falls between categories 4 and 2.
2	High reproductive capacity – High fecundity/late maturing	Species has high reproductive capacity, with high fecundity (greater than about 100 offspring per year) and a late age of sexual maturation (greater than about 4 years).
1	High reproductive capacity – High fecundity/early maturing	Species has high reproductive capacity, with high fecundity (greater than about 100 offspring per year) and an early age of sexual maturation (less than about 4 years).

Recovery Score	Category	Description
RANGE WHEN IN STUDY AREA		
5	Endemic to Study area	When the species is present in Study area, the entire population is within Study area.
4	Regional Oceanic Basin	When the species is present in Study area, the entire population is within the regional oceanic basin (e.g., the northeast Pacific Ocean).
3	Regional Hemispheric Oceanic Basin or circumpolar	When the species is present in Study area, the entire population is within the regional hemispheric oceanic basin, or is circumpolar.
2	Northern and southern hemisphere Pacific/Atlantic; or multiple ocean basins, northern hemisphere only	When the species is present in Study area, the entire population is within both the northern and southern hemisphere Pacific/Atlantic Ocean; or in the northern hemisphere only, but in multiple ocean basins (e.g., in both the north Pacific and north Atlantic).
1	Multiple ocean basins, northern and southern hemispheres	When the species is present in Study area, the population is distributed across multiple ocean basins and in the northern and southern hemispheres.
ADULT SURVIVAL		
5	>0.90	Very high adult survival rates, a.k.a. K-selected species with low natural mortality rates with populations more sensitive to additional mortality from OFW ICFs
4	0.86-0.90	High adult survival rates
3	0.81-0.85	Moderate adult survival rates
2	0.75-0.80	Low adult survival rates
1	<0.75	Very low adult survival rates, a.k.a. r-selected species with populations adapted to high natural mortality rates, thus likely lower population-level effects of additional mortality from OFW ICFs
BREEDING SCORE		
5	Regularly forages	Species is known to regularly forage to feed young in study area, highest vulnerability of breeders.
3	Some individuals may forage	Some individuals of species will forage for young in study area, mid-level vulnerability for breeders.
1	Unlikely to forage	Species is unlikely to be foraging to feed young in the study area, lowest vulnerability for breeders.

B.6 Level of Uncertainty

For each impact and recovery potential rank assigned, a level of uncertainty (LoU) for each scoring parameter is assigned. This metric was drawn directly from Adams et al. (2016) and categorically assessed the level of confidence in the information that went into making the decision for each parameter score. By keeping track of this information, several goals are accomplished. Data gaps may easily be identified for species or groups that are continually marked with low data certainty information. Results derived from species and assessments with low data certainty may be considered ‘less important’ than those with higher data certainty. And finally, using the associated data certainty information, species sensitivity scoring can be binned into lower, ‘best’, and upper estimates for all impact potential scoring.

The level of uncertainty for each metric is determined to be low (10%), medium (25%), or high (50%) depending on the number of data sources, how current the data sources were, and the range of values published in those data sources. For a quantitative assessment metric, such as the percent of time a bird/bat species spent flying at night, the uncertainty levels were defined as follows:

- low (10%) = published values fall within a single category range, optimally based on multiple sources or one source of expert information (e.g., NOAA, USFWS, Audubon websites);
- medium (25%) = published values fall within two category ranges, but most current and/or most abundant literature supports chosen value, or published values fall within a single category range but literature is limited (fewer than 2 sources); and
- high (50%) = published values vary between three or more category ranges, but most current and/or most abundant literature supports chosen value, or published values fall within one or two category ranges and literature sources are limited (fewer than 3 sources), or there was no data found on the species of interest so values assigned were based on data from a similar or proxy species.

For a qualitative or descriptive assessment metric, such as whether a species is an opportunistic forager (high habitat flexibility) or a highly-specific forager (low habitat flexibility), the uncertainty levels were defined as follows:

- low (10%) = consensus on answer among all literature sources / answer found in reliable source;
- medium (25%) = inconsistent or conflicting answers reported in literature (fewer than 3 sources); and
- high (50%) = little to no data available, answer assigned based on similar/proxy species.

Uncertainty scores were on a 1-3 scale, with 1 indicating low uncertainty and 3 indicating high uncertainty. The uncertainty percentage (as a fraction) is multiplied by 4 (the difference between the greatest and least values [5-1=4]) to provide the 3 uncertainty ranges:

- low (10%) = 0.10 * 4 = 0.4;
- medium (25%) = 0.25 * 4 = 1.0; and
- high (50%) = 0.50 * 4 = 2.0.

The application of the LoU score in the model served to vary the assigned rank score by a prescribed amount to calculate lower and upper limits for each assigned rank score (Table B-37).

Table B-37. Level of uncertainty (LoU) score modifications

Rank Score Assigned	Lower and Upper Score Ranges after LoU Applied		
	Low LoU (Score 1 or 10%)	Medium LoU (Score 2 or 25%)	High LoU (Score 3 or 50%)
1	1 – 1.4	1 – 2	1 – 3
2	1.6 – 2.4	1 – 3	1 – 4
3	2.6 – 3.4	2 – 4	1 – 5
4	3.6 – 4.4	3 – 5	2 – 5
5	4.6 – 5	4 – 5	3 – 5

B.7 Scoring Example

An example of the entire species scoring process for one assessment metric is described below. Bigeye tuna was selected as the primary choice for the large pelagic fish sub-group in the HI study area because it is present throughout both HI study areas, EFH designations for all life stages overlap the HI study areas, and it is currently listed as 'vulnerable' on the IUCN Red List. Feeding method is an assessment metric representing an encounter impact for the fish and invertebrates sub-group. The ranking given for this metric and the associated ICF scores were used to calculate the ICF impact score for accidental spills (AS), artificial light (AL), electromagnetic fields (EMF), and habitat disturbance (HD). To provide a ranking for the feeding method assessment metric for bigeye tuna, a literature review was conducted. According to NOAA and a review by the IUCN Red List, bigeye tuna forage opportunistically within the water column through all life stages and primarily consume locally abundant crustaceans, cephalopods, and fish (WPRFMC 2009; Collette et al. 2011). Based on this information, the assessment metric of feeding method for bigeye tuna was assigned a rank score of 3 for the pelagic non-filter feeder category. A ranking of 3 for the feeding method assessment metric translated to scores of 3 for AS and AL, 1 for EMF, and 2 for HD. These scores will contribute to the AS, AL, EMF, and HD scoring equations for this species. Because the information used to rank this metric came from two reputable sources, the level of uncertainty was scored as 1 or low uncertainty. A summary of the justification and reference codes linked to the literature was also included with the metric ranking and uncertainty score. This process was repeated for all impact and recovery potential metrics and for each individual species included in the database.

Table B-38. Fish and invertebrates feeding method assessments for encounter impact during all three project phases

Ranking Score - Category	Category Description	ICF Scores							
		AS	AL	CAS	CSE	EMF	HD	S/N	VS
(5) Surface/pelagic filter feeding planktivore	Species utilizes filter-feeding strategies to extract plankton from the upper water column (e.g., whale shark, sunfish)	5	5	--	--	1	5	--	--
(4) Sessile filter feeder	Species utilizes filter-feeding strategies to extract plankton from the water (e.g., mollusks, coral)	5	0	--	--	3	3	--	--
(3) Pelagic non-filter feeder	Feeds on plankton, fish, and invertebrates from within water column (e.g., jellyfish, herring).	3	3	--	--	1	2	--	--
(2) Non-filter feeding benthic planktivore, piscivore, or scavenger	Species feeds in deeper water near the seafloor (e.g., crabs, flatfish).	1	0	--	--	5	3	--	--

Table B-39. Example of the species scoring process for feeding method assessment metric

Data Recorded for Feeding Method Assessment Metric	HI Bigeye Tuna
Ranking Score	3
Level of Uncertainty	1
Notes / Rationale	Bigeye tuna feed on a variety of fishes, cephalopods and crustaceans in the water column.
Reference Code(s)	ST-040, SB-161

B.8 References

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Appendix C: OFWESA Model Implementation

C.1 Hypothetical Minimum and Maximum Values

A key difference between the OFWESA model and previous relative environmental sensitivity models (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 closer to a realistic assessment of sensitivity in each study area, and not dependent on the sensitivity of other regions in the model. 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 different model parameters and carried through each step of the model calculations. Two “dummy” regions were incorporated into the model to calculate the hypothetical values for some of the habitat-related parameters. These regions were the Economic Exclusion Zones (EEZ) for HI (clipped to include only the EEZ for the major southeastern islands) and for CA. Hypothetical values (HYP_Min and HYP_Max) were developed for the following parameters:

- Water Column Habitat: The team assigned a HYP_Min and HYP_Max score for each study area and season based on the minimum and maximum Net Primary Productivity (NPP) measured for each period within the CA EEZ and HI EEZ regions.
- Marine Bottom Habitat: The team assigned a HYP_Min and HYP_Max score for each study area assuming that these regions contained 100% of the least sensitive natural habitat (vulnerability score of 1) and 100% of the most sensitive habitat (vulnerability score of 5), respectively.
- Protected Area Modifier (PAM): The team calculated a HYP_Min and HYP_Max score for each study area assuming that 0% and 100% of the hypothetical regions consisted of protected marine areas. For the EFH portion of the PAM calculation, the team compiled the number of EFH species/complexes present in the CA EEZ and HI EEZ regions.
- Species Seasonal Presence: The team assigned presence score of 0.167 for a HYP_Min “species” in each season. This value is a result of the requirement for inclusion in the model that a species needed to be fully present in a study area for at least one season, divided over 6 seasons (i.e., 1 ÷ 6 = 0.167). The team assumed a presence score of 1 (fully present) for a HYP_Max “species” in each season.
- Species Impact and Recovery Scoring: For each species group, the team assigned a zero score to every ICF score for a HYP_Min “species”, and the highest possible rank score of five to each ICF score for a HYP_Max “species”. These hypothetical species scores were then carried through the rest of the model calculations to the final environmental sensitivity results.
- Large-Scale Event (LSE) Rate Scores: There was not a feasible way to calculate HYP_Min and HYP_Max LSE scores using the CA EEZ or HI EEZ regions. Instead, the team assigned the maximum score across all seasons and regions as the HYP_Max for all regions. In this iteration of the model, the maximum value was 1.965 for Hawaii during Period 5. The HYP_Min was assumed to be 1.
- Baseline Conditions: For each baseline condition spatial dataset, the team assigned a HYP_Max score for each region based on the measured data (e.g., counts of points, lengths of lines, or areas of polygons) that fell within the CA EEZ and HI EEZ regions. The HYP_Min was assumed to be zero for all datasets in both regions.

C.2 OFWESA Model Steps

The OFWESA model consists of a series of rank scores and normalization steps in simple multiplication, addition, and averaging calculations, as described in the steps below.

1. **Impact Magnitude –** This parameter combined 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 scores for each impact parameter and the final impact magnitude ranged from 0 – 5. Impact parameters for scale and level decreased for some ICFs under the mitigation option and increased for some ICFs under the influence of large-scale event occurrence. The impact magnitude values were applied in multiple algorithms throughout the model.

2. **Large-Scale Event Rate Scores (LSE) –** This parameter incorporated results presented in Appendix F. Seasonal frequencies of occurrence of hurricanes, earthquakes, tsunamis, and vessel accidents for two different magnitudes (partial and full structural failure of the wind facility) were calculated for each study area. A LSE Level score of either 1 (partial) or 1.5 (full) was assigned for each event type in each region. The impact magnitude scores of the ICFs expected to increase during LSEs were averaged and then multiplied by the LSE Level and seasonal frequency for each region and event magnitude. All scores within each region were summed and added to 1 to result in LSE Rate scores ranging from 1 – 1.96 for the hypothetical minimum and maximum region scores. The highest score across all seasons and regions (HI during Period 5) was assigned as the hypothetical maximum region score.

3. **Habitat Sensitivity –** This parameter is composed of water column habitat sensitivity, marine bottom habitat sensitivity, and a protected area modifier.

    3.1. **Water Column Habitat (WCHab) –** The mean NPP in each region and season, normalized to a regional minimum and maximum across all seasons for the hypothetical scenarios and scaled from 1 – 20.

    3.2. **Marine Bottom Habitat (MBHab) –** The proportion of the seafloor composed of different substrate types in each region, multiplied by the sensitivity to habitat disturbance of each substrate type, was summed to an impact score for each substrate type. These were summed and then multiplied by the impact magnitude values for habitat disturbance during the site assessment, construction, and operation phases. These phase impact scores were then summed for a habitat impact score.

        3.2.1. The impact score was multiplied by the LSE rate score for each region and season, to arrive at a marine bottom habitat impact score for each season and region that incorporate the increased potential for impact in regions with higher frequency of LSEs. These scores were normalized to a regional minimum and maximum across all seasons for the hypothetical scenarios and scaled from 1 – 20.

        3.2.2. No mitigation options were assumed for habitat disturbance impacts.

    3.3. **Protected Area Modifier (PAM)** – The protected area modifier averaged the proportion of marine area within each study area protected as parks, reserves, etc. with the proportion of species or complexes with Essential Fish Habitat (EFH) designated within each study area compared to a larger regional max number of EFH. The modifier was scaled from 1 – 2 and served to increase habitat sensitivity of regions with higher proportions of protected areas and EFH.

3.4. **Habitat Sensitivity (HS) –** 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 sensitivity and recovery 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. **Assessment Metric Rank Scores –** These scores were part of the input data collected during the species literature review. The metric rank scores ranged from 0 – 5 for questions that captured a species' potential for interacting with OFW ICFs. Researchers assigned both a score to evaluate an assessment metric question and a level of uncertainty (LoU) score to indicate how accurate the assigned metric score might be based on data availability, reliability, and professional opinion.

4.1.1. Before inclusion in subsequent model calculations, the assessment metric rank scores were converted to scores for each relevant ICF that pertained to that assessment metric and species. These ICF scores varied by metric and species and are presented in the scoring tables of Appendix A.

4.1.2. The LoU scores corresponded to a possible range within which the assigned metric score might fall. The LoU scores and interpretations are explained in Section D.4.1.5. Applying LoU to the assessment metric scores led to repeating model calculations for three scenarios:

(1) a 'mid' scenario where the assessment metric scores were applied as they were assigned,

(2) a 'min' scenario where the LoU-dictated lower limit of the assessment metric score was applied, and

(3) a 'max' scenario where the LoU-dictated upper limit of the assessment metric score was applied.

The application of LoU to the assessment metric scores was designed so that the converted min scores for each ICF (AS, AL, CAS, CSE, EMF, SN, HD, and VS [as described in Section D.4.1.5]) could not be lower than 1 and max ICF scores could not be greater than 5.

4.2. **Species Presence –** These scores were part of the input data collected during the species literature review. Scores were 0, 0.5, or 1 for each season based on presence of a species in a region at that time.

4.3. **Species-specific Sensitivity (SppSens) –** Species-specific sensitivity was composed of impact potential scores modified by the impact magnitude during each project phase, recovery potential scores, and seasonal presence and LSE rate scores.

4.3.1. Impact scores were calculated for each species based on the ICF scores derived from the assessment metric and LoU input data and sensitivity calculations for each ICF that varied by species group. The ICF sensitivity scoring equations for each ICF are presented in Appendix A. These ICF sensitivity scores were multiplied by the impact magnitude for each project phase and summed for a final species impact score. The range for impact scores varied for each species group due to different scoring equations for each ICF.

4.3.2. Recovery scores for each species were based on the recovery assessment metric scores and LoU input data. Recovery scores for each metric were summed for each species and divided by 10 to scale the scores between 0.5 – 2.2 for the 'mid' score scenario for BB, 0.5 – 2.2 for MT, and 0.4 – 2.0 for FI.

4.3.3. Species-specific sensitivity scores were calculated by multiplying the impact scores by the LSE rate scores for each season and region to account for the increase in potential impact of LSE-related ICFs, then by the recovery scores and presence scores for each season and region.

4.3.4. A mitigated scenario was calculated for species sensitivity by using the mitigated impact magnitude values for specific ICFs when multiplying by the ICF scores in step 4.3.1. This brought the range for impact scores for each species group slightly down.

4.4. **Species Group Sensitivity (SS) –** Species group level 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 three species group sensitivity scores for each season and study area. Each regional sensitivity score was normalized to the hypothetical minimum and maximum species score for each species group, and scaled from 1 – 5. Normalized species group scores for BB, MT, and FI were then added together for the final species sensitivity scores for each region and season, ranging from 3 – 15.

5. **Environmental Sensitivity (ES) –** This parameter is an interim result calculated by adding the habitat sensitivity (HS) score to the species sensitivity (SS) score for each region and season.

6. **Baseline Conditions (BC) –** This parameter combined scores from several spatial datasets to capture previously existing anthropogenic impacts in each study area. See Section D.1.2 for details of the dataset. Data for each condition in each region were normalized to the maximum measurement in the CA and HI EEZs on a scale of 0 – 1. These raw BC scores were then summed and normalized again to the hypothetical regional max for both CA and HI on a scale of 1 – 2.

7. **Final Environmental Sensitivity (FES) –** This result was calculated by multiplying the environmental sensitivity (ES) by the baseline conditions score (BC) to arrive at a final environmental sensitivity score for each region and season. The season scores were also averaged together for one score per region.

7.1. The SS, ES, and FES calculations were repeated for the 'mid', 'min' (lower LoU), and 'max' (upper LoU) scenarios and the mitigated option.

C.3 OFWESA Model Algorithms

This appendix contains the calculations used for each step of the model.

C.3.1 Impact Magnitude

The Impact Magnitude attribute assesses the spatiotemporal extent of the impact factor within the broad OCS region as a function of Impact Duration (m_d), Impact Scale (m_s), Impact Level (m_l), and Current Level of Development (m_c).

$$m = (0.2 * m_d) + (0.2 * m_s) + (0.5 * m_l) + (0.1 * m_c)$$

Impact Magnitude returns a value ranging from 0 to 5, with 0 representing negligible impact magnitude (e.g., a non-occurring impact factor) and 5 representing the largest possible impact magnitude.

C.3.2 Large-Scale Event Rate Scores

Large-scale event (LSE) rate scores are calculated for each region and period at two magnitude levels (partial structural failure and full structural failure) for four LSE types (earthquake, hurricane, tsunami, and vessel accidents). The *ICF Impact* score varies by LSE type.

Average impact magnitude of relevant ICFs for each LSE event type using adjusted impact scale and level for LSEs during the Operation and Maintenance phase:

$$ICF\ Impact_e = ((m_{AS}) + (m_{CAS}) + (m_{CSE}) + (m_{HD}))\ /\ 4$$

where *e* = event type and *m* = impact magnitude for specific ICFs. Average ICF impact value was 3.600 for hurricanes and tsunamis and 3.375 for earthquakes and vessel accidents.

LSE score:

$$LSE\ Score_{jk} = 1 + \sum (Frequency_{ejk}\ \times\ LSE\ Level\ \times\ ICF\ Impact_e)$$

where *e* = event type (HU, TS, EQ, or VA), *j* = region and *k* = season. LSE level is 1 for partial and 1.5 for full structural failure LSE magnitude categories. LSE Scores range from 1 – 1.965.

C.3.3 Water Column Habitat (WCHab)

Water column habitats are defined by the net primary productivity (NPP) within the OFW WEA study area. Due to a lack information regarding the direct interaction of OFW ICFs and NPP, no interactions are assessed within the model. Rather, mean seasonal NPP rates within the OFW WEA region are calculated by season and those rates serve as a direct proxy for the sensitivity of the water column habitats within the region. Average NPP for each season, region, and buffer zone were normalized to regional hypothetical maximum values and scaled from 1 – 20.

Normalization of water column habitat score on a scale of 1 – 20:

$$WCHab_{jkb} = (19\ \times \left(\frac{WCHab_{jkb} - minWCHab}{maxWCHab -\ minWCHab} \right)) + 1$$

where *j* = region, *k* = season, and *b* = buffer zone. Min and max WCHab values are derived from the min and max seasonal values for the larger EEZ regions of each study area.

C.3.4 Marine Bottom Habitat (MBHab)

Total marine bottom habitat sensitivity is determined by the proportion of seafloor habitats that comprise a study area and the sensitivity scores of those habitats to habitat disturbance.

Marine bottom habitat impact score for each region and buffer zone:

$$SumHabScore_{jb} = \sum \left(Proportion\ Bottom\ Habitat\ type_{jbh} * Sensitivity_h \right)$$

$$MBHabImp_{jb} = \sum \left(SumHabScore_{jb} * m_p \right)$$

where *j* = region, *b* = buffer zone, *h* = habitat type, and m_p = impact magnitude for each project phase.

Sensitivity of marine bottom habitat to habitat disturbance for each region, buffer zone, and season incorporating large-scale event effects:

$$MBHab_{jbk} = MBHabImp_{jb} * LSE\ Score_{jk}$$

where *j* = region, *b* = buffer zone, and *k* = season.

Normalization of marine bottom habitat sensitivity score on a scale of 1 – 20:

$$MBHab_{jkb} = (19\ \times \left(\frac{MBHab_{jkb} - minMBHab}{maxMBHab -\ minMBHab}\right)) + 1$$

where *j* = region, *b* = buffer zone, and *k* = season. Hypothetical min and max HS values are derived from scores calculated for the larger EEZ regions assuming 100% percent cover of the least and most sensitive habitat types, respectively.

C.3.5 Protected Area Modifier (PAM)

The proportion of protected marine area is calculated by dividing the total areal coverage of protected area types in a given region by the total marine area of the region. For each region, the number of species or complexes with EFH designated in the region is divided by the maximum number of EFH species or complexes in the larger EEZ regions. The maximum attainable protected area modifier is 2.0, a score that would effectively double the habitat sensitivity score of a given region.

Protected area modifier for each region on a scale of 1 – 2:

$$PAM_{jb} = 1 + \left(\frac{\frac{Protected\ Marine\ Area_{jb}}{Total\ Marine\ Area_{jb}} + \frac{\#\ of\ EFH_{jb}}{Max\ Regional\ \#\ of\ EFH}}{2}\right)$$

where *j* = region and *b* = buffer zone.

C.3.6 Habitat Sensitivity Score (HS)

Final habitat sensitivity score (HS) calculated for each region, season, and buffer zone:

$$HS_{jkb} = \left(WCHab_{jkb} + MBHab_{jkb}\right) * PAM_{jb}$$

Normalization of final HS score on a scale of 1 – 15:

$$HS_{jkb} = (14\ \times \left(\frac{HS_{jkb} - minHS}{maxHS -\ minHS}\right)) + 1$$

where *j* = region, *k* = season, and *b* = buffer zone. Hypothetical min and max HS values are derived from scores calculated for the larger EEZ regions.

C.3.7 Species Group ICF Scoring Equations

See Appendix A for these scoring equations. They are used to calculate an $ICF\ Score_{ni}$ for each ICF (*i*, AS, AL, CAS, CSE, EMF, HD, SN, VS) and species (*n*). The assessment metric scores that comprise the ICF scoring equations vary for each species group.

C.3.8 Species-Specific Impact and Recovery Scores

Impact score for each species:

$$SppImp_n = \sum (ICF\ Score_{ni} * m_p)$$

where n = species, i = ICF, and m_p = impact magnitude for each project phase. This step is repeated to derive a mitigated *SppImp* score that incorporates mitigated impact magnitude values.

Recovery score for each species:

$$SppRec_n = \frac{Recovery\ Score_n}{10}$$

where n = species. The *SppRec* score is not ICF-dependent, so it does not need to account for any impact magnitudes or project phases. It is simply the sum of all the scores assigned to the recovery assessment metrics divided by 10 to allow it to serve as a modifier to the final species sensitivity score. The model is designed such that species with a lower resilience to disturbance will have higher recovery scores, which will increase sensitivity when combined with impact scores in later equations. *SppRec* scores range from 0.5 (representing species that are globally distributed, have high population levels, and have high fecundity) to 2.2 (representing species that are endemic to the region being studied, are endangered, and have low fecundity).

C.3.9 Species-Specific Sensitivity Scores (SppSens)

Species-specific sensitivity scores for each region and season are calculated based on the presence/absence, impact potential, and recovery potential of individual species as well as the seasonal large-scale event rate scores for each species' associated study area.

Species sensitivity incorporating relative abundance (i.e., seasonal presence scores or *SppPres*) and large-scale event effects:

$$SppSens_{jkn} = SppPres_{jkn} * \ SppImp_n * SppRec_n * LSE\ Score_{jk}$$

where j = region, k = season, and n = species. This step is repeated using the mitigated *SppImp* and *LSE Score* values for the mitigated scenario.

C.3.10 Species Group Sensitivity Scores (GroupSens)

A separate species sensitivity score is calculated for each species group: marine mammals and sea turtles (MT), birds and bats (BB), and fish and invertebrates (FI).

Sensitivity score calculated for each species group (MT, BB, and FI):

$$GroupSens_{jkg} = \frac{\sum\left(SppSens_{jkng}\right)}{\#\ of\ spp\ in\ group}$$

where *j* = region, *k* = season, g = group, and *n* = species. This step is repeated for the mitigated scenario scores.

Normalization of GroupSens scores on a scale of 1 – 5:

$$GroupSens_{jkg} = (4\ \times\left(\frac{GroupSens_{jkg} - HYPMin_{jkg}}{HYPMax_{jkg} -\ HYPMin_{jkg}}\right)) + 1$$

where *j* = region, *k* = season, and *g* = species group. Hypothetical min and max values are derived from scores calculated by assigning the lowest and highest impact, recovery, and species presence scores to the assessment metrics and scoring equations for each species group. This normalization step allows the three species groups to be compared to each other.

C.3.11 Final Species Sensitivity Scores (SS)

Final species sensitivity score (SS) calculated for each region and season by adding normalized species group scores together, resulting in a range of scores from 3 – 15:

$$SS_{jk} =\ MTGroupSens_{jkg} + BBGroupSens_{jkg} + FIGroupSens_{jkg}$$

where *j* = region, *k* = season, and *g* = species group This step is repeated for the mitigated scenario scores.

C.3.12 Environmental Sensitivity

The overall environmental sensitivity (ES) for each region and season is calculated as the sum of habitat sensitivity (HS) and species sensitivity (SS). In this equation, the habitat sensitivity and species sensitivity scores contribute equally to the environmental sensitivity score.

Overall environmental sensitivity (ES) score calculated for each region and season:

$$ES_{jk} =\ HS_{jk} + SS_{jk}$$

C.3.13 Baseline Conditions (BC)

Baseline conditions serve as a modifier to the overall environmental sensitivity of a study area. In order to combine disparate data types and units, each individual baseline condition is first normalized based on its data type. For instance, the number of oil and gas wells count within a given study area is normalized based on the maximum oil and gas wells count within the larger EEZ region. The following standard min-max normalization equation was used:

$$Normalized(e_i) = (e_i\ -\ E_{min})\ /\ (E_{max}\ -\ E_{min})$$

where e_i is the sample metric, and E_{min} and E_{max} are the minimum and maximum metric values within the regional EEZ zone.

Then, the overall baseline condition modifier is calculated by first summing each respective normalized baseline condition score within a region.

$$RawBC_{jb} = BC_1 + BC_2 + BC_n$$

where *j* = region, *b* = buffer zone, and *n* = total number of baseline conditions assessed.

The RawBC score is then normalized to the maximum total baseline condition score calculated for each larger EEZ region and scaled from 1 – 2.

$$BC_{jb} = (RawBC_{jb}/RawBC_{HYPmax}) + 1$$

where *j* = region and *b* = buffer zone. By this metric, baseline conditions may double the environmental sensitivity of a given region at its maximum score.

C.3.14 Final Environmental Sensitivity (FES)

The final environmental sensitivity equation incorporates the environmental sensitivity (ES, either impact mitigated or unmitigated) and baseline conditions by region, season, and buffer zone.

$$FES_{jkb} = ES_{jk} * BC_{jb}$$

$$AvgFES_{jb} = \frac{FES_{jkb}}{6}$$

where *j* = region *k* = season, and *b* = buffer zone. The FES score for each region can be averaged across seasons and results in scores that range from 4 – 60 for the hypothetical minimum and maximum scenarios.

C.4 References

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Reich DA, Balouskus R, French McCay D, Fontenault J, Rowe J, Singer-Leavitt Z, Schmidt Etkin D, Michel J, Nixon Z, Boring C, McBrien M, Hay B. 2014. Assessment of marine oil spill risk and environmental vulnerability for the state of Alaska.

Appendix D: Model Inputs and Results

This appendix contains information on the implementation of the OFWESA model. It includes a summary of input data as well as model results table for LSE rates, baseline conditions, habitat sensitivity, species sensitivity, and final environmental sensitivity calculations. It also includes a comparison of the differences in habitat sensitivity and baseline conditions when analyzed for different buffer sizes around the WEA lease blocks. Each of the following sections provides a description of the input data per parameter (e.g., large-scale event rates, baseline conditions, habitat sensitivity and species sensitivity) and an overview of the “interim results”. In this instance, “interim results” refers to all the pieces of the model pertaining to that particular parameter before it is incorporated into the final environmental sensitivity score for each region. It is also important to note that this report presents the initial run of the OFWESA model; therefore, the results presented herein represent the information gleaned from the initial data collected, analyzed and processed through the model. Future runs of the model can be conducted with further data collection, input and analysis.

D.1 Large-Scale Event Parameter

D.1.1 Large-Scale Event Inputs

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. If more than one structure fails and releases oil and chemicals, this would most likely constitute a moderate-sized spill. Each large-scale event has a rate or likelihood metric computed (dependent on available data) for two different levels of events: partial structure failure and complete structure failure.

Seasonal frequencies were calculated for hurricanes, while annual frequencies were calculated for earthquakes and tsunamis. Annual frequencies were converted to seasonal frequencies for use in the model by dividing by 6. 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 6 to estimate seasonal vessel accident frequencies for use in the model. Overall, an increase in vessel density increases the potential encounter rate between vessels or between vessels and stationary objects such as wind turbines.

Table D-1 provides the seasonal and annual large-scale event frequencies used to calculate the LSE scores used in the final sensitivity model. These frequencies are more intuitively interpreted as 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 used in the model are discussed in the following section.

D.1.2 Large-Scale Event Results

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 recurrence time of 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.

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 both California and Hawaii is very low, except for Category 5 hurricanes that could potentially cause a full failure event in Hawaii. Hurricanes of this magnitude are the third most frequent event for Hawaii, with partial-failure magnitude tsunamis and earthquakes likely to occur most often in both California and Hawaii. 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 and pronounced for Hawaii, with hurricane frequency increasing by 87-91% between the lowest frequency (February – May) and highest frequency (August – September) seasons. This suggests that LSEs, specifically high magnitude hurricanes, have the potential to increase the occurrence of ICFs in Hawaii.

For all periods, both unmitigated and mitigated LSE scores were higher for Hawaii than for California (Table D-2). Period 5 and period 4 had the first and second highest scores, respectively, and period two and three had the lowest scores for both study areas. Unmitigated scores were higher than the mitigated scores. These scores are applied as a multiplier to sensitivity calculations throughout the model.

Table D-1. Seasonal large-scale event frequencies used to calculate LSE scores, and recurrence times defined as one event every number of years. P=partial structural failure, F=full structural failure. Cells are color-coded along a gradient from low frequencies or recurrence times (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	no occurrence
	Vessel Accident	F – Large Vessels	0.0007	0.0007	0.0007	0.0007	0.0007	0.0007	0.0044	227
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

Table D-2. Unmitigated and mitigated LSE scores for each period used in calculating the habitat and species sensitivity scores.

Region	Scenario	LSE Score Pd1	LSE Score Pd2	LSE Score Pd3	LSE Score Pd4	LSE Score Pd5	LSE Score Pd6
CA	unmitigated	1.13	1.13	1.13	1.14	1.17	1.13
HI	unmitigated	1.42	1.41	1.41	1.64	1.96	1.51
CA	mitigated	1.12	1.12	1.12	1.14	1.16	1.13
HI	mitigated	1.39	1.38	1.38	1.59	1.91	1.47
HYP_Min	hypothetical	1.00	1.00	1.00	1.00	1.00	1.00
HYP_Max	hypothetical	1.96	1.96	1.96	1.96	1.96	1.96

D.2 Baseline Conditions Parameter

D.2.1 Baseline Condition Inputs

Baseline condition datasets that were available at similar data quality and structure for all study areas were included in the OFWESA analysis. The model was reliant upon data inputs being of similar quality and scope. For instance, if data for a baseline condition dataset was entirely unavailable for the HI region, it was not incorporated into the CA assessment. Data for individual layers were assessed within the 25 nm, 10 nm, and 5 nm buffer zones around the WEA lease blocks in each study area using ArcGIS, as well as within the CA and HI EEZs to derive values for the hypothetical maximum scenarios used during normalization steps. A table of the baseline condition dataset sources is presented in Table D-3. Major sources include Marine Cadastre (BOEM and NOAA 2016) and Halpern et al. (2015).

For the point, line, or polygon datasets, the count, length, or area of the baseline features that occurred within each study area was summarized. Some of the baseline conditions were raster datasets derived from a global model where the data had been previously normalized, prior to downloading (Halpern et al. 2008). To analyze each score type dataset, values within each raster cell were categorized as low, medium, or high using natural breaks in the data on the global scale and converted to point data that was then counted. Each count was converted to a weighted score by multiplying by either 1 (low), 3 (medium), or high (4). The scores for each category were then summed for each region: CA, HI_N, HI_S, the CA EEZ, and the HI EEZ and normalized to the hypothetical maximum scores (derived from the regional EEZs) and scaled from 0 – 1.

Table D-3. Baseline condition data sources

Dataset	Download Source	Type	Description	Units
Oil/Gas Pipelines	Pacific Cadastral Data (BOEM 2014)	Polylines	Polyline locations of subsurface oil and gas pipelines	Presence/ Absence - Type
Drilling Platforms - Pacific OCS Region	Marine Cadastre (BOEM and NOAA 2016)	Points	Point locations of structures used to drill into the seabed for mineral Site Assessment or to bring resources to the surface. These structures are particularly used for oil and gas.	Presence/ Absence
Oil and Natural Gas Wells	Marine Cadastre (BOEM and NOAA 2016)	Points	Point locations of surface boreholes drilled into the seabed within the Outer Continental Shelf for mineral Site Assessment and mining.	Presence/ Absence - Type & Status
Coastal Energy Facilities	Marine Cadastre (BOEM and NOAA 2016)	Points	Point locations of coastal facilities that generate energy.	Presence/ Absence - Type & Energy Capacity (MW)
NOAA Submarine Cables	Marine Cadastre (BOEM and NOAA 2016)	Polylines	Polyline locations of submarine cables in US Navigable waters. Some cables may be present in the dataset, but no longer actually located in the seabed.	Presence/ Absence
Danger Zones and Restricted Areas	Marine Cadastre (BOEM and NOAA 2016)	Polygons	Polygon locations of zones within coastal and marine waters. A Danger zone is defined as "A defined water area (or areas) used for target practice, bombing, rocket firing, or other especially hazardous operations, normally for the armed forces. The danger zones may be closed to the public on a full-time or intermittent basis, as stated in the regulations."	Presence/ Absence
Shipping Lanes	Marine Cadastre (BOEM and NOAA 2016)	lines/ polygons	Polygons delineating activities and regulations for marine vessel traffic.	Presence/ Absence - Type
Wastewater Outfalls	Marine Cadastre (BOEM and NOAA 2016)	Points	Point locations of EPA's Facility Registry Service	Presence/ Absence - Type
Ocean Disposal Sites	Marine Cadastre (BOEM and NOAA 2016)	Polygons	Polygon locations of permitted areas for ocean disposal. Materials that are dumped include dredged material (sediments), fish wastes, human remains, and vessels	Presence/ Absence - Type, Status, Coverage Area
Invasive Species	KNB Data Repository (Halpern et al. 2015)	TIF	Raw stressor data (2013) of invasive species	Low, Medium, High Score
Light Pollution Levels	KNB Data Repository Halpern et al. 2015)	TIF	Raw stressor data (2013) of light pollution levels	Low, Medium, High Score
Rates of Ocean Acidification	KNB Data Repository Halpern et al. 2015)	TIF	Raw stressor data (2013) of ocean acidification	Low, Medium, High Score
Ocean Pollution	KNB Data Repository (Halpern et al. 2015)	TIF	Raw stressor data (2013) of ocean pollution derived from shipping data	Low, Medium, High Score

D.2.2 Baseline Conditions Results

To calculate the baseline condition score that would be incorporated into the model, the normalized metrics for each baseline conditions datasets were summed for each region and buffer zone. These raw baseline condition scores were then normalized once more to the CA EEZ or HI EEZ scores and scaled from 1 – 2 (Table D-4).

The normalized baseline condition score for California within the 25-nm buffer zone was 1.028. The normalized baseline condition scores for Hawaii North and Hawaii South within the 25-nm buffer zone were 1.168 and 1.233, respectively. A region with the maximum baseline conditions score of 2 would have its environmental sensitivity doubled in the final environmental sensitivity calculation.

Table D-4. Baseline condition (BC) scores applied in the final environmental sensitivity algorithm

Region	Buffer Zone	Raw BC Score	Normalized BC Score
CA	25 nm	0.364	1.028
CA	10 nm	0.028	1.002
CA	5 nm	0.010	1.001
CA_HYP_Min	EEZ	0	1.000
CA_HYP_Max	EEZ	13.000	2.000
HI_N	25 nm	1.682	1.168
HI_N	10 nm	0.703	1.070
HI_N	5 nm	0.432	1.043
HI_S	25 nm	2.330	1.233
HI_S	10 nm	0.813	1.081
HI_S	5 nm	0.265	1.027
HI_HYP_Min	EEZ	0	1.000
HI_HYP_Max	EEZ	10.000	2.000

D.3 Habitat Sensitivity Parameters

D.3.1 Habitat Sensitivity Inputs

This parameter is comprised of water column habitat sensitivity, marine bottom habitat sensitivity, and a protected area modifier.

D.3.1.1 Water Column Habitat

Net Primary Productivity (NPP) data from the NASA Moderate Resolution Image Spectroradiometer (MODIS) was analyzed as a proxy for sensitivity of water column habitats (Running 2015). Regions with higher NPP were assumed to be more sensitive to OFW impacts. Monthly data from five years (2012-2016) was downloaded as Hierarchical Data Format files (a standardized format for data storage in environmental science) and then converted and projected into North American Albers Equal Area Conic projection. The NPP (in mg C/m^2/day) was averaged within each region for six, two-month periods as seen in Table D-5.

Table D-5. Net primary productivity by season and region within each buffer zone

Region	Period	25 nm – Mean NPP (mg C / m^2 / day)	10 nm – Mean NPP (mg C / m^2 / day)	5 nm – Mean NPP (mg C / m^2 / day)	Regional* Minimum NPP for each Period	Regional* Maximum NPP for each Period
CA	PD 1	1,124	1,141	1,113	385	2,328
	PD 2	1,283	1,231	1,192	437	3,933
	PD 3	2,078	2,097	2,076	407	7,357
	PD 4	2,404	2,360	2,364	421	6,599
	PD 5	2,405	2,388	2,288	405	6,443
	PD 6	1,644	1,580	1,525	397	4,607
HI_N	PD 1	267	264	261	179	436
	PD 2	278	277	275	189	442
	PD 3	254	258	258	170	339
	PD 4	246	249	250	170	385
	PD 5	226	228	227	145	312
	PD 6	236	237	234	153	422
HI_S	PD 1	253	253	257	179	436
	PD 2	270	271	273	189	442
	PD 3	241	243	247	170	339
	PD 4	233	234	237	170	385
	PD 5	212	212	216	145	312
	PD 6	223	223	225	153	422
*Note: Regional minimum and maximum NPP for both Hawaii study areas are identical because used NPP measurements from the Hawaii EEZ for both.						

D.3.1.2 Marine Bottom Habitat

Marine bottom habitats are considered to be vulnerable to a single OFW ICF: habitat disturbance due to anchors or marine cables potentially inducing damage. Total marine bottom habitat sensitivity is determined by vulnerability of habitats (including submerged aquatic vegetation) to habitat disturbance and the proportion of bottom habitat comprised of different habitat types. The site assessment, construction and operation and maintenance of OFW lease blocks (including turbines and floating substations) are extremely unlikely to result in large subsea accidental spills that would result in the oiling of subsea habitats. As a result, accidental spills interacting with marine bottom habitats were not included within the model.

Habitat disturbance to marine benthic habitats is assessed on two metrics to capture impact from OFW anchoring and cable laying; short-term impacts (minutes to days) and long-term impacts (months to years). These scores also reflect the sensitivity of species occupying that habitat that are not explicitly assessed elsewhere in the risk model. Each factor is scored on a 1 to 5 scale, where a score of 5 represents the greatest vulnerability and a score of 1 represents the least vulnerability (Table D-6). A score of 1 implies that habitat disturbance caused by anchoring or a marine cable would have negligible or very minor negative impact on the bottom habitat substrate and related organisms. A score of 5 implies significant sensitivity to habitat disturbance resulting in displacement of the habitat and lethal impacts to related species. Habitat disturbance scores have been created specifically for this project by project researchers based on available literature and professional judgement. The short-term and long-term scores were averaged together to derive the total HD vulnerability score applied in marine bottom habitat sensitivity calculations in the model.

Bottom habitats were analyzed using a California Substrate dataset, created from seven paper maps from the California Continental Geologic Map Series and a Bottom Type dataset for Hawaii from the Office of Planning for the State of Hawaii. Data from the nation-wide U.S. Seabed dataset was slated to be used; however, the dataset did not provide sufficient points in the areas of interest. Bathymetric data for California and Hawaii were downloaded from NOAA National Centers for Environmental Information and NOAA Center for Tsunami Research, respectively (NOAA 2017a; NOAA 2017b).

Substrate types from each dataset were grouped and coded into bottom habitat categories for the OFWESA model, as shown in Table D-7. Sensitivity scores were assigned to each bottom habitat type, based on short- and long-term sensitivity to habitat disturbance impacts. These ranking scores are shown in Table D-6. The short- and long-term rankings were averaged to obtain the sensitivity scores that were incorporated into the calculations for marine bottom habitat sensitivity.

Thiessen polygons were created for the Hawaii data to approximate the spatial areas of cover of each bottom type in square kilometers. The California data were already in a polygon shapefile format. Using bathymetric data, contour lines were created and a 200-m depth contour line was used to define the boundary between shallow and deep habitats. Areas for each bottom type were calculated for each buffer region, along with total buffer area, total land within each buffer, and total area with no data within each buffered region.

Table D-6. Habitat vulnerability score reference table

Habitat Name	Short-Term HD Rank*	Long-term HD Rank*	Total HD Vulnerability*	Vulnerability Score Rationale
Anthropogenic – Shallow	0	0	0	Anthropogenic / artificial bottom types are assumed to be unaffected by OFW.
Anthropogenic – Deep	0	0	0	
Volcanic – Shallow	1	1	1	Volcanic bottom types are assumed to be very minorly affected by OFW.
Volcanic – Deep	1	1	1	
Soft Bottom – Shallow	2	2	2	Shallow soft-bottom habitat regularly experiences disturbance and environmental variability in coastal waters. These habitats are expected to recover from impacts relatively quickly.
Soft Bottom – Deep	3	3	3	Deep soft-bottom habitat is typically composed of unstable, mobile substrata and adaptable communities. Recovery is expected to take longer than in shallow water but to be faster than in hard bottom habitat.
No Data	3	3	3	Conservative, mid-range vulnerability assumed where data were missing.
Hard Bottom – Shallow	3	4	3.5	Hard bottom habitats typically support less resilient organisms than soft-bottom habitats, with longer recovery times. Shallow habitat will be less vulnerable than deep habitat
Hard Bottom – Deep	4	5	4.5	Hard bottom habitats typically support less resilient organisms than soft-bottom habitats, with longer recovery times. Deep hard bottom habitat will be more vulnerable than shallow habitat as it is more stable and less adapted to disturbance.
Coral/Sponges – Shallow	5	5	5	Major disturbance expected to sensitive habitats with slow recovery rates.
Coral / Sponges – Deep	5	5	5	
Kelp – Shallow	5	5	5	
Seagrass – Shallow	5	5	5	
*HD = Habitat Disturbance				

Table D-7. The OFWESA bottom habitat categories applied to source data seafloor categories that fell within the study areas

OFWESA Category	Source Dataset Seafloor Category		
	California	Hawaii North	Hawaii South
Corals / Sponges	n/a	Coral Coral Mud Coral Rocky Coral Sand Coral Sand Mud Coral Sand Rock Coral Weeds Sand Coral Sand Coral Rocky	Broken Coral Broken Coral Mud Coral Coral Mud Coral Sand Coral Sand Mud
Soft Bottom – Deep or Shallow	Mud	Black Sand Coarse Sand Pebbles Fine Sand Gravel Gray Sand Mud Mud Clay Mud Gravel Mud Sand Sand Sand Gravel Sand Mud Sand Mud Lava Sand Shells Shells Silt	Black Sand Clay Clay Shells Coarse Sand Pebbles Fine Sand Gravel Gravel Sand Gray Sand Light Shells Mud Mud Clay Mud Sand Mud Shells Sand Sand Sand Broken Shells Sand Gravel Sand Mud Sand Pebbles Sand Shells Sand Sticky Shells Shells Sand
Hard Bottom – Deep or Shallow	Rock	Hard Rock Rocky	Hard Hard Mud Mud Rocky Rock Rocky Sand Rocky Sand Shells Rocky
Volcanic	n/a	Lava Volcanic Ashes Volcanic Mud	Volcanic Gravel Volcanic Mud

D.3.1.3 Protected Areas

In the OFWESA model, the protected area modifier (PAM) was intended to add sensitivity to regions with a higher proportion of area considered important habitats or resources. Spatial datasets of different types of protected areas were downloaded from National Marine Protected Areas Center, World Database on Protected Areas (WDPA), and the U.S. Fish and Wildlife Service (USFWS) Threatened and Endangered Species Act Report (NOAA and USDOI 2017; UNEP and IUCN 2017; USFWS 2017a). All data were converted to North American Albers Equal Conic projection. State parks, easements, and fishing management areas were not included in the PAM because resource use is not prohibited in these lands and waters. Summary tables for each buffer region were created detailing protected areas in the area along with their designation type. Total protected area (km^2) within each region was calculated, along with a breakdown of area over land and over water. These values were used to obtain the proportion of each buffered region comprised of a protected area type (Table D-8).

In addition to including the proportion of protected areas, the PAM includes the number of EFH complexes in each study area. This data were compiled from the Essential Fish Habitat mapper website (NOAA 2017c). The site was reviewed to record every designated EFH in each study areas, as well as the maximum number of EFH species or complexes protected within the Southeast Hawaiian Islands and California EEZs (Table D-9).

Table D-8. Total area of marine habitat and protected marine habitat area in each buffer zone

Region	Buffer Zone	Total Marine Area (km^2)	Protected Marine Area (km^2)
CA	25 nm	10,218	7,016
CA	10 nm	3,176	2,015
CA	5 nm	1,479	820
HI_N	25 nm	11,366	497
HI_N	10 nm	3,691	179
HI_N	5 nm	1,919	85
HI_S	25 nm	14,330	1,906
HI_S	10 nm	5,440	777
HI_S	5 nm	3,286	372

Table D-9. Essential Fish Habitat (EFH) designations within each study area

Maximum Possible EFH in the California EEZ	CA EFH	Maximum Possible EFH in Southeast Hawaii EEZ	HI_N EFH	HI_S EFH
Groundfish	X	Blue stripe snapper/gray jobfish	X	X
Coastal pelagic species	X	Giant trevally	X	X
Krill - *Eusphausia pacifica*	X	Amberjack/black jack/sea bass	X	X
Krill - *Thysanoessa spinifera*	X	Pink snapper	X	X
Finfish	X	Silver jaw jobfish/thicklip trevally	X	X
Market squid	X	Red snapper/longtail snapper/yellowtail snapper/pink snapper/snapper	X	X
Other krill species	X	Hawaiian coral reef ecosystem	X	X
All fresh-water salmon				
Chinook salmon				
Coho salmon				
Dorado				
Albacore tuna	X			
Bigeye tuna	X			
Northern bluefin tuna	X			
Skipjack tuna	X			
Yellowfin tuna	X			
Blue shark	X			
Common thresher shark	X			
Shortfin mako shark	X			
Broadbill swordfish	X			
Striped marlin	X			
Max Number = 21	**16**	**Max Number = 7**	**7**	**7**

D.3.2 Habitat Sensitivity Interim Results

Table D-10 presents the normalized water column habitat sensitivity scores for each study area, buffer zone, and period. Overall, waters within the regional California EEZ have higher NPP than waters within the Hawaii EEZ (Table D-5). However, normalized water column habitat sensitivity scores are, for the most part, higher in Hawaii than in California because scores were calculated based on comparisons of the study area score against each regional EEZ. Within the California study area using the 25-nm buffer zone, the water column sensitivity score was highest, at 8.22, during period 1 (December – January) and lowest, at 5.57, during period 3 (April-May). Conversely, the highest sensitivity score for both Hawaii North and Hawaii South study areas, using the 25-nm buffer zone, occurred during period 3 (April-May).

Table D-10. Normalized water column habitat sensitivity scores for each season, region, and buffer zone. Cells are color-coded along a gradient of low (green) to high (red) sensitivity.

Region	Buffer Zone	Period 1 (Dec-Jan)	Period 2 (Feb-Mar)	Period 3 (Apr-May)	Period 4 (Jun-Jul)	Period 5 (Aug-Sep)	Period 6 (Oct-Nov)
CA	25 nm	8.224	5.598	5.567	7.097	7.293	6.627
CA	10 nm	8.397	5.315	5.619	6.964	7.241	6.340
CA	5 nm	8.116	5.100	5.562	6.976	6.926	6.091
HI_N	25 nm	7.467	7.688	10.372	7.692	10.164	6.910
HI_N	10 nm	7.290	7.607	10.830	7.994	10.382	6.938
HI_N	5 nm	7.046	7.498	10.914	8.080	10.294	6.750
HI_S	25 nm	6.442	7.078	8.946	6.564	8.633	5.974
HI_S	10 nm	6.477	7.181	9.227	6.665	8.625	5.965
HI_S	5 nm	6.783	7.323	9.625	6.972	9.019	6.128
HYP_Min		1	1	1	1	1	1
HYP_Max		20	20	20	20	20	20

The majority (69%) of marine habitat within the California study area (within the 25-nm buffer zone) was categorized as deep soft bottom (Table D-11). In addition, a large portion (27%) of the bottom habitat within the California study area (within the 25-nm buffer zone) was unidentifiable and categorized as 'No Data' and given a conservative, medial sensitivity rating of 3 out of 5. This conservative score protects sensitive habitats that may be present. Specifically, in the California area, deep sea coral reefs may be present in the study area and are very sensitive to disturbance, but presence in study area is currently unknown. The most prevalent bottom habitat types in the northern and southern Hawaiian study areas (within the 25-nm buffer zones) were deep soft bottom (52% and 54%, respectively) and deep volcanic bottom (10% and 14%, respectively) for both regions. The marine bottom habitat sensitivity scores ranged from 1 – 20 for the hypothetical min and max, with the highest scores occurring for all three study areas in Period 5 (August-September), likely due to the influence of higher LSE rates during this season (Table D-12). The highest normalized bottom habitat sensitivity scores were 6.41 for California, 11.72 for Hawaii North, and 12.77 for Hawaii South (Table D-12).

Table D-11. Area (km^2) of bottom habitat types within each buffer zone for each region (dp=deep, sh=shallow)

Region	Buffer Zone	Buffer Area	Marine Area	Soft Bottom - dp	Soft Bottom - sh	Hard Bottom - dp	Hard Bottom - sh	Corals / Sponges - dp	Corals / Sponges - sh	Volcanic - dp	No Data
CA	25 nm	11,429	10,218	7,087	403	0	10	0	0	0	2,717
	10 nm	3,176	3,176	2,532	0	0	0	0	0	0	644
	5 nm	1,479	1,479	1,384	0	0	0	0	0	0	94
HI_N	25 nm	12,302	11,366	6,454	321	1,095	149	505	87	1,135	1,619
	10 nm	3,713	3,691	2,009	66	47	74	52	23	17	1,403
	5 nm	1,919	1,919	1,260	36	0	22	0	0	21	579
HI_S	25 nm	15,849	14,330	8,617	838	420	152	1,044	802	2,074	382
	10 nm	5,636	5,440	2,520	450	120	65	766	331	184	1,004
	5 nm	3,286	3,286	1,418	319	67	19	428	108	0	928

Table D-12. Normalized bottom habitat sensitivity scores by period, for each region and buffer zone. Cells are color-coded along a gradient of low (green) to high (red) sensitivity.

Region	Buffer Zone	Period 1 (Dec-Jan)	Period 2 (Feb-Mar)	Period 3 (Apr-May)	Period 4 (Jun-Jul)	Period 5 (Aug-Sep)	Period 6 (Oct-Nov)
CA	25 nm	6.044	6.037	6.037	6.150	6.313	6.084
CA	10 nm	6.139	6.131	6.131	6.246	6.411	6.180
CA	5 nm	6.139	6.131	6.131	6.246	6.411	6.180
HI_N	25 nm	8.131	8.030	8.030	9.512	11.654	8.657
HI_N	10 nm	8.178	8.077	8.077	9.566	11.719	8.706
HI_N	5 nm	7.939	7.840	7.840	9.291	11.389	8.453
HI_S	25 nm	7.922	7.823	7.823	9.272	11.366	8.436
HI_S	10 nm	8.943	8.833	8.833	10.445	12.775	9.515
HI_S	5 nm	8.851	8.743	8.743	10.339	12.648	9.418
HYP_Min		1	1	1	1	1	1
HYP_Max		20	20	20	20	20	20

Table D-13 summarizes protected areas within each study area. Within the California study area (25-nm buffer zone), 69% of the areas is protected. Within the Hawaii North and Hawaii South study areas (25-nm buffer zone), 4% and 13% are considered protected, respectively. There are 15 to 16 EFH designations within the California and both Hawaiian study areas (25-nm buffer zone). The protected area modifier used to calculate the combined habitat sensitivity score was 1.72, 1.52, and 1.57 for the California, Hawaii North, and Hawaii South study areas (25-nm buffer zones), respectively.

Table D-13. Proportion of protected marine habitat and EFH designations for each region and buffer zone used to calculate the protected area modifier

Region	Buffer Zone	Proportion of Marine Area Protected	# EFH Designations	Protected Area Modifier
CA	25 nm	0.69	15	1.72
CA	10 nm	0.63	7	1.67
CA	5 nm	0.55	7	1.63
HI_N	25 nm	0.04	15	1.52
HI_N	10 nm	0.05	7	1.52
HI_N	5 nm	0.04	7	1.52
HI_S	25 nm	0.13	16	1.57
HI_S	10 nm	0.14	7	1.57
HI_S	5 nm	0.11	7	1.56
CA & HI	HYP_Min	0	0	1.00
CA	HYP_Max	1.00	21	2.00
HI	HYP_Max	1.00	7	2.00

The habitat sensitivity scores are presented in Table D-14. This parameter is 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. For the California study area (25-nm buffer zone), the normalized habitat sensitivity score was highest during period 1 (December – January) and was 5.06. For the Hawaii North and Hawaii South study areas (25-nm buffer zone), the habitat sensitivity scores were highest during period 5 (August – September) and were 6.60 and 6.26, respectively.

Table D-14. Normalized habitat sensitivity (HS) scores by period for each region and buffer zone. These scores are calculated by adding the normalized water column sensitivity score to the normalized marine bottom sensitivity score, then multiplying by the protected area modifier. Cells are color-coded along a gradient of low (green) to high (red) sensitivity.

Region	Buffer Zone	Period 1 (Dec-Jan)	Period 2 (Feb-Mar)	Period 3 (Apr-May)	Period 4 (Jun-Jul)	Period 5 (Aug-Sep)	Period 6 (Oct-Nov)
CA	25 nm	5.057	4.242	4.232	4.741	4.852	4.575
HI_N	25 nm	4.902	4.934	5.668	5.340	6.601	4.893
HI_S	25 nm	4.680	4.831	5.356	5.093	6.264	4.692
CA	10 nm	5.009	4.081	4.172	4.611	4.744	4.404
HI_N	10 nm	4.873	4.932	5.814	5.445	6.688	4.921
HI_S	10 nm	4.990	5.158	5.735	5.467	6.677	5.007
CA	5 nm	4.823	3.936	4.072	4.520	4.554	4.241
HI_N	5 nm	4.735	4.832	5.765	5.387	6.565	4.795
HI_S	5 nm	5.009	5.129	5.773	5.478	6.694	4.984
HYP_Min		1	1	1	1	1	1
HYP_Max		15	15	15	15	15	15

D.3.3 Analysis of Sensitivity of Results to Buffer Zone Size

When analyzing the habitat sensitivity results for the three buffer zone sizes around each WEA lease block region (25 nm, 10 nm and 5 nm), the expected trend would be that as the area of evaluation gets smaller, the proportion of sensitive habitat would become larger and thus the area would appear more sensitive to potential impacts. This is the case for most of the parameters analyzed. The results for each of the habitat sensitivity inputs and resulting scores vary slightly and are discussed in this section. Generally, the pattern shifts based on the parameters being analyzed (e.g., baseline conditions, protected marine habitat, water column habitat, and bottom habitat) and the resolution at which they overlap with the different buffer zone sizes.

For the baseline conditions (Table D-4), the largest (25-nm) buffer zone in the California study area had a score that goes into the sensitivity analysis that was 92% higher than that for the 10-nm buffer zone and 97% higher than that for the 5-nm buffer zone. For the Hawaii North study area, the score for the 25-nm buffer zone was 58% higher than that for the 10-nm zone and 74% higher than that for the 5-nm zone. Similarly, for the Hawaii South study area, the score for the 25-nm zone was 65% higher than that for the 10-nm zone and 89% higher than that for the 5-nm zone. These results are due to the larger spatial coverage within the 25-nm buffer zone and more baseline metrics falling within that zone. For instance, in the case of the wastewater outfalls, there were a total of 2,717 outfalls in the whole Hawaii EEZ with 488 outfalls occurring within the Hawaii North study area 25-nm buffer zone, and only 4 within the 10-nm buffer zone. Similarly, out of the 2,717 outfalls within the Hawaii EEZ, 1,788 outfalls were within the Hawaii South study area 25-nm buffer and only 140 outfalls were within the 10-nm buffer zone. Therefore, a larger buffer zone is related to a higher baseline conditions score.

Similar to the baseline conditions, the protected marine habitat modifiers (Table D-13) increase with increasing buffer zone size. This is related to the area of protected marine habitat and the proportion of total marine area that is protected in each zone (Table D-8). For instance, there is a 20% increase in the protected marine area between the California 5-nm buffer zone and the 25-nm buffer zone. After taking into consideration the proportion of total marine area that is protected and the number of EFH designations in each zone, this equates to an increase in the protected area modifier for California from 1.63 for the 5-nm buffer zone to 1.72 for the 25-nm buffer zone.

Contrary to the baseline conditions and the protected area modifiers, there is no clear pattern between buffer zone area and water column habitat sensitivity. While in several cases, the water column mean NPP by season and study area increased with increasing buffer zone size (Table D-5), there are several instances in which NPP increased from the 25-nm buffer zone to the 10-nm buffer zone and/or from the 10-nm buffer zone to the 5-nm buffer zone. This is then carried over to the normalized water column habitat sensitivity scores (Table D-10) in which scores increased with decreasing buffer zone size. For example, in the Hawaii South study area during Period 3 (April-May), the score increased by 7% between the 25-nm buffer and the 5-nm buffer. This is due to the much smaller size of the overall buffer zones (e.g., 15,849 km^2 for the 25-nm buffer and 3,286 km^2 for the 5-nm buffer in the Hawaii South study area) and the proportion of available sensitive habitat being higher with the smaller buffer zone area.

For marine bottom habitat, the area of specified bottom habitat types increased with increasing buffer zone size (Table D-11). However, when comparing the sum sensitivity scores, calculated by multiplying the proportion of the area within the study area for each habitat by the impacts score for each habitat, the pattern generally shifts (Table D-12). For this parameter, the smaller sum sensitivity scores in the 25-nm and 10-nm buffer zone as compared to the 5-nm zone are due to the lower proportion of marine bottom habitat sensitive habitats in the larger buffer zones.

D.4 Species Sensitivity Parameters

D.4.1 Species Sensitivity Inputs

The three main components of the species sensitivity score include: the presence/absence of a population (i.e., how much of the species population in the study area would be affected), ICF impact score (i.e., how severely a species would be affected by different ICFs), and recovery potential (i.e., how quickly the species population would be able to recover from impact). The seasonal LSE rate scores for each region are also incorporated into the species-specific ICF impact scores.

D.4.1.1 Species Selection

Species were initially categorized into three broad groups: marine mammals and sea turtles (MT), birds and bats (BB), and fish and invertebrates (FI). To capture a wide range of ecological niches and behavior groups, species were further divided into unique sub-groups (Appendix D.2.5). These sub-groups were intended to capture various 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) are 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 contaminants or ICFs affecting the water column while feeding, but surface divers would have a higher chance of encountering ICFs at the water’s surface because of the larger amount of time spent inhabiting it. Thus, sensitivity to ICFs such as accidental spills would be higher for surface seabirds than for aerial seabirds, and including sub-groups in the species selection process insures that such differences are captured for a more complete picture of the ecosystem in each study area.

The selection of species aimed to capture the sensitivity of species that filled a variety of ecological roles, some of which were endemic or wide-ranging, of conservation concern, and/or commercially important. Primary and secondary species were selected for each sub-group based on an initial review of literature on species distribution, conservation status, and life history. For this initial iteration of the OFWESA model, 22 species were chosen for each of two study areas (CA and HI), with 7 or 8 species included for each species group (BB, MT, and FI). Details of the species selection process and a table describing the different sub-groups can be found in Appendix D.2.5.

D.4.1.2 Seasonal Presence

Seasonal presence/absence information was incorporated into the model to reflect migratory behaviors and habitat use patterns of species that inhabit the study areas. This parameter assessed the regional presence of a species during different periods of the year to determine whether a species was present, absent, or migrating in or out of the study area. Presence/absence scores were based on a three-level scale, with a score of 0 representing absence, 0.5 representing a species/region/season combination in which the species is migrating in or out of the region, and 1 representing that a species is fully present in the region during that season. Historic stock assessments, literature, and web databases were used to conduct in-depth examinations of local presence and migratory patterns for all species included in the final model. Notes were taken to justify each score assignment based on the references reviewed. The hypothetical maximum presence score was a 1 in each season, while the hypothetical minimum presence score was a 1 in 1 season (or 0.167 divided across all 6 seasons).

D.4.1.3 Species Scoring: Impact Potential

The impact parameter score evaluates how severely a species would be affected in the event of spatiotemporal overlap with each ICF. Although each species group is vulnerable to a unique subset of ICFs, this parameter is assessed using 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). Assessment metrics (i.e., questions based on ecological characteristics of a species group) designed to evaluate these ecological themes could differ for each species group. For example, there was a nocturnal flight activity assessment metric to evaluate encounter for birds, while there was an egg location assessment metric to evaluate encounter for fish. However, the aggregation assessment metric to evaluate concentration was the same for all species groups. For each individual species, assessment metrics are scored on a 0 to 5 ranking scale to correspond to a particular category (i.e., answer to the assessment question). The rankings assigned for each species are based on a thorough literature search and accompanied by a short rationale for that assignment as well as all related references in the database.

The assigned scores were translated into ICF scores for each relevant ICF, as presented in the species scoring tables in Appendix B before incorporation into model calculations. The ICFs considered in the OFWESA model include: accidental spills (AS); artificial light (AL); collisions with above surface structures (CAS); collisions with subsurface structures or entanglement (CSE); electromagnetic fields (EMF); habitat disturbance/displacement (HD); sound/noise (SN); and vessel strikes (VS). Some ICFs did not apply to certain species groups (e.g., EMF is not relevant for birds/bats); the ICFs assessed for each group are presented Table D-15. The ICF impact scores for each assessment metric category were based on the impact magnitude of the associated ICF on the assessment metric/ecological characteristic and follow a 0 – 5 scoring scale, with 0 indicating no impact and 5 indicating greatest impact. An example of the species scoring process is provided in Appendix B.7.

Table D-15. ICFs that are assessed for each species group. "X" indicates that an ICF was assessed

Species Group	Assessed ICFs							
	AS	AL	CAS	CSE	EMF	HD	S/N	VS
Birds / Bats	X	X	X			X	X	
Marine Mammals / Sea Turtles	X	X		X		X	X	X
Fish / Invertebrates	X	X			X	X	X	X

D.4.1.4 Species Scoring: Recovery Potential

The recovery potential score assesses how quickly a species population would be able to recover in the event of an incident. Recovery parameters were the same for the three species groups and included metrics assessing:

- conservation/population status;
- reproductive potential;
- species range while in study area;
- adult survival rate; and
- breeding score to describe how much a species forages for their young, which can be risky for both parent and offspring (mammals/sea turtles and birds/bats only).

These parameters are important counterparts to the impact parameters, as certain species (e.g., Pacific sardine) may suffer a large impact from a given ICF, but are less vulnerable overall if they can recover quickly due to large population numbers and high fecundity. The scoring scale was the same as that for the impact parameter, with a score of 0 indicating high recovery potential (lower impact), and a score of 5 indicating low recovery potential (higher impact). The recovery parameter scores assigned for each species were based on a thorough review of historic stock population data, the literature, and web databases and were accompanied by a written rationale for that assignment as well as all related references. A table detailing the scoring scheme for the recovery parameter is in Appendix B.5.

D.4.1.5 Level of Uncertainty (LoU)

For each impact and recovery potential rank assigned, the rationale for the rank assignment, and associated references, as well as a score for the Level of Uncertainty (LoU) was recorded for each scoring parameter. This metric was drawn directly from Adams et al. (2016) and categorically assessed the level of confidence in the information that went into making the decision for each parameter score. By keeping track of this information, several goals are accomplished. Data gaps may easily be identified for species or groups that are continually marked with low data certainty information. Results derived from species and assessments with low data certainty may be considered 'less important' than those with higher data certainty. And finally, using the associated data certainty information, species sensitivity scoring can be binned into lower, mid, and upper estimates for all impact potential scoring.

The level of uncertainty for each metric is determined to be low (10%), medium (25%), or high (50%) depending on the number of data sources, how current the data sources were, and the range of values published in those data sources. For a quantitative assessment metric, such as the percent of time a bird/bat species spent flying at night, the uncertainty levels were defined as follows:

- low (10%) = published values fall within a single category range, optimally based on multiple sources;

- medium (25%) = published values fall within two category ranges, but most current and/or most abundant literature supports chosen value, or published values fall within a single category range but literature is limited (fewer than 3 sources), and
- high (50%) = published values vary between three or more category ranges, but most current and/or most abundant literature supports chosen value, or published values fall within one or two category ranges and literature sources are limited (fewer than 3 sources), or there was no data found on the species of interest so values assigned were based on data from a similar or proxy species.

See Appendix B.6 and B.7 for more details about LoU assignments and an example of the species scoring process.

D.4.2 Species Sensitivity Interim Results

The impact scores for each ICF and the total impact and recovery scores for birds and bats, mammals and turtles, and fish and invertebrates are presented in Tables D-18 to D-20. Normalized species sensitivity scores for each region and season, which combine impact and recovery scores with seasonal LSE scores, are presented in Table D-24 for the unmitigated and mitigated scenarios. Mitigated scores are consistently lower than the unmitigated scores for all species and throughout each period. Further detail on the species sensitivity scoring is provided in Appendix B.

D.4.2.1 Species Selected

For the species selection process, the initial species sub-groups were reviewed by BOEM's subject matter experts (SMEs) during the model development task. Their feedback was incorporated and the lists of selected species were reviewed by SMEs prior to the full literature search and species scoring exercises were conducted. The SMEs provided feedback on: 1) the appropriateness of the primary species choices as representatives of each sub-group; 2) whether the secondary choice species needed to be included in the model to appropriately represent the sub-group; 3) any concerns regarding the selection process or rationale provided for each choice; and 4) any species not in the list that the SME believed should be included instead of one of the primary or secondary choices that had been selected. The SME feedback was incorporated and some changes were made to regional sub-groups and species to be included into the database, as listed in Table D-16. For example, baleen whales are not as common around HI as toothed whales, so only one baleen whale and three toothed whale species were selected for HI, while two baleen and two toothed whale species were selected to represent CA. Although the unique subgroups and species selected for inclusion in the database characterize a wide range of the ecological niches in these study areas, they are not representative of the entire ecosystem. Species included in the model can be changed in future iterations by BOEM users and the sub-groups are only used as a guideline for the selection process to help narrow the focus down to regionally and ecologically important species. Species sub-groupings are not factored into any of the model algorithms and can be changed to suit the user's needs.

Table D-16. Species group and sub-group definitions for species selection

Species Group	Sub-Group	Sub-Group Description
Birds/Bats	bats	nocturnal flying mammals that are occasionally observed over water
	raptors	birds of prey that nest on land and hunt over water
	aerial seabirds	spend most of the time in flight over water and dive below the surface for food, often migratory
	surface seabirds	spend most of the time on the water's surface (flying rarely) and dive below the surface for food
	shorebirds / wading birds	nearshore birds that wade or swim in shallow water or intertidal habitats
	waterbirds	nearshore birds that spend most of the time on the water's surface
Fish/Invertebrates	corals	colonial invertebrates with or without carbonate exoskeletons in shallow or deep waters that either passively feed or contain symbiotic algae
	sponges	primitive, sessile invertebrates that rely on constant water flow through a central cavity for digestion and circulation
	benthic invertebrates	filter- or deposit-feeding invertebrates dwelling within or on the seafloor (e.g., worms, mollusks, crustaceans)
	pelagic invertebrates	invertebrates floating or swimming through the water column that are important forage species
	demersal fish	fish that feed and inhabit waters near the seafloor
	small pelagic fish	small fish that primarily inhabit the upper- to mid-water column that are important forage species
	large pelagic fish	large fish that primarily inhabit the upper- to mid-water column and are often apex predators
	anadromous / catadromous fish	fish that migrate between freshwater and saltwater habitats at different life stages
Marine Mammals/Turtles	baleen whales	filter-feeding cetaceans that use baleen plates to lung- or skim-feed and sieve prey from the water, often migratory
	toothed whales	toothed cetaceans that feed on fish, squid, or other marine mammals, some migrate
	pinnipeds	semiaquatic marine mammal group comprised of true seals, fur seals, sea lions, and walruses that feed mostly on marine fish and invertebrates
	sea turtles	omnivorous reptiles that occupy seaweed mats in the pelagic zone, forage underwater, surface to breathe, and go ashore to lay eggs

D.4.2.2 Birds and Bat Impact and Recovery

As indicated in Table D-17 with further detail provided in Appendix B, the bird/bat species from the California and Hawaii study areas with the highest impact scores for accidental spills were the Brandt's cormorant at 5.51 and wedge-tailed shearwater at 5.83 (out of a hypothetical maximum impact score of 8.10), respectively. For artificial light impacts (hypothetical maximum of 5.50), Ashy Storm Petrel in the California study area had the highest impact score at 4.09, while wedge-tailed shearwater had the highest impact scores for birds in the Hawaii study area at 4.71. Hoary bats in the California area and wedge-tailed shearwaters in the Hawaii area had the highest impact scores for collisions with above surface structures (3.29 and 3.04, respectively, out of a hypothetical maximum of 3.80). Both Scripp's murrelet and ashy storm petrel in the California study area scored highest for the habitat disturbance impact (4.50 out of the hypothetical maximum of 5.00), while Hawaiian petrel scored highest among the Hawaii species (4.50). For the sound/noise ICF, Brandt's cormorant (6.41) and wedge-tailed shearwater (7.83) scored highest for the California and Hawaii areas, respectively (out of a hypothetical maximum of 8.90).

Of the Californian bird and bat species, ashy storm petrels had the highest impact score across all ICFs and project phases, with 22.05 (70% of the hypothetical maximum impact score of 31.30), while the western snowy plover had the lowest impact score with 12.18 (39% of hypothetical maximum). Wedge-tailed shearwater had the highest impact score of the Hawaiian birds and bats included in the model, with a score of 24.92 (80% of hypothetical maximum), while Hawaiian coot had the lowest impact score, with 11.35 (36% of hypothetical maximum). Recovery scores were used in the model to assess a population's ability to recover from impact. Of the Californian species, ashy storm petrel had the highest recovery score, which translates to the lowest recovery potential/highest sensitivity, with a score of 2.30 out of 2.50 (92% of hypothetical maximum). Of the Hawaiian species, Hawaiian petrel had the highest recovery score with 2.40 out of 2.50 (96% of hypothetical maximum).

D.4.2.3 Mammal and Turtle Impact and Recovery

In the California study region, accidental spill impact scores were highest for the California sea lion with an impact score of 5.67 out of the hypothetical maximum score of 8.10 (Table D-18). In the Hawaiian study region, accidental spill impact scores were highest for Hawaiian monk seals which scored 4.05 out of the hypothetical maximum score of 8.10. For artificial light impact scores, leatherback turtles scored highest of California species with 4.03 and Hawaiian humpback whales scored highest for Hawaiian species with 3.30 out of the hypothetical maximum score of 5.50. Harbor porpoise (6.80 out of the hypothetical maximum score of 8.50) and pantropical spotted dolphins and bottlenose dolphins (each with a 7.65 out of the hypothetical maximum score of 8.50) had the highest scores for collisions and entanglement with subsurface structures out of the Californian and Hawaiian species, respectively. The CMX DPS humpback whale and fin whale scored highest among species in their respective regions for the habitat disturbance with scores of 3.00 and 3.25 out of the hypothetical maximum score of 5.00, respectively. Killer whales and CMX DPS humpback whales from the California study region and HI DPS humpback whales, pantropic spotted dolphin and bottlenose dolphin from the Hawaii study region scored highest (6.82 and 7.12 out of 8.90, respectively) for sound/noise impacts. For vessel strikes, California sea lion scored highest of California species (6.60 out of the hypothetical maximum score of 9.00), while pantropical spotted dolphin and bottlenose dolphin scored highest of Hawaii species (6.60 out of the hypothetical maximum score of 9.00). Of the species in the California and Hawaii study areas, the CMX DPS humpback whales, pantropical spotted dolphin and bottlenose dolphin had the highest overall impact scores of 29.76 (66%) and 29.45 (65%), respectively, out of the hypothetical maximum score of 45.00. The Northern fur seal and Hawaiian monk seal both had the lowest scores for their regions with 23.21 or 52% of the maximum (CA) and 17.54 or 39% of the maximum (HI). The CMX humpback whales (CA) and false killer whales (HI) both had the highest recovery scores of the species in their respective regions, with a score of 2.00 or 91% and 2.50 or 100% of the hypothetical maximum recovery score of 2.50, which represents the low recovery potential and high sensitivity of their populations.

D.4.2.4 Fish and Invertebrate Impact and Recovery

Of the fish and invertebrates featured in this analysis, krill and midway/pink coral had the highest impact scores for accidental spills in the California and Hawaii study regions, with scores of 6.08 and 5.87 out of a hypothetical maximum score of 8.10, respectively (Table D-19). For artificial light, krill in California and bigeye tuna in Hawaii had the highest scores of the species in each region at 4.40 and 4.03, respectively (out of the hypothetical maximum score of 5.50). Cowcod and Hawaiian spiny lobster, each with a score of 1.38 had the highest impact scores for EMF in the California and Hawaii study regions (out of the hypothetical maximum score of 2.30). Habitat disturbance impact scores were highest among California species for orange sea pen and among Hawaii species for massive black sponge at 2.86 and 2.43, respectively (out of the hypothetical maximum score of 5.00). Pacific sardines in California and bigeye tuna in Hawaii had the highest sound/noise impact scores at 8.90 and 7.71 respectively (out of the hypothetical maximum score of 8.90). None of the species evaluated in either the California or Hawaii study area models had scores for vessel strikes. Species likely to be impacted by vessel strikes, include shark or sturgeon species, which were not included in this model, but could be added to subsequent iterations. Pacific sardines (CA) and bigeye tuna (HI) had the highest impact scores of all the species in their respective regional groups with scores of 21.12 for sardines and 20.28 (54% and 52%, respectively, of the hypothetical maximum score of 38.80). The highest recovery scores (lowest recovery potential) were observed for cowcod in the California study region and massive black sponge in the Hawaii region at 1.30 (or 65% of the hypothetical maximum of 2.20) for each.

D.4.2.5 Species Sensitivity Scores

In the California study region, the first and second highest unmitigated sensitivity scores for birds and bats occurred during period 6 and period 1, respectively, for ashy storm petrel (Table D-20). For the combined Hawaii study regions, Hawaiian stilt present in the study regions had the highest unmitigated score.

For mammals and turtles in the California study region, CMX DPS humpback whales in August-September had the highest sensitivity score (Table D-21). Of the mammals and turtles in the Hawaiian study regions, false killer whales in August-September (period 5) had the highest unmitigated species sensitivity scores.

Black abalone during period 5 had similar scores and were the highest unmitigated sensitivity scores of all fish and invertebrate species included in the California study region analysis (Table D-22). For fish and invertebrates in the Hawaiian study regions, midway/pink coral had the highest species sensitivity scores for all periods. For both species, the highest scores were observed during period 5.

The normalized species groups and the summed sensitivity scores by season and region and for both unmitigated and mitigated scenarios are presented in Table D-23. For the bird and bat species from the California study region, period 1 had the highest sensitivity score. For Hawaiian birds and bats, period 5 had the highest sensitivity score. For mammals and turtles in California and Hawaii, period 6 had the highest sensitivity scores. Fish and invertebrates had the highest sensitivity score during period 5 in California and Hawaii. For all species groups combined, period 6 had the highest sensitivity score for California and period 5 was highest for Hawaii. Mitigated scenario patterns were similar in all cases and mitigated scores were consistently lower than the unmitigated scores.

Table D-17. Impact-causing factor vulnerability scores, summed impact scores, and recovery scores for all bird and bat (BB) species from the unmitigated, mid-LoU value scenario. Cells within each column are color-coded from lowest (green) to highest (red) vulnerability.

Species	Region	Sub-Group	All Phase AS	All Phase AL	All Phase CAS	All Phase HD	All Phase SN	Impact Score	Recovery Score
Western Snowy Plover	CA	Shorebirds / Wading Birds	3.24	2.20	1.82	1.00	3.92	12.18	1.50
Bald Eagle	CA	Raptors	2.59	2.04	0.96	2.75	4.27	12.62	1.80
Hoary Bat	CA	Bats	3.56	3.61	3.29	2.75	4.63	17.85	1.40
Scripps's Murrelet	CA	Surface Seabirds	5.18	3.30	1.62	4.50	4.98	19.59	2.00
Western Grebe	CA	Waterbirds	5.18	3.46	2.13	3.50	5.34	19.61	1.70
Brandt's Cormorant	CA	Aerial Seabirds	5.51	2.99	2.23	2.50	6.41	19.63	1.60
Ashy Storm Petrel	CA	Aerial Seabirds	5.18	4.09	2.23	4.50	6.05	22.05	2.30
Hawaiian Coot	HI	Waterbirds	3.24	2.04	1.47	1.75	2.85	11.35	1.90
Hawaiian Hoary Bat	HI	Bats	1.94	2.51	2.23	2.25	2.85	11.79	1.60
Hawaiian Stilt	HI	Shorebirds / Wading Birds	4.54	2.51	1.42	2.75	4.63	15.85	2.30
Great Frigatebird	HI	Aerial Seabirds	4.54	3.46	2.69	2.75	5.70	19.12	1.60
Laysan Albatross	HI	Surface Seabirds	5.18	3.93	2.38	3.50	7.12	22.11	2.20
Hawaiian Petrel	HI	Aerial Seabirds	4.86	3.93	2.84	4.50	6.41	22.53	2.40
Wedge-Tailed Shearwater	HI	Aerial Seabirds	5.83	4.71	3.04	3.50	7.83	24.92	1.80
Maximum Possible BB Scores:			8.10	5.50	3.80	5.00	8.90	31.30	2.50

Table D-18. Impact-causing factor vulnerability scores, summed impact scores, and recovery scores for all marine mammal and turtle (MT) species from the unmitigated, mid-LoU value scenario. Cells within each column are color-coded from lowest (green) to highest (red) vulnerability.

Species	Region	Sub-Group	All Phase AS	All Phase AL	All Phase CSE	All Phase HD	All Phase SN	All Phase VS	Impact Score	Recovery Score
Northern Fur Seal	CA	Pinnipeds	4.32	3.30	3.40	1.75	5.04	5.40	23.21	1.80
Killer Whale	CA	Toothed Whales	2.70	2.20	6.38	2.75	6.82	4.80	25.65	1.70
Blue Whale	CA	Baleen Whales	3.51	3.30	5.95	2.50	6.53	4.20	25.99	1.80
Harbor Porpoise	CA	Toothed Whales	2.97	2.57	6.80	2.00	6.53	5.40	26.26	1.50
Leatherback Turtle	CA	Sea Turtles	4.05	4.03	4.68	2.50	5.64	5.40	26.30	1.30
California Sea Lion	CA	Pinnipeds	5.67	2.57	5.10	2.75	5.64	6.60	28.32	1.80
Humpback Whale - CMX DPS	CA	Baleen Whales	4.32	3.67	5.95	3.00	6.82	6.00	29.76	2.00
Hawaiian Monk Seal	HI	Pinnipeds	4.05	1.83	2.55	2.25	3.86	3.00	17.54	2.00
Green Turtle	HI	Sea Turtles	3.51	2.57	4.68	3.00	4.45	4.80	23.00	1.80
Fin Whale	HI	Baleen Whales	3.24	2.93	5.53	3.25	6.23	3.60	24.78	2.10
False Killer Whale	HI	Toothed Whales	3.51	2.57	6.80	2.50	6.53	5.40	27.30	2.50
Humpback Whale - HI DPS	HI	Baleen Whales	3.51	3.30	6.80	2.75	7.12	5.40	28.88	1.70
Pantropical Spotted Dolphin	HI	Toothed Whales	3.51	2.57	7.65	2.00	7.12	6.60	29.45	2.10
Bottlenose Dolphin	HI	Toothed Whales	3.51	2.57	7.65	2.00	7.12	6.60	29.45	1.90
Maximum Possible MT Scores:			8.10	5.50	8.50	5.00	8.90	9.00	45.00	2.50

Table D-19. Impact-causing factor vulnerability scores, summed impact scores, and recovery scores for all fish and invertebrate (FI) species from the unmitigated, mid-LoU value scenario. Cells within each column are color-coded from lowest (green) to highest (red) vulnerability.

Species	Region	Sub-Group	All Phase AS	All Phase AL	All Phase EMF	All Phase HD	All Phase SN	All Phase VS	Impact Score	Recovery Score
South-Central California Coast Steelhead	CA	Anadromous / Catadromous Fish	2.63	2.20	0.46	1.43	2.97	0.00	9.69	0.90
Cowcod	CA	Demersal Fish	2.03	1.47	1.38	1.29	4.15	0.00	10.31	1.30
Orange Puffball Sponge	CA	Sponges	3.44	1.10	1.27	1.86	3.56	0.00	11.22	0.90
Black Abalone	CA	Benthic Invertebrates	3.85	2.20	1.15	2.00	3.56	0.00	12.76	1.20
Orange Sea Pen	CA	Corals	4.25	1.47	1.27	2.86	4.75	0.00	14.59	0.80
Krill	CA	Pelagic Invertebrates	6.08	4.40	0.23	2.43	4.75	0.00	17.88	0.60
Pacific Bluefin Tuna	CA	Large Pelagic Fish	5.27	3.67	0.58	2.00	6.53	0.00	18.03	0.90
Pacific Sardine	CA	Small Pelagic Fish	5.67	4.03	0.23	2.29	8.90	0.00	21.12	0.60
Hawaiian Spiny Lobster	HI	Benthic Invertebrates	2.84	2.20	1.38	2.14	2.37	0.00	10.93	0.80
Hawaiian Grouper	HI	Demersal Fish	3.04	1.47	1.15	1.86	4.15	0.00	11.66	1.20
‘O‘opu naniha	HI	Anadromous / Catadromous Fish	4.05	3.12	0.23	1.43	3.56	0.00	12.39	0.80
Massive Black Sponge	HI	Sponges	4.25	1.47	1.27	2.43	4.75	0.00	14.16	1.30
Box Jelly	HI	Pelagic Invertebrates	4.25	2.57	0.58	2.29	4.75	0.00	14.43	0.50
Pink Coral	HI	Corals	5.87	2.02	0.92	2.29	4.75	0.00	15.84	1.20
Mackeral Scad	HI	Small Pelagic Fish	4.46	3.30	0.12	2.00	6.53	0.00	16.40	0.40
Bigeye Tuna	HI	Large Pelagic Fish	5.67	4.03	0.58	2.29	7.71	0.00	20.28	0.60
Maximum Possible FI Scores:			8.10	5.50	2.30	5.00	8.90	9.00	38.80	2.00

Table D-20. Unnormalized species sensitivity scores by season and region for birds and bats (BB) from the unmitigated, mid-LoU value scenario. The last two columns show the average score across seasons for both the unmitigated and mitigated scenarios. Cells within these columns are color-coded from lowest (green) to highest (red) relative sensitivity.

Species Common Name	Region	Period 1 (Dec-Jan)	Period 2 (Feb-Mar)	Period 3 (Apr-May)	Period 4 (Jun-Jul)	Period 5 (Aug-Sep)	Period 6 (Oct-Nov)	Average Sensitivity Score	
								Unmitigated	Mitigated
Western Snowy Plover	CA	10.31	10.30	20.60	20.93	21.39	10.37	15.65	12.50
Western Grebe	CA	37.63	37.59	18.80	0.00	0.00	18.92	18.82	15.38
Hoary Bat	CA	14.11	28.18	28.18	0.00	14.63	28.37	18.91	15.56
Bald Eagle	CA	25.64	25.62	12.81	13.01	13.30	25.79	19.36	15.94
Brandt's Cormorant	CA	17.73	17.71	17.71	35.98	36.78	17.83	23.96	19.24
Scripps's Murrelet	CA	22.12	22.09	22.09	44.88	45.88	22.24	29.88	24.67
Ashy Storm Petrel	CA	57.26	28.60	28.60	29.05	29.70	57.58	38.47	31.67
Hawaiian Hoary Bat	HI	26.86	26.57	26.57	30.85	37.05	28.38	29.38	24.07
Hawaiian Coot	HI	30.72	30.38	30.38	35.29	42.37	32.46	33.60	26.86
Great Frigatebird	HI	21.79	21.56	43.11	50.07	60.13	23.03	36.62	29.25
Laysan Albatross	HI	69.30	68.54	68.54	39.80	47.80	36.61	55.10	44.07
Hawaiian Stilt	HI	51.92	51.35	51.35	59.64	71.62	54.86	56.79	45.34
Wedge-Tailed Shearwater	HI	31.94	31.60	63.19	73.39	88.13	67.51	59.29	47.26
Hawaiian Petrel	HI	38.52	38.10	38.10	88.49	106.27	81.39	65.15	52.78
Max BB	HYP_Max	153.76	153.76	153.76	153.76	153.76	153.76	153.76	122.44

Table D-21. Unnormalized species sensitivity scores by season and region for marine mammals and turtles (MT) from the unmitigated, mid-LoU value scenario. The last two columns show the average score across seasons for both the unmitigated and mitigated scenarios. Cells within these columns are color-coded from lowest (green) to highest (red) relative sensitivity

Species Common Name	Region	Period 1 (Dec-Jan)	Period 2 (Feb-Mar)	Period 3 (Apr-May)	Period 4 (Jun-Jul)	Period 5 (Aug-Sep)	Period 6 (Oct-Nov)	Average Sensitivity Score	
								Unmitigated	Mitigated
Leatherback Turtle	CA	19.30	19.28	19.28	39.16	40.03	19.40	26.07	21.97
Northern Fur Seal	CA	47.17	47.12	47.12	23.93	24.47	47.44	39.54	32.87
Blue Whale	CA	26.40	26.38	26.38	53.58	54.78	53.10	40.10	34.10
California Sea Lion	CA	57.56	57.49	28.75	29.20	29.85	57.88	43.45	36.51
Harbor Porpoise	CA	44.47	44.43	44.43	45.13	46.13	44.72	44.89	38.34
Killer Whale	CA	49.22	49.17	49.17	49.95	51.06	49.50	49.68	42.58
Humpback Whale - CMX DPS	CA	67.19	67.12	67.12	68.18	69.70	67.57	67.82	57.44
Humpback Whale - HI DPS	HI	34.97	69.17	34.59	0.00	0.00	0.00	23.12	19.44
Green Turtle	HI	58.97	58.33	29.17	33.87	40.68	62.31	47.22	39.69
Hawaiian Monk Seal	HI	49.97	49.42	49.42	57.40	68.93	52.80	54.66	44.89
Fin Whale	HI	74.12	73.31	36.66	42.57	51.12	78.31	59.35	49.96
Bottlenose Dolphin	HI	79.69	78.83	78.83	91.55	109.94	84.20	87.17	73.10
Pantropical Spotted Dolphin	HI	88.08	87.12	87.12	101.18	121.51	93.07	96.35	80.80
False Killer Whale	HI	97.23	96.17	96.17	111.69	134.12	102.73	106.35	89.34
Max MT	HYP_Max	221.06	221.06	221.06	221.06	221.06	221.06	221.06	182.94

*CMX = Mexico/Central American DPS

Table D-22. Unnormalized species sensitivity scores by season and region for fish and invertebrates (FI) from the unmitigated, mid-LoU value scenario. The last two columns show the average score across seasons for both the unmitigated and mitigated scenarios. Cells within these columns are color-coded from lowest (green) to highest (red) relative sensitivity

Species Common Name	Region	Period 1 (Dec-Jan)	Period 2 (Feb-Mar)	Period 3 (Apr-May)	Period 4 (Jun-Jul)	Period 5 (Aug-Sep)	Period 6 (Oct-Nov)	Average Sensitivity Score	
								Unmitigated	Mitigated
South-Central California Coast Steelhead	CA	9.84	9.83	4.92	4.99	5.11	4.95	6.61	5.37
Pacific Sardine	CA	7.15	7.15	14.29	7.26	7.42	7.19	8.41	6.67
Krill	CA	6.06	6.05	12.10	12.29	12.56	6.09	9.19	7.37
Orange Puffball Sponge	CA	11.40	11.39	11.39	11.57	11.83	11.47	11.51	9.47
Pacific Bluefin Tuna	CA	9.16	9.15	9.15	9.30	19.01	18.43	12.37	9.87
Orange Sea Pen	CA	13.18	13.16	13.16	13.37	13.67	13.25	13.30	10.96
Cowcod	CA	15.13	15.12	15.12	15.35	15.70	15.22	15.27	12.58
Black Abalone	CA	17.28	17.26	17.26	17.54	17.93	17.38	17.44	14.31
Mackeral Scad	HI	4.67	4.62	4.62	5.37	12.89	9.87	7.01	5.48
Box Jelly	HI	10.27	10.16	10.16	11.80	14.17	10.86	11.24	8.95
Hawaiian Spiny Lobster	HI	12.46	12.32	12.32	14.31	17.18	13.16	13.63	10.90
Bigeye Tuna	HI	17.33	17.14	8.57	9.95	11.95	18.31	13.88	11.27
‘O‘opu naniha	HI	14.11	13.96	13.96	16.21	19.47	14.91	15.44	12.13
Hawaiian Grouper	HI	19.94	19.72	19.72	22.90	27.50	21.07	21.81	17.60
Massive Black Sponge	HI	26.22	25.93	25.93	30.12	36.17	27.70	28.68	23.09
Pink Coral	HI	27.08	26.78	26.78	31.10	37.35	28.61	29.62	23.45
Max FI	HYP_Max	152.48	152.48	152.48	152.48	152.48	152.48	152.48	122.72

Table D-23. Normalized species group sensitivity scores used to obtain summed species sensitivity scores by season and region for the mid-LoU value impact scores for both unmitigated and mitigated scenarios. Cells are color-coded from lowest (green) to highest (red) sensitivity relative to the hypothetical minimum and maximum scores.

Species Group	Region	Mitigation Scenario	Period 1 (Dec-Jan)	Period 2 (Feb-Mar)	Period 3 (Apr-May)	Period 4 (Jun-Jul)	Period 5 (Aug-Sep)	Period 6 (Oct-Nov)	Average
BB	CA	unmitigated	1.69	1.63	1.55	1.53	1.60	1.67	1.61
FI	CA	unmitigated	1.29	1.29	1.32	1.30	1.34	1.31	1.31
MT	CA	unmitigated	1.72	1.72	1.73	1.80	1.82	1.88	1.78
BB	CA	mitigated	1.56	1.52	1.45	1.44	1.49	1.55	1.50
FI	CA	mitigated	1.24	1.24	1.26	1.24	1.27	1.25	1.25
MT	CA	mitigated	1.61	1.61	1.62	1.68	1.69	1.74	1.66
BB	HI	unmitigated	2.01	2.00	2.19	2.40	2.68	2.20	2.25
FI	HI	unmitigated	1.43	1.43	1.40	1.46	1.58	1.47	1.46
MT	HI	unmitigated	2.25	2.32	2.06	2.13	2.36	2.22	2.23
BB	HI	mitigated	1.81	1.80	1.96	2.13	2.35	1.97	2.00
FI	HI	mitigated	1.35	1.34	1.32	1.37	1.46	1.38	1.37
MT	HI	mitigated	2.05	2.11	1.89	1.95	2.13	2.03	2.03
Species Group Sensitivity HYP_Min			1						
Species Group Sensitivity HYP_Max			5						
All	CA	unmitigated	4.70	4.64	4.60	4.63	4.76	4.86	4.70
All	CA	mitigated	4.41	4.36	4.33	4.36	4.46	4.55	4.41
All	HI	unmitigated	5.69	5.75	5.66	6.00	6.62	5.90	5.94
All	HI	mitigated	5.21	5.26	5.17	5.44	5.94	5.37	5.40
Summed Species Sensitivity HYP_Min			3						
Summed Species Sensitivity HYP_Max			15						

D.5 Final Environmental Sensitivity Results

The environmental sensitivity scores added the combined group species sensitivity score to the habitat sensitivity score for each region and season (Table D-24). These scores ranged from a hypothetical minimum of 4 to a hypothetical maximum of 30. The unmitigated environmental sensitivity scores for California ranged from 9.7 in period 1 (December to January) to 8.83 in Period 3 (April to May). The mitigated scores for each season were approximately 2.9% – 3.3% lower than the unmitigated scores in California. The unmitigated environmental sensitivity scores for Hawaii North ranged from a low of 10.6 in period 1 to a high of 13.2 in period 5. Similarly, the unmitigated environmental sensitivity scores for Hawaii South ranged from 10.4 in period 1 to 12.9 in period 5. The mitigated scores for each season were approximately 4.3% – 5.3% lower than the unmitigated scores for both Hawaii study areas.

The final environmental sensitivity (FES) score was calculated by modifying (i.e., multiplying) the environmental sensitivity score by the baseline conditions score (Table D-25). This served to increase the sensitivity of regions with greater amounts of potential stress from anthropogenic sources. The baseline conditions score ranged from 1 – 2, which increased the hypothetical maximum score to 60. Unmitigated FES scores ranged from 9.1 – 10.0 for California, from 12.4– 15.4 for Hawaii North, and from 12.7 – 15.8 for Hawaii South, with the highest scores occurring during period 1 (December – January) for California and period 5 (August – September) in both Hawaii regions. The highest seasonal scores for California, Hawaii North, and Hawaii South represent 16.7%, 25.7%, and 26.4% of the hypothetical maximum final environmental sensitivity score, respectively. The mitigation options lowered scores by 2.9% – 3.3% for California, 4.3% – 5.2% for Hawaii North, and 4.4 – 5.3% for Hawaii South.

Averaged annual FES scores for all three uncertainty values (lower, mid, upper) of the 25-nm buffer size and both scenarios (unmitigated, mitigated) are displayed in Table D-26. The range between the upper and lower estimates for FES scores for California was 0.6 for the unmitigated scenario and 0.5 for the mitigated scenario, while upper and lower scores differed by approximately 1.1 for Hawaii North and Hawaii South for the unmitigated scenario and 0.9 for the mitigated scenario.

Table D-24. Environmental sensitivity (ES) scores by season and region for both the unmitigated and mitigated, mid-LoU value scenarios in the 25-nm buffer zone*. Cells are color-coded along a gradient of low (green) to high (red) sensitivity.

Region	Mitigation Scenario	Period 1 (Dec-Jan)	Period 2 (Feb-Mar)	Period 3 (Apr-May)	Period 4 (Jun-Jul)	Period 5 (Aug-Sep)	Period 6 (Oct-Nov)
CA	unmitigated	9.75	8.88	8.83	9.38	9.61	9.43
HI_N	unmitigated	10.59	10.68	11.33	11.34	13.23	10.80
HI_S	unmitigated	10.37	10.58	11.02	11.09	12.89	10.60
CA	mitigated	9.47	8.60	8.56	9.10	9.31	9.12
HI_N	mitigated	10.11	10.19	10.84	10.78	12.54	10.27
HI_S	mitigated	9.88	10.09	10.53	10.54	12.20	10.07
HYP_Min	both	4					
HYP_Max	both	30					

*Note: These ES scores were calculated by adding the habitat sensitivity and species sensitivity scores together.

Table D-25. Final environmental sensitivity (FES) scores by season and region in the 25-nm buffer zone for both unmitigated and mitigated, mid-LoU value scenarios*. Cells are color-coded along a gradient of low (green) to high (red) sensitivity.

Region	Mitigation Scenario	Period 1 (Dec-Jan)	Period 2 (Feb-Mar)	Period 3 (Apr-May)	Period 4 (Jun-Jul)	Period 5 (Aug-Sep)	Period 6 (Oct-Nov)	Average FES
CA	unmitigated	10.03	9.13	9.08	9.64	9.88	9.70	9.58
HI_N	unmitigated	12.36	12.47	13.22	13.24	15.44	12.60	13.22
HI_S	unmitigated	12.75	13.01	13.55	13.64	15.85	13.03	13.64
CA	mitigated	9.73	8.85	8.80	9.35	9.57	9.38	9.28
HI_N	mitigated	11.80	11.90	12.66	12.59	14.64	11.99	12.60
HI_S	mitigated	12.16	12.40	12.95	12.96	15.01	12.38	12.98
HYP_Min	both	4						
HYP_Max	both	60						

* Note: This parameter multiplies the environmental sensitivity in each region and season by the baseline conditions score for a region.

Table D-26. Averaged annual final environmental sensitivity (FES) scores by region for all three LoU values (mid, min, and max) in the 25-nm buffer zone for both unmitigated and mitigated scenarios.

Region	Mitigation Scenario	Annual Average FES Score			Percent of Max FES Score		
		Mid	Lower	Upper	Mid	Lower	Upper
CA	unmitigated	9.58	9.30	10.17	16.0%	15.5%	16.9%
HI_N	unmitigated	13.22	12.67	14.28	22.0%	21.1%	23.8%
HI_S	unmitigated	13.64	13.06	14.75	22.7%	21.8%	24.6%
HYP_Min	both	4			6.7%		
HYP_Max	both	60			100%		
CA	mitigated	9.28	9.05	9.77	15.5%	15.1%	16.3%
HI_N	mitigated	12.60	12.14	13.45	21.0%	20.2%	22.4%
HI_S	mitigated	12.98	12.50	13.88	21.6%	20.8%	23.1%

D.6 References

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Appendix E: Species Database References

This appendix contains all of the references with reference code and full citation from the OFWESA database following species sensitivity literature review.

Ref_Code	Full Citation
AM-01	Harris J. 2008. Life History Account for Big Brown Bat (*Eptesicus fuscus*). California Wildlife Habitat Relationships System. California Department of Fish and Wildlife - California Interagency Wildlife Task Group; [accessed October 2017]. https://nrm.dfg.ca.gov/taxaquery/SpeciesDocumentList.aspx?AssociatedItemID=552&STitle=Eptesicus+fuscus&PTitle=Big%2bBrown%2bBat
AM-02	Rainey W. 2008. Range Map for Big Brown Bat (*Eptesicus fuscus*). California Wildlife Habitat Relationships System. California Department of Fish and Wildlife - California Interagency Wildlife Task Group; [accessed October 2017]. https://nrm.dfg.ca.gov/taxaquery/SpeciesDocumentList.aspx?AssociatedItemID=552&STitle=Eptesicus+fuscus&PTitle=Big%2bBrown%2bBat
AM-03	California Department of Fish and Wildlife (CDFW). 2017. Species & Vegetation - Species Explorer. [accessed October 2017]. https://nrm.dfg.ca.gov/taxaquery/
AM-04	Polite C, Pratt J. 2008. Life History Account for Bald Eagle (*Haliaeetus leucocephalus*). California Wildlife Habitat Relationships System. California Department of Fish and Wildlife - California Interagency Wildlife Task Group; [accessed October 2017]. https://nrm.dfg.ca.gov/taxaquery/SpeciesDocumentList.aspx?AssociatedItemID=858&STitle=Haliaeetus+leucocephalus&PTitle=bald%2beagle
AM-05	Hunting K. 2008. Range Map for Bald Eagle (*Haliaeetus leucocephalus*). California Wildlife Habitat Relationships System. California Department of Fish and Wildlife - California Interagency Wildlife Task Group; [accessed October 2017]. https://nrm.dfg.ca.gov/taxaquery/SpeciesDocumentList.aspx?AssociatedItemID=858&STitle=Haliaeetus+leucocephalus&PTitle=bald%2beagle
AM-06	Polite C, Pratt J. 2008. Life History Account for Peregrine Falcon (*Falco peregrinus*). California Wildlife Habitat Relationships System. California Department of Fish and Wildlife - California Interagency Wildlife Task Group; [accessed October 2017]. https://nrm.dfg.ca.gov/taxaquery/SpeciesDocumentList.aspx?AssociatedItemID=877&STitle=Falco+peregrinus&PTitle=Peregrine%2BFalcon
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AM-10	National Park Service (NPS). 2016. Channel Islands National Park California: Scripp's Murrelet. [accessed October 2017]. https://www.nps.gov/chis/learn/nature/xantus-murrelet.htm
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AM-12	US Environmental Protection Agency (USEPA). 2010. Endangered Species Facts: California Clapper Rail (*Rallus longirostris obsoletus*). Endangered Species Protection Program (ESPP). [accessed October 2017]. https://www.epa.gov/sites/production/files/2013-08/documents/ca-clapper-rail.pdf
AM-13	Rigney M. 2008. Life History Account for Snowy Plover (*Charadrius alexandrinus*). California Wildlife Habitat Relationships System. California Department of Fish and Wildlife - California Interagency Wildlife Task Group; [accessed October 2017]. https://nrm.dfg.ca.gov/taxaquery/SpeciesDetail.aspx?taxonid=905&STitle=Charadrius+alexandrinus&PTitle=Snowy+Plover
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AU-54	Orr, A.J., J.D. Harris, K.A. Hirschberger, J.L. Laake, R.L. DeLong, and G.S. Sanders. 2016. Characterizing and quantifying California sea lion (Zalophus californianus) use of offshore oil and gas platforms in California. US Department of the Interior, Bureau of Ocean Energy Management, Pacific OCS Region, Camarillo, CA. OCS Study BOEM 2016-009. 35 p.
AU-55	Palmer Long Tern Ecological Research. 2012. Investigating behavior of krill. [date accessed Apr 2018]. http://pal.lternet.edu/blogs/2012/files/2013/01/Investigating-Krill-Behaviors-FINAL.pdf
AU-56	Pacific Rim Conservation. 2012. Hawaiian Bird Conservation Action Plan. [date accessed 2018 Apr 20]. https://www.pacificrimconservation.org/wp-content/uploads/2013/10/Albatrosses.pdf
AU-57	Pelletier, S.K., K.S. Omland, K.S. Watrous, and T.S. Peterson. 2013. Information Synthesis on the Potential for Bat Interactions with Offshore Wind Facilities: Final Report. OCS Study BOEM 2013-01163, 119. Herndon, VA: U.S. Department of the Interior, Bureau of Ocean Energy Management.
AU-58	Pennisi E (2007) Spawning for a better life. Science 318:1712–1717
AU-59	Reeves, R.R., P.J. Clapham, R.L. Brownell, Jr., and G.K. Silber. Recovery plan for the blue whale (Balaenoptera musculus). Office of Protected Resources, National Marine Fisheries Service, 48 pp. Available: http://www.nmfs.noaa.gov/pr/pdfs/recovery/whale_blue.pdf
AU-60	Reed, JM, C.S. Elphick, and L. Oring. 1998a. Life-history and viability analysis of the endangered Hawaiian stilt. Biological Conservation 84:35- 45.
AU-61	Riggs RA. 2016. Movement and sexual dimorphism of the endangered hawaiian coot, (fulica alai), on Oahu. The University of Hawaiʻl at Mānoa Master's Thesis. https://scholarspace.manoa.hawaii.edu/bitstream/10125/51574/1/2016-12-ms-riggs.pdf
AU-62	Robinson Willmott, J., G.M. Forcey, and L.A. Hooton. 2015. Developing an automated risk management tool to minimize bird and bat mortality at wind facilities. Ambio 44(Suppl. 4). doi: 10.1007/s13280-015-0707-z

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AU-64	Sekiguchi, K. 1987. Occurrence and behaviour of harbour porpoises (Phocoena phocoena) at Pajaro Dunes, Monterey Bay, California. MSc thesis, San Jose State University, California
AU-65	Southern WE. 1963. Winter populations, behavior and seasonal dispersal of Bald Eagles in northwestern Illinois. Wilson Bull. 75:42-55.
AU-66	Spanier, Ehud & Lavalli, Kari & Edelist, Dor. (2011). Artificial reefs for Lobsters An Overview of Their Application for Fisheries Enhancement, Management, and Conservation. 77-109.
AU-67	Secretariat of the Pacific Community (SPC) and the LMMA Network. 2015. Marine Species Information Sheets: Spiny Lobsters. [date accessed Apr 2018]. https://spccfpstore1.blob.core.windows.net/digitallibrary-docs/files/7b/7b27b050a0015f888818dfc456232c8e.pdf?sv=2015-12-11&sr=b&sig=RK0uD3lDy93bA%2FGisPF0aYZeZgB8YaklF04s2CwwlJs%3D&se=2018-10-28T14%3A42%3A42Z&sp=r&rscc=public%2C%20max-age%3D864000%2C%20max-stale%3D86400&rsct=application%2Fpdf&rscd=inline%3B%20filename%3D%22Anon_11_ISFC_13_SpinyLobsters.pdf%22
AU-68	Stafford KM, Fox CG, Clark DS (1998) Long-range acoustic detection and localization of blue whale calls in the northeast Pacific Ocean. J Acoust Soc Am 104: 3616–3625
AU-69	SWCA Environmental Consultants. 2010. Kahuku Wind Power Habitat Conservation Plan. In preparation for Kahuku Wind Power LLC. Kahului, HI. [date accessed 2018 Apr 20]. http://dlnr.hawaii.gov/wildlife/files/2013/10/Kahuku-Wind-Power-HCP-FINAL-TEXT.pdf
AU-70	SYDEMAN, W. J., K. A. HOBSON, P. PYLE, AND E. B. MCLAREN. 1997. Trophic relationships among seabirds in central California: combined stable isotope and conventional dietary approach. Condor 99: 327–336.
AU-71	This Fish. 2013. Hapuʻupuʻu (Grouper). [date accessed Apr 2018]. https://thisfish.info/fishery/species/hapuupuu-grouper/
AU-72	Thomsen, F., K. Lüdemann, R. Kafemann, and W. Piper. 2006. Effects of Offshore Wind Farm Noise on Marine Mammals and Fish. Biola, Hamburg, Germany, on behalf of COWRIE Ltd., Newbury, UK, 62 pp.
AU-73	Tsounis G, Rossi S, Grigg R, Santangelo G, Bramanti L, Gili JM (2010) The exploitation and conservation of precious corals. Oceanogr Mar Biol Annu Rev 48:161–211
AU-74	University of Hawaii (UHI). 2018. Waikiki Aquarium: Box Jelly. Available online at: http://www.waikikiaquarium.org/experience/animal-guide/invertebrates/jellies/box-jellies/. Accessed April 2018.
AU-75	U.S. Fish and Wildlife Service. 2011. Recovery Plan for Hawaiian Waterbirds, Second Revision. U.S. Fish and Wildlife Service, Portland, Oregon. xx + 233 pp.
AU-76	U.S. Fish and Wildlife Service. 2018.Western Snowy Plover (Charadrius nivosus nivosus). [date accessed 2018 Apr 20]. https://www.fws.gov/arcata/es/birds/wsp/plover.html. Accessed: April 2018.
AU-77	Walker, M. M., J. L. Kirschvink, S. B. R. Chang, and A. E. Dizon. 1984. A candidate magnetic sense organ in the yellowfin tuna, *Thunnus albacares*. Science 224:751-753.

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AU-78	Williams, R., Lusseau, D., & Hammond, P. S. (2006). Estimating relative energetic costs of human disturbance to killer whales (*Orcinus orca*). Biological Conservation, 133(3), 301-311.
AU-79	U.S. Fish and Wildlife Service (USFWS). 2016. Bald and Golden Eagles: Population demographics and estimation of sustainable take in the United States, 2016 update. Division of Migratory Bird Management, Washington D.C., USA.

Appendix F: Model Background Research

This appendix provides an overview of the background research conducted for the model development and modeling approach. Modeling Approach: Large Scale Events. This section outlines the methodology for incorporating large scale events into environmental sensitivity scoring.

F.1 Literature Review

The conceptual foundation of the Offshore Floating Wind Environmental Sensitivity Analysis (OFWESA) model developed herein is provided by three key documents, *A Method for the Evaluation of the Relative Environmental Sensitivity and Marine Productivity of the Outer Continental Shelf* (BOEM 2013), *Assessment of Marine Oil Spill Risk and Environmental Vulnerability for the State of Alaska* (NOAA 2014),and *Collision and Displacement Vulnerability among Marine Birds of the California Current System Associated with Offshore Wind Energy Infrastructure* (Adams et al. 2016). While the first two methodologies were primarily designed to address environmental sensitivity to large oil spill events, the base ecological concepts of species and habitats encounter, impact, and recovery from a given ICF transfer well to the OFW sector. A major difference between these 'oil spill centric' models and the OFWESA is the potential for population level impacts. Concepts from the two oil-spill bases models that centered around the concept of population level impacts have been removed from the OFWESA model. The general concepts provided by these earlier sensitivity methodologies (which themselves were developed off of existing risk and sensitivity models) offer the basis for the current model:

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

The OFWESA model was developed to expand upon the earlier base studies to provide application directly to OFW for the U.S. OCS and coastal regions. Beyond the three base models examined, additional studies specific to wind energy environmental sensitivities and risks were collected and reviewed. Published, peer-reviewed, English language studies (or those that provided English language abstracts) indexed in scientific databases were the primary focus of the review, although relevant books, book chapters, government and industry technical reports, and websites were also included. Along with the extensive expertise of the project team, this review served as the basis for development of the OFWESA model.

A number of common ecological "themes" used to assess sensitivity of environmental resources to OFW were identified from the literature review (Table F-1). These themes form the core of the species sensitivity scoring and include abundance, impact potential (probability of encountering impacts, physiology, concentration/aggregation, and habitat flexibility), and recovery potential (conservation/population status, reproductive potential, geographic range, breeding score, and adult survival). Each document studied in the literature review also considered a unique suite of ICFs (Table F-2). Together, the set of ecological themes and ICFs provided by available literature were used to develop the species and habitat scoring scheme for the OFWESA model and ensure no concepts of potential, non-negligible impacts were omitted.

Table F-1. Overview of literature review results for species sensitivity metrics. Green shading indicates model/assessment included the theme.

				Impact Potential				Recovery Potential			
Study Name/Citation	**Study Location[1]**	**Species Groups[2]**	**Abundance/ Relative Abundance**	**Encounter**	**Physiology**	**Habitat Flexibility**	**Concentration/ Aggregation**	**Conservation/ Population Status**	**Reproductive Potential/Breeding**	**Geographic Range**	**Survival Rate**
BOEM RESA (2014a)	US OCS	F/I, M/T, B		🟩	🟩		🟩	🟩	🟩	🟩	
AK/Arctic Oil Spill Risk Assessment (NOAA 2014)	Alaska	F/I, M/T, B	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	
Adams et al. (2016)	California	B	🟩	🟩		🟩	🟩	🟩	🟩	🟩	🟩
Bergstrom et al. (2014)	Europe	F/I, M/T		🟩							
Furness et al. (2013)	Europe	B		🟩	🟩	🟩		🟩			
Scott et al. (2014)		B		🟩	🟩						
Johnston et al. (2014)	Europe	B		🟩							
Marques et al. (2014)		B		🟩	🟩		🟩			🟩	
Schwemmer et al. (2011)		B		🟩	🟩						
Garthe and Huppop (2004)	Europe	B	🟩	🟩	🟩		🟩	🟩			
Gill (2005)		F/I, M/T, B	🟩	🟩		🟩		🟩	🟩		
Goodale and Stenhouse (2016)		F/I, M/T, B	🟩	🟩	🟩			🟩	🟩		
Copping and Hanna (2011)		F/I, M/T, B	🟩	🟩	🟩	🟩		🟩	🟩		
OFWESA (Present Study)	US OCS	F/I, M/T, B	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩

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[1] Blank study location indicates model/assessment was not spatially explicit

[2] F/I – Fish and Invertebrates, M/T – Marine Mammals and Turtles, B – Birds.

Table F-2. Overview of literature review results for ICFs. Green shading indicates model/assessment included the ICF

Study Name/Citation	Study Location	Species Groups	ICFs							
			Accidental Spill	Artificial Light	Collisions Above-Surface	Entanglement Sub-Surface	Electromagnetic Fields	Habitat Disturbance/ Displacement	Sound/Noise	Vessel Strikes
BOEM RESA (2014a)	US OCS	F/I, M/T, B	🟩		🟩			🟩	🟩	🟩
AK/Arctic Oil Spill Risk Assessment (NOAA 2014)	Alaska	F/I, M/T, B	🟩							
Adams et al. (2016)	California	B			🟩			🟩		
Bergstrom et al. (2014)	Europe	F/I, M/T					🟩	🟩	🟩	
Furness et al. (2013)	Europe	B			🟩				🟩	
Scott et al. (2014)		B			🟩			🟩		
Johnston et al. (2014)	Europe	B			🟩					
Marques et al. (2014)		B		🟩	🟩					
Schwemmer et al. (2011)		B						🟩	🟩	🟩
Garthe and Huppop (2004)	Europe	B	🟩		🟩			🟩	🟩	
Gill (2005)		F/I, M/T, B			🟩		🟩	🟩	🟩	
Goodale and Stenhouse (2016)		F/I, M/T, B								
US DOE ERES		F/I, M/T, B	🟩		🟩		🟩		🟩	
OFWESA (Present Study)	US OCS	F/I, M/T, B	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩

F.2 Accidental Spills Risk for OFW facilities

Accidental spills of oil and chemicals are one of the ICFs identified for offshore wind turbines in the original Relative Environmental Sensitivity Analysis (RESA) model developed for BOEM (Minerals Management Service [MMS] 2007; Niedroda et al. 2014) and included in the current study, *Environmental Sensitivity and Associated Risk to Habitats and Species on the Pacific West Coast and Hawaii with Offshore Floating Wind Technologies*, as part of the OFWESA model.

For OFW facilities, there are several types of chemicals and oils that may accidentally spill. For floating wind turbines, these include but are not limited to, lubricators (e.g., Mobil SCH 632, Optimol Synthetic A320, Mobil SHC XMP 220, polyalphaolefin/ester-based products), phenol, acetone, and polyethylene terephthalate. Accidental chemical spills from floating substations may include naphthenic mineral oil, dielectric fluid, transformer oil (motor and/or diesel), Edisol XT, and sulfuric acid (Bejarano et al. 2013).

The potential causes of spills from OFW facilities include natural events, such as earthquakes, tsunamis, and storms (hurricanes) that cause sufficient structural damage. There may also be fires or explosions that occur in one of the facility components that, with sufficient damage, could result in spillage. Other potential causes of spillage are structural failures, such as corrosion, cracking, and wind or water erosion that result in breakage of components that hold or transport oil or chemicals.

There may also be mechanical or equipment failures (e.g., failure in one of the mechanical, electrical, or computerized components due to lack of necessary maintenance, negligence, or some unforeseen problem) that result in spillage. In addition, routine errors during operation and maintenance, including those that occur during oil transfers (replenishing, exchanging, or refueling from either the delivery vessel or from the facility side) may lead to an unintended release.

There is the possibility of intentional damage, which could take the form of vandalism, such as intentionally breaking, damaging, or manipulating the controls or mechanics of the components, or a terrorist attack involving an airplane or vessel ramming into one of the components. Bombs or other incendiary devices could be dropped from an airplane or launched from a vessel as part of a terrorist attack or as an act of war (Etkin 2006a; Etkin 2008).

Another possible cause of spillage is from vessel accidents (Etkin 2006b; Etkin 2008). Passing vessels or even vessels supplying or servicing the OFW facility may cause spills through allisions[3] with facility structures. Spillage could occur from either the wind facility structure(s), the vessel, or both. There could also be spills from vessels that collide with each other due to the presence of the wind facility, which interferes with communications or vision to the extent that vessels collide and then spill their own fuel or even cargo in the case of tank vessels carrying oil or chemicals. Hypothetically, there could also be an accidental grounding if the vessel goes off-course due to the presence of the wind facility.

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[3] The term “allision” is used rather than “collision” in this case, because a moving object (vessel) is hitting a stationary object (wind facility component). In a “collision,” both objects are moving, as for example when two vessels hit each other.

F.2.1 Types of Spills Potentially Associated with OFW facilities

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,[4] and storms (hurricanes);
2. spills caused by fires and explosions in facility structures;
3. spills resulting from structural or equipment failures in facility structures;
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.[5]

Spills from wind facility components themselves could involve various chemicals and oils, as described in Section F.3.2. 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 (a few gallons to 40,000-100,000 gallons for electric service platforms). Therefore, the majority of these spills would not be considered "major" according to the criteria in the National Contingency Plan (NCP). According to the NCP, a "major" oil spill is defined 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). The relatively localized effects of small to moderate spills are considered in the OFWESA model.

Spills that might occur from vessels that strike or allide with a floating offshore wind 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 and are described in Section F.3.7.1.

F.2.1.1 Types of Spill Probabilities Outside the OFWESA Model

As mentioned in Section 1 of this report, the *absolute* impacts of potential spills worsened by large-scale events are not inputs to the OFWESA model. However, the *relative* differences in the frequency and magnitude of spills that might occur in different locations are important. The spill categories listed in Section F.3.1.1 were evaluated with respect to the likelihood that there would be relative differences between OFW facility locations in the frequency and magnitude of large-scale events and spills. It was assumed that the basic infrastructure and operations of the facilities would be analogous in different locations.

The probability of spills due to fire and explosions, structural or equipment failures, and operational errors of the OFW structures themselves were not able to be effectively incorporated into the OFWESA model, because they would theoretically have the same likelihood of occurrence regardless of location

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[4] 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.

[5] 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.

and thus would not result in a different probability ranks for different study areas. When probability ranks between different study areas are identical, they do not affect the overall score in the model used to evaluate the relative sensitivity and respective risk of the area.

Furthermore, there are no specific data or records of fires and explosions occurring at OFW facilities outside of one report of a fire that occurred due to structural damage in a storm (Diamond 2012), nor are there data or records about structural and equipment failures in OFW facilities that occur unrelated to external force from natural events or vessel allisions—though this does not imply that this does not or could not occur. These types of spills would generally involve relatively small to moderate volumes of oil and/or chemicals and if such a spill were to occur, the volume would not typically exceed the "major" spill threshold of 100,000 gallons (40 CFR § 300.5) and the impacts would likely be localized.

In the context of land-based wind turbines, there is anecdotal information about spillage that occurs during routine maintenance as well as spillage that occurs during fires. Examples of such anecdotes have been reproduced below (Rafferty 2012).

- A damaged transformer leaked 491 gallons of mineral oil in 2007 at the Maple Ridge Wind Farm's substation in New York; in 2009, a transformer at the same site was destroyed by fire, the *Watertown Daily News* reported.
- A Sheffield, Vermont wind turbine spilled 55-60 gallons of gear oil, spraying it out 200 yards; each turbine generator holds about 110 gallons of hydraulic and lubricating oils, the *Burlington Free Press* reported.
- In White Deer Texas, News Channel 10 reported oil seeping down the sides of multiple turbines.
- Around 168 wind turbine fires have been documented. Some sparked brush fires and left some fire departments helpless to watch as oil in turbine components burned hundreds of feet in the air—out of reach of hoses—whirling burning debris across the landscape.

Some non-governmental organizations have collected anecdotal information about a variety of potential environmental issues related to wind energy facilities, including spills. The World Council for Nature (2014) has expressed concerns about land-based wind turbines causing environmental damage from leaks. The Wind Action Group Corp., a group that professes to have been formed "to counteract the misleading information promulgated by the wind energy industry and various environmental groups"[6] has also collected various news stories about spills associated with land-based wind energy facilities.[7] However, information collected by this organization has not undergone any rigorous review or analyses.

Intentional damage would probably differ by location, at least to some extent. However, analyzing the likelihood of vandalism, terrorism, or war by geography is complex and beyond the scope of this study.

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[6] http://www.windaction.org

[7] For example, http://www.windaction.org/posts/46701-wind-power-pollution-turbine-oil-seeps-into-the-land-in-mexico#.WUlm_9yQyJA
http://www.windaction.org/posts/44755-oil-leaks-at-wind-turbines-in-the-thumb-not-a-rarity#.WUlnS9yQyJA
http://www.windaction.org/posts/44482-fallen-turbine-s-oil-spill-shouldn-t-be-a-problem#.WUlnkdyQyJA
http://www.windaction.org/posts/40854-investigation-launched-into-hydraulic-oil-leaks-at-ocotillo-wind-facility#.WUlnydyQyJA
http://www.windaction.org/posts/37492-wind-farm-oil-spill-causes-uproar#.WUlodtyQyJA
http://www.windaction.org/posts/32037-sheffield-wind-turbine-spills-gear-oil#.WUlpldyQyJA
http://www.windaction.org/posts/32028-a-wind-turbine-springs-oil-leak#.WUlppNyQyJA

F.2.1.2 Approach to Incorporation into OFWESA Model

Impacts due to damages from external environmental forces and vessel-related accidents that cause spillage from OFW facility components were incorporated into the OFWESA model, as they can be ranked by probabilities of occurrence in different study areas (Table F-3), which is necessary for use as a regional modifier for environmental sensitivity. In order to include spills from vessels that occur when vessels collide with one another or ground due to the presence of the OFW facility in the model framework, a number of site- and project-specific conditions would be required. Because there are too many unknown variables based on site- and project-specific conditions that would be required to derive a meaningful event probability, spill impacts from these types of vessel incidents cannot be appropriately factored into the model's probability ranking system. In addition, the presence of a large amount of vessel traffic and the propensity for spills will already be captured under the analysis of vessel allision incidents that cause spillage from wind facility components.

Table F-3. Large Scale Event Types Considered in the Analysis

Large-Scale Event Type	Relation to OFWESA Model
Earthquakes	Regional differences in probability of occurrence calculated and included in relative risk assessment
Tsunamis	Regional differences in probability of occurrence calculated and included in relative risk assessment
Storms/Hurricanes	Regional and seasonal differences in probability of occurrence calculated and included in relative risk assessment
Fire/Explosions	No data available to calculate probabilities of occurrence in different regions, so not usable in relative risk assessment
Structural/Equipment Failure	No data available to calculate probabilities of occurrence in different regions, so not usable in relative risk assessment
Operational Errors/Maintenance	No data available to calculate probabilities of occurrence in different regions, so not usable in relative risk assessment
Intentional Damage	Geographical influence too complex to estimate probabilities of occurrence in different regions, so not usable in relative risk assessment
Vessel Allision with Facility – Contaminant Release from Wind Facility	Regional differences in vessel traffic density included as a proxy for allisions with wind facility in relative risk assessment
Vessel Allision with Facility – Contaminant Release from Vessels	The probabilities of contaminant releases from vessels are impossible to estimate without project-specific details and in-depth vessel traffic studies, so not able to include in a general relative risk assessment
Collision between Vessels due to Presence of Facility – Contaminant Release from Vessels	

Large-scale events could cause or increase the occurrence of various ICFs, including:

- 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.

In the OFWESA model, each large-scale event is also mapped to a set of ICFs that are likely to occur or increase in relation to the event (Table F-4). These ICFs were previously evaluated for their scale of impact (site-specific, small, moderate, large) in the Task 1 report to BOEM (RPS ASA and ICF, 2017). The large-scale event rates evaluated in this report are applied as a modifier to the combined habitat and species sensitivity score for each study area to represent the potential intensifying effect of large-scale events on the scale of impact for related ICFs.

Table F-4. Relationship between Large-Scale Events and ICFs

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

F.2.2 Incorporation of Seasonal Component

There is a seasonal component to some of the large-scale incidents shown in Table F-4 and under evaluation for spills. For the OFWESA model, the seasonal analysis is based on a division of the year into six two-month periods, as show in Table F-5.

Table F-5. Seasonal Time Periods in the OFWESA Model

Period	Months Included
1	December, January
2	February, March
3	April, May
4	June, July
5	August, September
6	October, November

To the extent feasible, the degree to which there may be a clearly-defined temporal pattern to large-scale incident frequencies and magnitudes that may affect spills (and other ICFs) was incorporated into the analysis. It was anticipated that seasonality will be clearly defined for storms and hurricanes. There are no known seasonal components for earthquake occurrence. Likewise, there is no clear seasonality to tsunamis.

The temporal association for vessel-related incidents was less clear. The most frequently-cited factors for vessels alliding with OFW facility structures are visibility and radar interference (ESS Group 2006; Etkin 2006b; The McGowan Group 2004), neither of which tend to have a seasonal component. While there are weather-related factors that do affect vessel accidents in general, storm or hurricane frequency is not necessarily the best indicator of the probability of vessel accidents. In the case of significant storms and hurricanes, larger vessels would usually take measures to reduce risk by taking refuge in a port or re-routing. Therefore, seasonality of vessel activity was not incorporated into the model.

F.3 Approach to Categorizing Large-Scale Events

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 wind energy facility structures, a simple algorithm was developed to classify the events on a geographic basis with regard to spill potential. The two selected regions (California and Hawaii) were used as examples of the application of the OFWESA approach. The OFWESA model was developed to be applicable to future proposals or lease sites in other locations should this be needed by BOEM.

For the vessel-related incidents, readily-available vessel traffic data were used to develop another simple algorithm that can be used to classify geographic regions with respect to risk of vessel-related spills. The relative density of vessel traffic is an obvious factor that would affect the likelihood of incidents. However, the makeup of vessel traffic with regard to vessel types (e.g., tankers, bulk carriers, fishing vessels) will also play an important role in determining the likelihood of a vessel allision actually causing a spill from a wind energy facility structure, so vessel traffic was categorized into either medium-sized or large vessel types.

The magnitudes of the large-scale incidents were categorized as to whether the events are likely to cause partial or complete structural failure resulting in spillage. 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. It will be straightforward to categorize those spills 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.

A risk matrix for the large-scale events that could cause spills is shown in Table F-6. Since the large-scale incidents that cause spills could also cause other types of impacts (as in Table F-4), the magnitude of these incidents with respect to those impacts will also need to be considered in a concurrent analysis.

The risk matrix presents types of data and the manner in which it should be applied for the OFWESA model. The factor magnitudes for the natural events (hurricanes, earthquakes, and tsunamis) are based on engineering studies and design features of the OFW facility components that stipulate the level of external force from winds, waves, and seismic activity that would be expected to potentially cause sufficient structural damage that may lead to a spill. For example, the annual frequency of hurricanes of the specified magnitudes needs to be determined for a particular site. Then, because the purpose of the OFWESA model is to conduct a relative comparison between sites, the absolute frequency of a particular site (e.g., 0.08 hurricane of Category 4 per year) needs to be compared to that of alternative site(s) under consideration (e.g., hypothetically, 0.02 hurricane per year). In this hypothetical case, the first site has four times the hurricane (and thus potential spill) frequency of the alternative site. This is further described in Section F.3.4 for hurricanes, Section F.3.5 for earthquakes, and Section F.3.6 for tsunamis. The probability of vessel allisions is dependent on the density of vessel traffic, as is described in Section F.3.7.

Table F-6. OFWESA Risk Matrix for Large-Scale Incidents Causing Spills

	Hurricane		**Earthquake**		**Tsunami**		**Vessel Allision with Damage to Wind Facility Structures**	
Location	**Partial Structure Failure**	**Major Structure Failure**	**Partial Structure Failure**	**Major Structure Failure**	**Partial Structure Failure**	**Major Structure Failure**	**Partial Structure Failure from Medium Vessel Allision**	**Complete Structure Failure from Larger Vessel Allision**
Data Applied	Annual Frequency of Hurricanes in Region by Category		Annual Frequency of Earthquakes in Region by Magnitude		Annual Frequency of Tsunamis in Region by Magnitude		Vessel Traffic Data Annual Tonnage	
							Annual Vessel Trips by Size	
Factor Magnitude	4	>5	5	>7	6	>7.9	Medium *Tows Tugs*	Larger *Tankers* *Bulkers* *Containers*

A second approach is to compare the absolute data for a particular site to a national average or a distribution of values across the entire U.S. offshore waters. In the hypothetical example, if the average hurricane frequency is 0.05 per year and varies from 0.0 to 0.10 hurricane per year, the hurricane frequency for the hypothetical site (0.08 hurricane per year) would fall on the higher end of the risk scale. The alternative site (0.02 hurricane per year) would fall on the lower end of the risk scale for hurricane-related spills. In comparing the data to national averages, as one might do if one were comparing sites in a number of locations across the US, the data would need to be normalized with area of coverage (e.g., average tsunamis per square mile).

F.3.1 Hazardous Substances in OFW facilities

For OFW facilities, there are several types of chemicals and oils that could accidentally spill. Exact quantities and types of oils stored in wind facility components, and thus subject to spillage, would vary depending on the specifications of the facility structures.

The nature and potential frequency of spills from OFW facilities is theoretical, as there are no known databases of spills of chemicals or oils from OFW facilities. There is only one operational OFW facility in the US (Deep Water Wind off Block Island, Rhode Island) that has been in operation for eight months at the time of the writing of this report. There are no reports of spills from the wind farm components. There are also no known databases of spill events from any wind farms in the North Sea.

F.3.1.1 Structural Components of Floating Wind Turbines

American Bureau of Shipping conducted state-of-the-art reviews of floating offshore wind turbine (FOWT) technologies for BOEM that included at least 13 different design concepts that could be categorized into six main groups:

1. Spar-based FOWTs
2. Tension leg platform-based FOWTs
3. Monohull (barge-based) FOWTs
4. Column-stabilized (semi-submersible-based) FOWTs
5. Multiple-unit design concepts
6. Other innovative design concepts (e.g., vertical axis wind turbines) (Yu and Chen 2012; American Bureau of Shipping 2011).

F.3.1.2 Chemicals and Oils in OFW Facility Components

The types of chemicals and oils that would likely be contained in OFW facility components are shown in Table F-7 through Table F-9. 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 in Table F-7 through Table F-9 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. In the event of a spill of any of these chemicals and oils, the impacts would be expected to be relatively localized due to the low volumes. The spills would not be considered “major” spills based on the criteria in the National Contingency Plan (40 CFR § 300.5) that designate spills of 100,000 gallons as major.

Table F-7. 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 F-8. 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 F-9. 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[8] with bio-based content over 50% (for extreme pressure)	220 gallons total

Source: Bejarano et al. 2013

F.3.2 Fate and Effects of Hazardous Substance Spills

The fate and effects or environmental impacts of spilled oils and chemicals in marine waters depend on several factors including:

- chemical and physical properties of the substance;
- volume spilled;
- degree of toxicity, persistence, and adherence of the substance in location of spillage;
- environmental conditions at the spill site, including winds that blow spilled substances across the water surface, waves that entrain substances into the water column, currents that transport the substance, and air and water temperature that affect weathering processes like evaporation;
- spread of the spilled substance;
- proximity of sensitive habitats and species;
- spatiotemporal overlap of spill with presence and life stages of sensitive species (e.g., migration, breeding);
- spatial coverage of sensitive habitats; and
- population numbers of sensitive species.

In this portion of the analysis, the expected spatial extent and general behavior of the spilled substances with respect to evaporation, dissolution, and spread in the aftermath of a hypothetical spill were considered. While individual substances are presented, it should be noted that if there is a large-scale event (e.g., ship allision, hurricane, earthquake) that has sufficient force to damage an OFW turbine or other facility component, more than one substance might spill.

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

The physical and chemical properties of substances likely to be present in OFW turbines and other facility components, as well as potential effects, were described in detail in a report prepared for BOEM (Bejarano et al. 2013). The potential fate and effects of spilled oil and/or chemicals due to a large-scale incident at an OFW facility as part of the OFWESA model is discussed in the Task 1 Report (RPS ASA and ICF 2017).

F.4 Hurricanes and Storms

Hurricanes[9] have caused about $10 billion in mainland damage in the U.S., as documented for the last century. Damages in the 1996–2005 decade (including Hurricane Katrina) were the second highest after the 1926–1935 decade, which included the 1926 Great Miami Storm (Pielke et al. 2008).

Damage to offshore structures from hurricanes could come not only from the high winds, which would exceed 74 mph, and the direct impact of waves. In high-intensity hurricanes, wave height can be extreme. In Hurricane Ivan (2004), for example, waves of greater than 50 feet were recorded (Wang et al. 2005). Another mechanism for damage is wave-induced high sea-floor stress (Wijesekera et al. 2010). Strong surface waves and currents during a hurricane can produce extreme forces at the seabed that cause massive underwater mudslides.

F.4.1 Hurricane Damage to Offshore Structures

Damage to offshore oil and gas platforms has been well-documented for the U.S. Gulf of Mexico (Energo 2006; Energo 2010; MMS 2008; Farber et al. 2009). For example, in 2004, Hurricane Ivan destroyed seven fixed offshore platforms (Energo Engineering 2006). Six of those platforms failed due to the environmental loads (i.e., wind, wave, and current) and one toppled due to a mudslide. In addition, there were 18 other fixed platforms that incurred major damage, and 9 that sustained minor damage. An engineering study conducted for MMS concluded:

> *Some of the damage and failures were not considered a surprise, since many of the platforms that failed or sustained major damage tended to be older vintage facilities designed to lower global strength characteristics (e.g., weaker joints, less robust bracing patterns, etc.) than platforms designed to existing industry practices. Additionally, these older platforms typically have lower topside deck heights which make them significantly more susceptible to wave-in-deck, which can increase the loads on the platform well over the platform's ultimate capacity. However, the extent of topside damage both structural and non-structural (i.e., process equipment, safety systems, controls, etc.) on many of the platforms, both new and older vintage, indicated Ivan caused extremely large waves and associated wave crest heights, possibly larger than the hindcast predictions* (Energo 2006).

In Hurricanes Gustav and Ike (both in 2008), the damages were even more extensive. Of the more than 3,800 production platforms in the Gulf of Mexico at the time, 60 platforms were completely destroyed, 31 platforms had extensive damage that took 3 to 6 months to repair, and 93 platforms had moderate damage that took 1 to 3 months to repair (Energo 2010; MMS 2008). By inference, one could assume that hurricanes could also do extensive damage to OFW turbines and other wind facility components.

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[9] Tropical cyclones are classified by the National Oceanic and Atmospheric Administration as follows: Tropical Depression: A tropical cyclone with maximum sustained winds of 38 mph (33 knots) or less. Tropical Storm: A tropical cyclone with maximum sustained winds of 39 to 73 mph (34 to 63 knots). Hurricane: A tropical cyclone with maximum sustained winds of 74 mph (64 knots) or higher. In the western North Pacific, hurricanes are called typhoons; similar storms in the Indian Ocean and South Pacific Ocean are called cyclones. Major Hurricane: A tropical cyclone with maximum sustained winds of 111 mph (96 knots) or higher, corresponding to a Category 3, 4 or 5 on the Saffir-Simpson Hurricane Wind Scale. (http://www.nhc.noaa.gov/climo/)

F.4.2 Hurricane Damage to OFW Facilities

Wind is both a source of power and a threat to OFW facilities, as illustrated in Figure F-1. 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 megawatt (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.

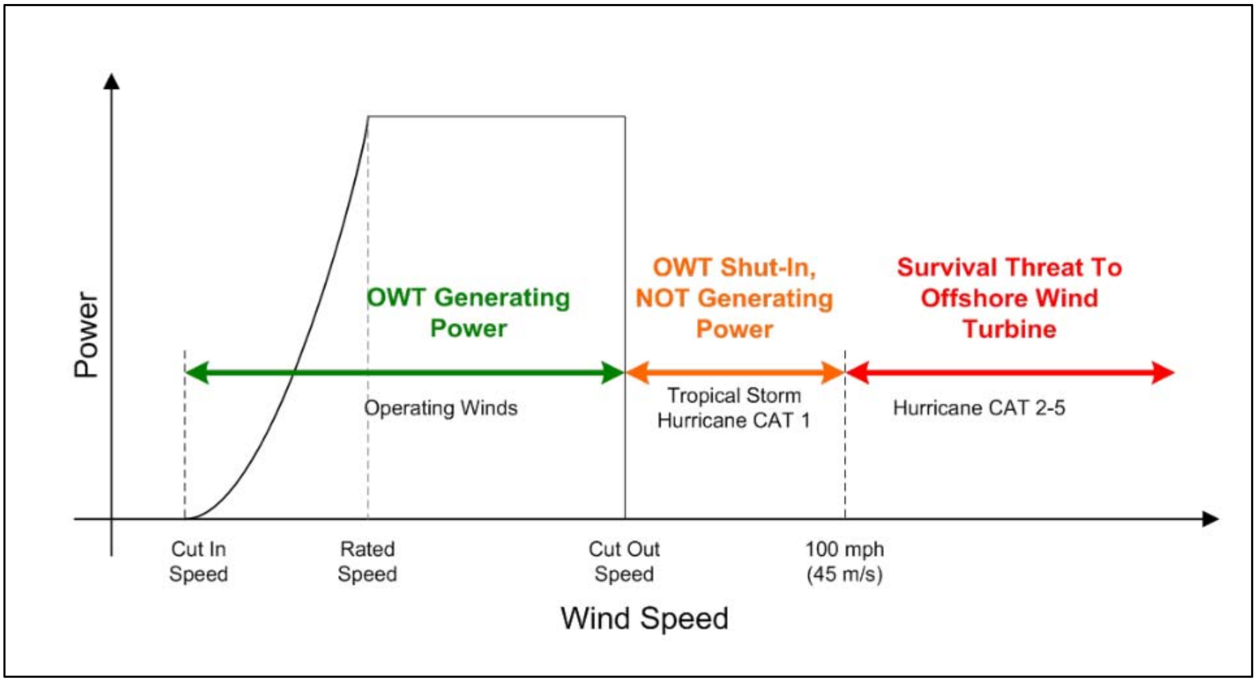

Figure F-1. Wind Speed as Source of Power and Threat for Offshore Wind Turbines (Source: Jha 2008)

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.

There is one well-documented case study of small land-based wind farm on Miyakojima Island in Okinawa Prefecture, Japan, in which all six of its wind turbines were extensively damaged by Typhoon Maemi in 2003 (Takahara et al. 2004). In that case, the typhoon[10] struck the island with average wind speeds of 86 mph, with gusts of up to 166 mph. At the site of the wind turbines, the maximum wind speed was 134 mph, with gusts up to 201 mph. Two Micon M750/400kW turbines collapsed by buckling of the towers, and one Enercon E40/500kW turbine turned over due to the destruction of its foundation. On the other three turbines, blades were broken and the nacelle cover was damaged. Tests showed that during the typhoon, the turbines suffered a larger wind load than the designed wind load. There were no reports of spillage of oil or chemicals due to the damage in the Miyakojima Island incident, though this does not preclude that spillage may have occurred. This particular case study has been used in the development of stricter guidelines for structural integrity in wind turbines.

Hurricane wind and wave loads on an OFW turbine exert large structural demands, but also change temporally with respect to direction. Winds can rapidly change direction during a hurricane. Waves are less susceptible to rapid changes in direction. The orientation of the wind turbine jackets can affect the failure mechanism (Wei et al. 2006.). Much of the research on this issue has been conducted on fixed-bottom structures.

For OFW turbines, wind-wave misalignment is of particular concern (Philippe et al. 2013; Barj et al. 2014.). Most fixed-bottom offshore wind turbines support structures are axisymmetric and stiff enough to ensure that wave loads do not have a significant impact on the overall structural loads above the water. According to one study, "in floating wind turbine systems, there is a greater potential for motion of the support structure, which combined with a lack of aerodynamic damping in the side-to-side direction, may cause wind, wave, and current directionality to more heavily impact both extreme and fatigue loading" (Barj et al. 2014). Based on modeling, this study recommended that at least two wave directions (aligned with the wind, and 90° misaligned) be included in the analysis of extreme and fatigue characteristics of spar-type and other floating platforms (Figure F-2).

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[10] A tropical cyclone is a generic term used by meteorologists to describe a rotating, organized system of clouds and thunderstorms that originates over tropical or subtropical waters and has closed, low-level circulation. Once a tropical cyclone reaches maximum sustained winds of 74 miles per hour or higher, it is then classified as a hurricane, typhoon, or cyclone depending upon where the storm originates in the world. In the western Pacific near Asia, tropical cyclones are called "typhoons," and in the Atlantic and eastern Pacific, these storms are called "hurricanes." In both cases, the winds are generally stronger than 74 mph. (Source: NOAA Ocean Service, http://oceanservice.noaa.gov/facts/cyclone.html)

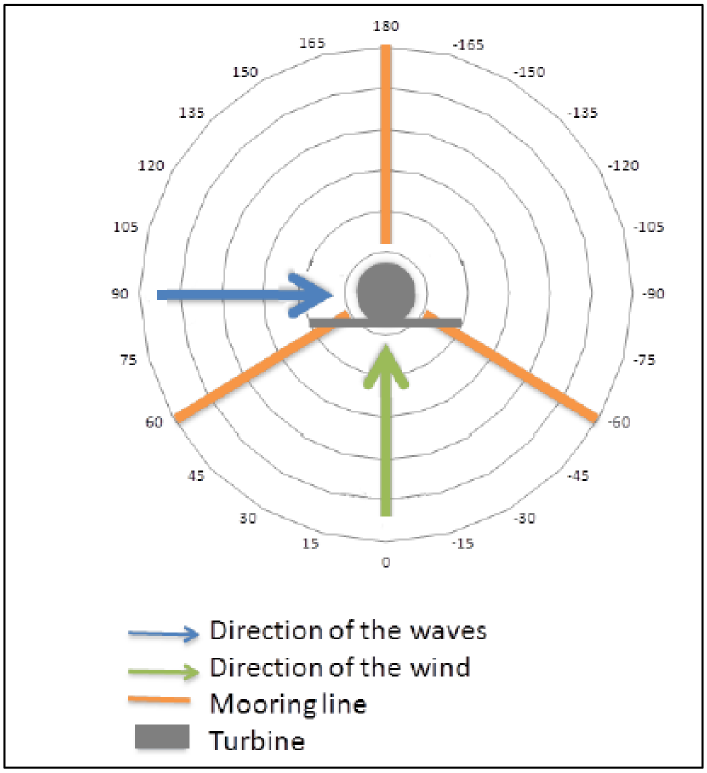

Figure F-2. Schematic of Floating Offshore Wind Turbine and Wind and Wave Direction (Source: Barj et al. 2014)

A 2012 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 F-10. Note that toppling does not necessarily mean that there would be a spill.

Table F-10. 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).

F.4.3 Standards for Structural Integrity of OFW Facilities

Clearly, there is a fundamental and practical need for OFW turbines to be able to withstand extreme storm and hurricane conditions. As the first proposals for OFW facilities were under development, in the late

2000s, there were no specific guidelines or standards for design requirements for structural integrity (MMI Engineering 2009).

The existing American Petroleum Institute (API) recommended practice for the design of fixed offshore platforms (API RP-2A), which was modified 21 times between 1969 and 2000, was based on 100-year storm conditions,[11] which matched current public perception of structural safety. API RP-2A was first developed in response to Hurricane Camille in 1969, and then modified (increased) with technological developments, as well as in the aftermath of storms. The 20th update was developed after Hurricane Andrew in 1992.

API RP-2A does not, however, address some of the issues specific to wind turbines, including:

- turbine-specific design load;
- wind fatigue loading;
- soil-structure interaction for large diameter piles; and
- grouted connections carrying significant moment load (Jha 2008; MMI Engineering 2009).

The International Electrotechnical Commission (IEC) developed an alternative guideline (IEC 61400-3) that is based on a more conservative assumption of the wave heights and wind speeds of a 50-year storm. In a study comparing API R-2A and IEC 61400-3, it was found that the coefficient of variation (CoV) or annual variability in tropical storm severity significantly affected the reliability of the two guidelines (Jha 2008; MMI Engineering 2009). For locations in which there was a low CoV, such as the North Sea, the use of the IEC 61400-3 resulted in higher reliability. However, in locations in which there was greater annual variability in storms, such as the Gulf of Mexico, the API RP-2A standard was more reliable. In other words, in the Gulf of Mexico, where storm activity was more variable, it was best to apply the 100-year standard, because of the greater likelihood of a more powerful storm. With three “100-year storms” within two years (Hurricanes Ivan, Katrina, and Rita), there have been questions about revising the “100-year” criteria (JHA 2008).

The American Bureau of Shipping (ABS) guidelines are similar to those in IEC 614300-3, but include several amendments that address tropical hurricanes in US waters and issues related specifically to the design of OFW turbines (National Academy of Sciences 2011; Yu et al. 2011; Yu and Chen 2012).

F.4.4 Categorization of Hurricane Damage

The Saffir-Simpson Hurricane Wind Scale (SSHWS) is a 1-5 rating based on the hurricane's present intensity (JHA 2008). This is used to give an estimate of the potential property damage and flooding expected along the coast from a hurricane landfall. Wind speed is the determining factor, as storm surge values are highly dependent on the slope of the continental shelf and the shape of the coastline, in the landfall region. Note that all winds are using the US one-minute average. The SSHWS includes descriptions of damage potential, though the damages described are based on land-fall (Table F-11). By inference, it may be assumed that analogous damages of similar intensity could occur on offshore facilities.

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[11] A “100-year storm” is an event that statistically has a one percent chance of occurring in any one given year. Over the course of 30 years, there would be a one percent chance in any one year that such a storm would occur. The fact that a severe storm occurred in one year has no impact on whether it might occur in the following year. Thus, there is the possibility of having two “100 year storms” two years in a row.

Table F-11. Damage Potential from Hurricanes with Land-Fall

Saffir-Simpson Category	Winds (mph)	Storm Surge (ft)	Damage Potential
One	74 – 95	4 – 5	No real damage to building structures. Damage primarily to unanchored mobile homes, shrubbery, and trees. Some damage to poorly constructed signs. Also, some coastal road flooding and minor pier damage.
Two	96 – 110	6 – 8	Some roofing material, door, and window damage of buildings. Considerable damage to shrubbery and trees with some trees blown down. Considerable damage to mobile homes, poorly constructed signs, and piers. Coastal and low-lying escape routes flood 2-4 hours before arrival of the hurricane center. Small craft in unprotected anchorages break moorings.
Three	111 – 130	9 – 12	Some structural damage to small residences and utility buildings with a minor amount of curtain-wall failures. Damage to shrubbery and trees with foliage blown off trees and large trees blown down. Mobile homes and poorly constructed signs are destroyed. Low-lying escape routes are cut by rising water 3-5 hours before arrival of the center of the hurricane. Flooding near the coast destroys smaller structures with larger structures damaged by battering from floating debris. Terrain continuously lower than 5 ft above mean sea level may be flooded inland 8 miles or more.
Four	131 – 155	13 – 18	More extensive curtainwall failures with some complete roof structure failures on small residences. Shrubs, trees, and all signs are blown down. Complete destruction of mobile homes. Extensive damage to doors and windows. Low-lying escape routes may be cut by rising water 3-5 hours before arrival of the center of the hurricane. Major damage to lower floors of structures near the shore. Terrain lower than 10 ft above sea level may be flooded.

Saffir-Simpson Category	Winds (mph)	Storm Surge (ft)	Damage Potential
Five	>155	> 18	Complete roof failure on many residences and industrial buildings. Some complete building failures with small utility buildings blown over or away. All shrubs, trees, and signs blown down. Complete destruction of mobile homes. Severe and extensive window and door damage. Low-lying escape routes are cut by rising water 3-5 hours before arrival of the center of the hurricane. Major damage to lower floors of all structures located less than 15 ft above sea level and within 500 yards of the shoreline. Only 3 Category Five hurricanes have made landfall in the United States since records began.

The tropical cyclone/hurricane classifications and their implications for the OFWESA model are summarized in Table F-12. The OFWESA factor magnitude ratings are based on the following assumptions:

- OFW facility components would be constructed to generally withstand Category 3 hurricanes (MMS 2009; Etkin 2006a);
- There would be some general improvements in structural stability based on implementation of standards and experience with offshore wind farms in locations subject to tropical cyclones or hurricanes;
- A degree of conservatism with respect to damage should be added, taking into account the calculations in Table F-10; and
- Damage would not necessarily result in spillage of chemicals or oils from wind facility components, but with partial structural failure past Category 3 hurricanes, one could expect spillage that would be commensurate with the degree of structural failure.

Table F-12. OFWESA Damage Magnitude by Tropical Cyclone Classification

SSHWS Classification	Sustained Winds (mph)		Storm Surge (ft)	OFWESA Damage Magnitude (Damage to OFW facility)
	1-Minute	10-Minute		
Tropical Depression	<37–38	<32–33	-	No Measurable or Consequential Damage
Tropical Storm	39–73	34–63	-	
Category 1 Hurricane	74–95	64–83	4–5	
Category 2 Hurricane	96–110	84–96	6–8	Minor Damage or Partial Structural Failure with No Spill
Category 3 Hurricane	111–130	97–113	9–12	
Category 4 Hurricane	131–155	114–130	13–18	Partial Structural Failure + Small Spill
Category 5 Hurricane	>155	>140	>18	Major Structural Failure + Larger Spill

F.4.5 Frequency and Seasonality of Hurricanes

Hurricanes (or tropical cyclones) occur in most of the offshore locations in the US that might be considered for OFW facilities, with the notable exceptions of the waters off Northern California, Oregon, Washington, and Alaska (Figure F-3).

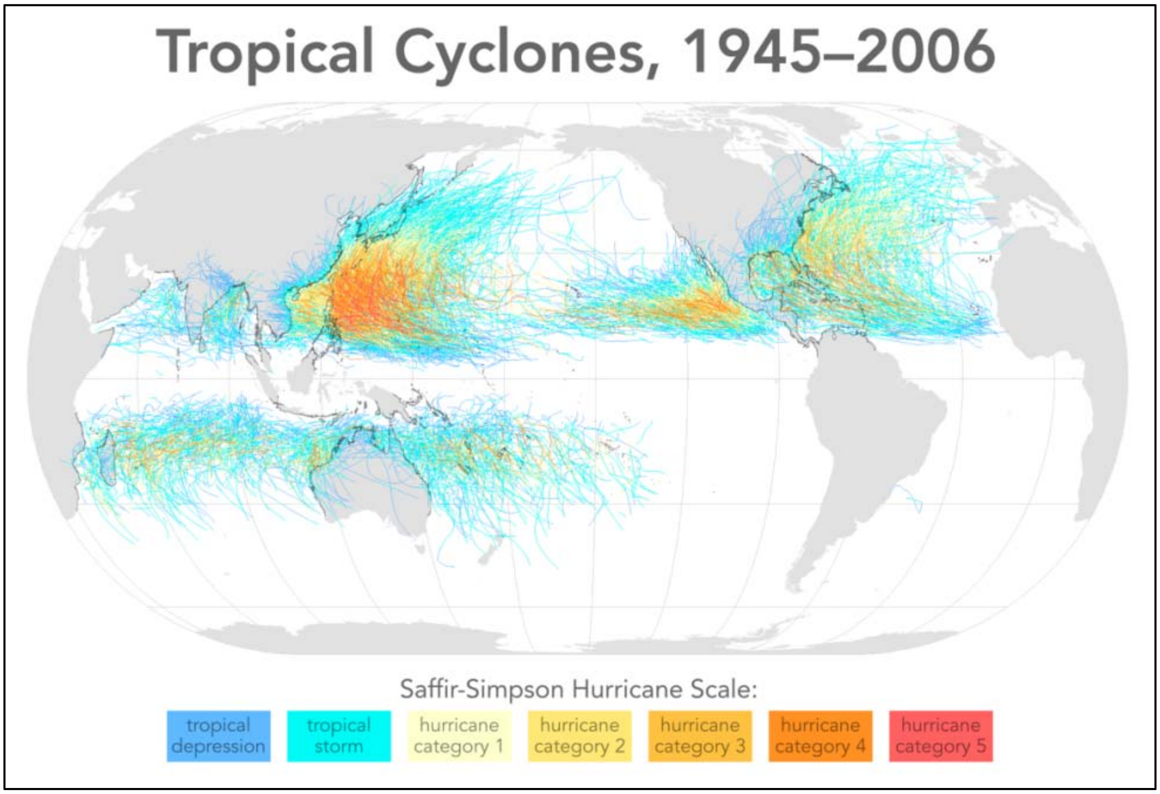

Figure F-3. Map of Paths of All Tropical Cyclones Worldwide (1945–2006) (Source: Citynoise at English Wikipedia 2008)

The frequency (annual probability) of hurricanes differs by geographic region and has a strong seasonal component. There is evidence that there may be an increasing frequency or intensity of tropical cyclones due to climate change (Elsner et al. 2008; Webster et al. 2005; Knutson et al. 2010), after earlier studies indicated that there was a decreasing frequency, at least in the Atlantic Basin (Landsea and Nicholls 1996). One study concluded that there may be a trade-off between frequency and intensity, with fewer cyclones that are more intense (Kang and Elsner 2015). This means that historical data applied to predictions of future hurricane/cyclone frequency and/or intensity may need to be adjusted or applied with a more conservative stance, *i.e.*, assuming an increased frequency of more intense storms than reflected in the historical data.

The Eastern Pacific Basin, which technically extends as far west as 140°W longitude and does not include the Hawaiian Islands, experiences a larger number of storms overall. On average, there are 15.3 storms annually, including 3.8 Category 3 or higher hurricanes. The storm season runs from mid-May through the end of November, with the most active season being from early August to early October (Figure F-4).

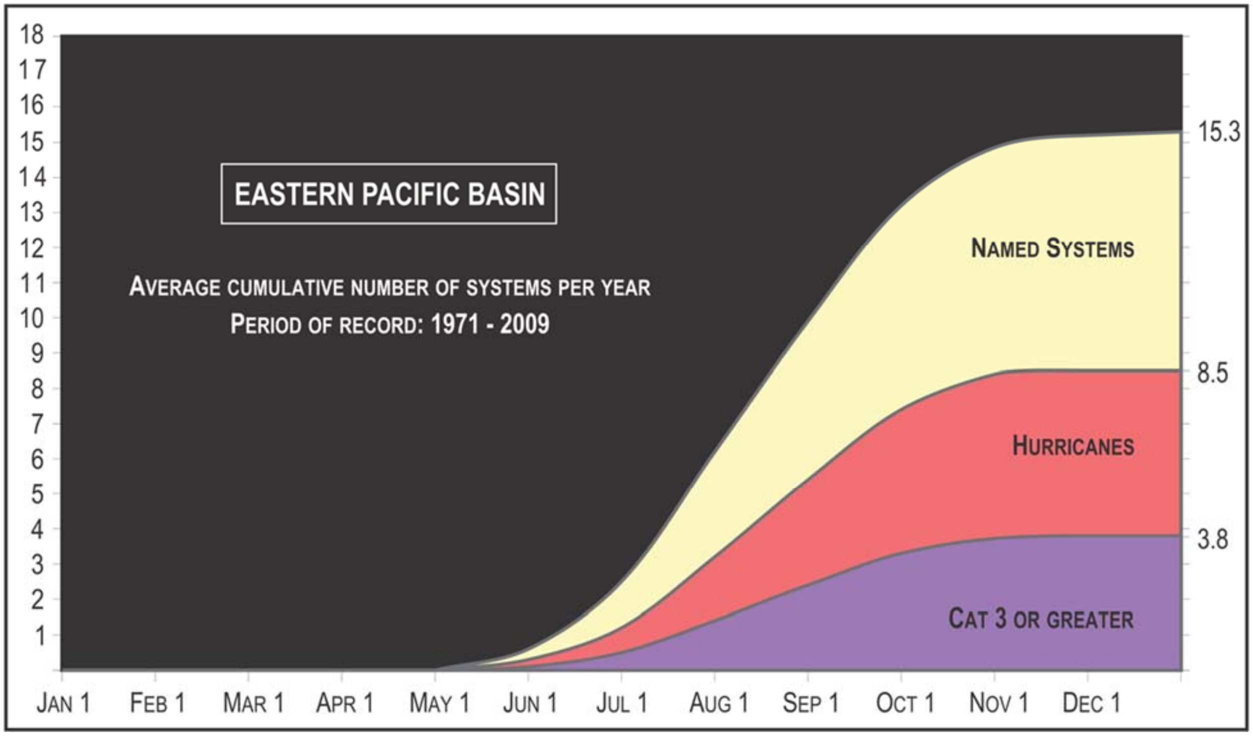

Figure F-4. Average Cumulative Number of Annual Storm Systems: Eastern Pacific Basin (Source: NOAA 2017a)[12]

Much of the Eastern Pacific Basin includes the region west of Central America, which experiences most of the storms in this region (Figure F-5). In California, there have only been seven tropical storms since 1850, or 0.042 storm per year, though none would have been of sufficient strength to cause damage to OFW facilities.

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[12] The Eastern Pacific basin extends to 140°W, thus not including the Hawaiian Islands.

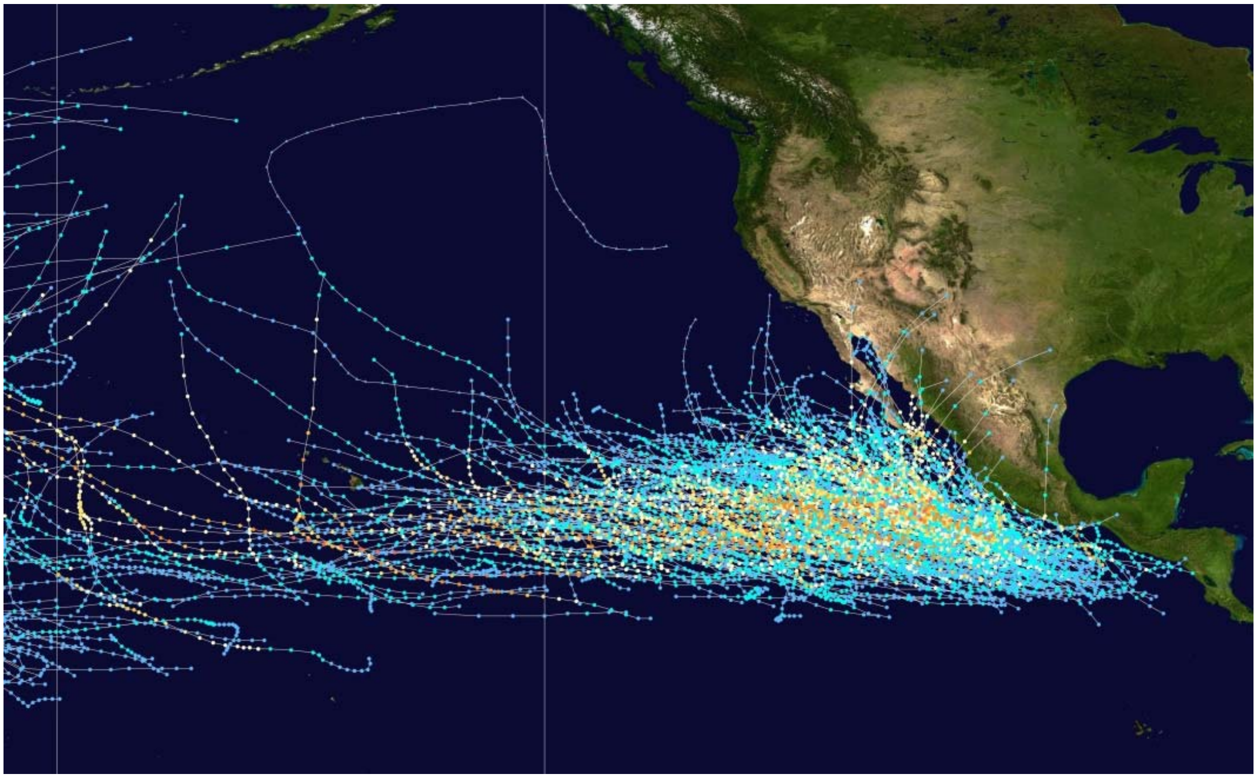

Figure F-5. Pacific Hurricane/Tropical Cyclone Paths (1980-2005) (Source: Wikimedia Commons 2007)

In the Central Pacific region, which includes the Hawaiian Islands, storms are considerably less frequent than in the other basins. On average, there are four to five storms in this area annually (Figure F-6 and Figure F-7). The seasonality of tropical cyclones in this area is depicted in Figure F-8. The highest numbers of cyclones occur in August, followed by July and September. They begin to wane in October. There have been cyclones at other times of the year, though much less frequently.

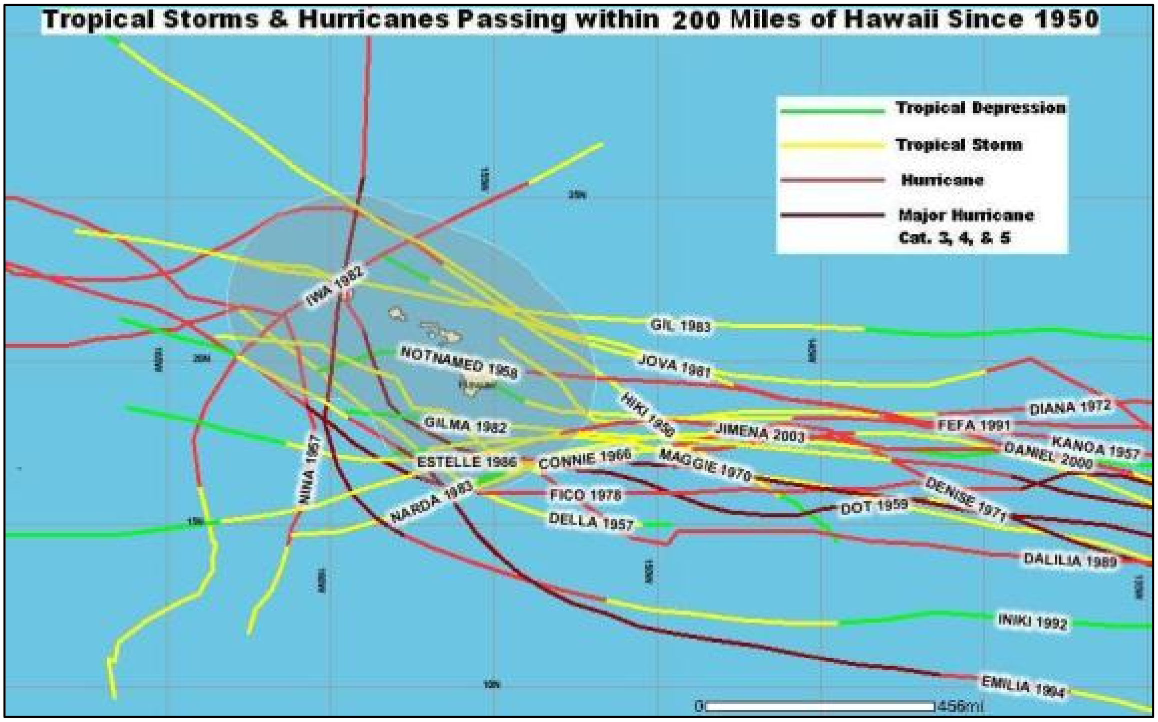

Figure F-6. Tropical Storms and Hurricanes Passing within 200 Miles of Hawaii Since 1950 (Source: NOAA 2017b)

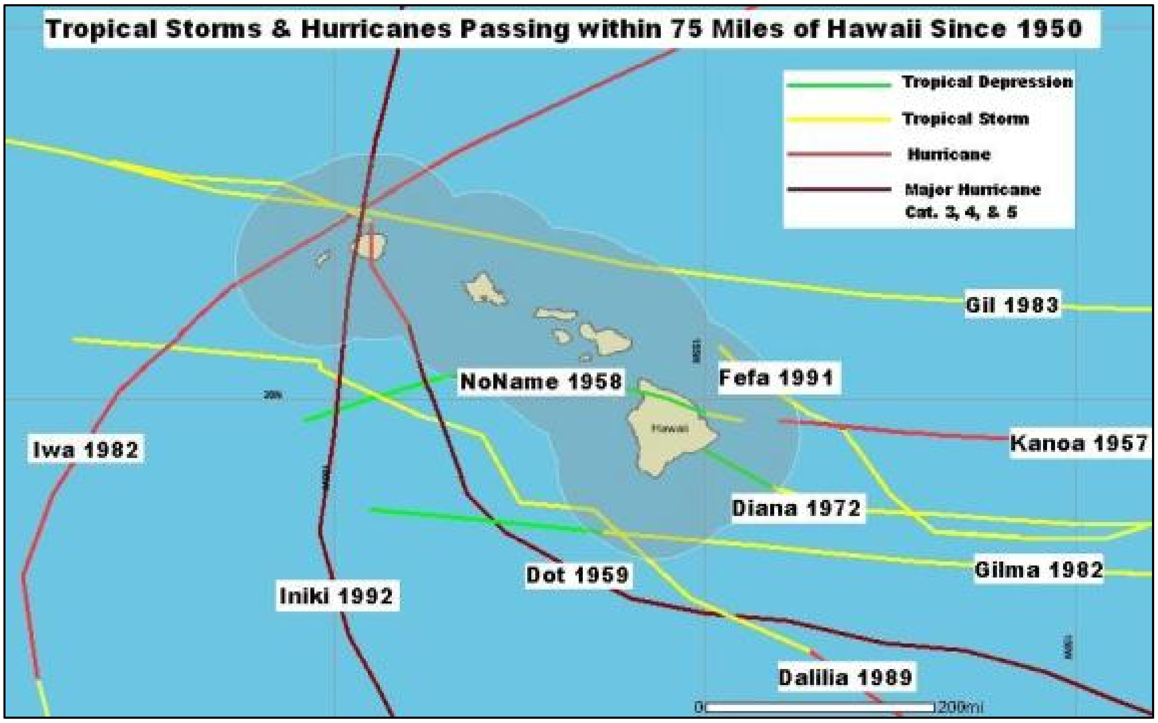

Figure F-7. Tropical Storms and Hurricanes Passing within 75 Miles of Hawaii Since 1950 (Source: NOAA 2017b)

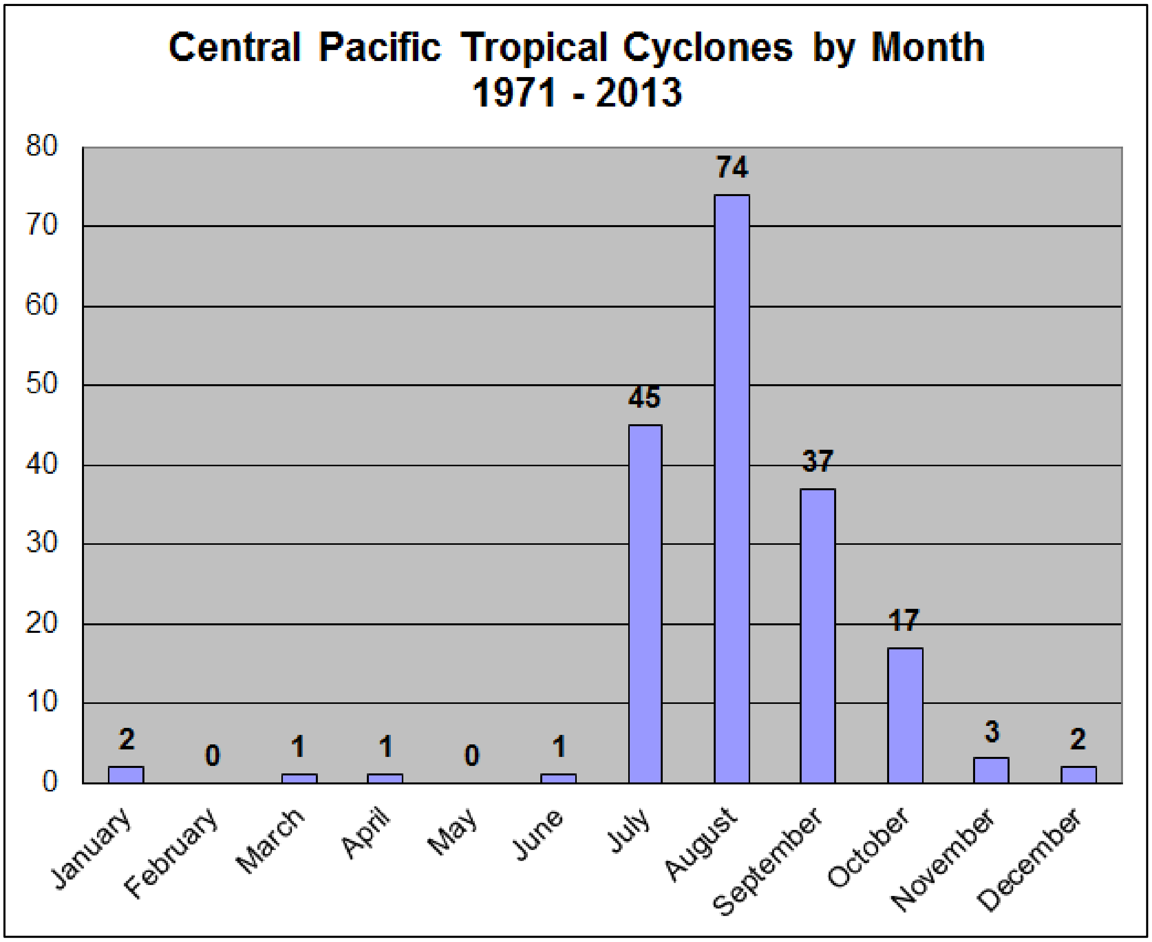

Figure F-8. Seasonality of Central Pacific Tropical Cyclones (1971–2013) (Source: NOAA 2017b)

According to the National Oceanic and Atmospheric Administration Central Pacific Hurricane Center (NOAA 2017c), there have been five Category 5 hurricanes (or tropical cyclones) in this region, which includes Hawaii, over the course of 58 years (1959 through 2016), for an annual frequency of 0.086 (one every 11.6 years). There have also been five Category 4 hurricanes over the same time period.

F.4.6 Incorporation of Hurricane Analysis into OFWESA Model

Damage to offshore wind turbines and other wind facility components does not necessarily result in spillage of oil and chemicals. In an environmental impact statement (EIS), it would be necessary to determine the probability of spillage and potential impacts from spills of various types in that particular environment (e.g., Etkin 2006a; Etkin 2006b; Etkin 2008; MMS 2009). For an EIS, it would be necessary to determine not only the probability of hurricanes of sufficient magnitude to cause damage, but also the probability that the damage would result in spillage as part of a fault tree analysis.

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. This fault tree approach would be undertaken when conducting a site assessment or EIS.

In this relative risk 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 simple estimates of hurricane frequency are sufficient.

Based on the classifications in Table F-12, Category 3 hurricanes (or tropical cyclones) and storms of lesser magnitude would not be expected to cause structural failure. 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.

F.4.6.1 Application of Hurricane Analysis to California

With no reported hurricanes, tropical cyclones, or hurricane-force winds and storm surges of sufficient strength (Category 4 or 5) to cause damage to OFW facilities off the coast of California, the risk is considered negligible, though not zero. For the OFWESA model, it was therefore assumed that the frequency would be about 0.01, or once in 100 years. However, the possibility that there may be changes in weather patterns in the future due to climate change needs to be considered.

According to Mei et al. (2015), tropical cyclones in the northwestern Pacific have strengthened by about 10% since the 1970s due to warming ocean temperatures. The study found that nearly 65% of typhoons now reach Category 3 or higher, compared with 45% a few decades ago. A second study by Mei and Xie (2016), indicated an increase in the proportion of Category 4 and 5 storms by a factor of two to three. These studies are based on data for the northwestern Pacific region, which included Hawaii. This study concludes that there are expected to be increases in the significant wave height associated with storms in the area off Central America (Figure F-9). This area is generally coincident with the location of tropical cyclones as shown in Figure F-5, which is somewhat south of the location of the lease block area off central California.

To account for a potential increase in future storm activity, an assumption of a 10% increase to 0.011 for Category 4 events was applied in the OFWESA risk matrix (Table F-6). Assuming that a Category 5 event is less likely than a Category 4 event, a lower value of 0.006 was applied for the factor related to major structural failure.

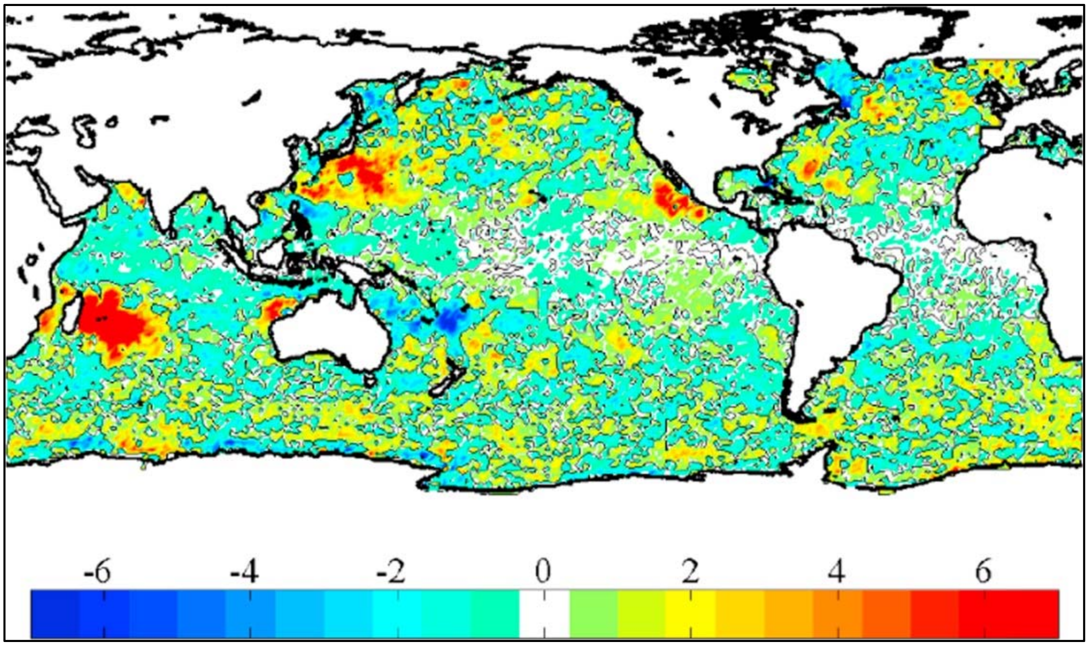

Figure F-9. Future Increases in Significant Wave Height in Storms. The figure shows the expected future change in the 50-year return value of significant wave height (the years 2075-2099 minus 1979-2004) (Source: Mei and Xie 2016).

The seasonal component of hurricanes (as in Figure F-8) was factored in by dividing the expected annual number of hurricanes across six model seasons as shown in Table F-13.

Table F-13. California Hurricane Frequency during Seasonal Time Periods in OFWESA Model

Period	Months Included	Relative Hurricane Frequency	Expected Annual Frequency	
			Category 4	Category 5
1	December, January	Low	0.00024	0.00013
2	February, March	Low	0.00006	0.00003
3	April, May	Low	0.00006	0.00003
4	June, July	High	0.00277	0.00151
5	August, September	High	0.00667	0.00364
6	October, November	Medium	0.00120	0.00066

F.4.6.2 Application of Hurricane Analysis to Hawaii

Based on the historical data for the Central Pacific region, a baseline rate of 0.086 storm per year was assumed for both Category 4 and Category 5 hurricanes (NOAA 2017b). However, based on the previously-cited studies related to changes in hurricane frequency due to climate change, adjustments were made as follows:

- Category 4 hurricanes were assumed to have increased in frequency by 10% to 0.095.
- Category 5 hurricanes were assumed to have increased in frequency by 25% to 0.108.

The Category 5 hurricane frequency increase was based on a 10% increase from the 1970s, as per Mei et al. (2015), and by an additional factor of 2.5 times above that to account for the increase in stronger hurricanes. This additional factor is mid-point of the two to three times increase cited in Mei and Xie 2016.

The seasonal component of hurricanes (as in Figure F-8) was factored into the model by dividing the expected annual number of hurricanes across six model seasons as shown in Table F-14.

Table F-14. Hawaii Hurricane Frequency during Seasonal Time Periods in OFWESA Model

Period	Months Included	Relative Hurricane Frequency	Expected Annual Frequency	
			Category 4	Category 5
1	December, January	Low	0.0021	0.0024
2	February, March	Low	0.0005	0.0006
3	April, May	Low	0.0005	0.0006
4	June, July	High	0.0239	0.0271
5	August, September	High	0.0576	0.0655
6	October, November	Medium	0.0104	0.0118

F.4.6.3 Process of Hurricane Analysis for Application to Other Locations

For other locations, the frequency of Category 4 and Category 5 hurricanes should be determined based on data from the NOAA National Hurricane Center (NOAA 2017a). The possibility that there would be future changes in hurricane activity needs to be taken into account.

The frequency (annual probability) of hurricanes differs by geographic region and has a strong seasonal component. There is evidence that there may be an increasing frequency or intensity of tropical cyclones due to climate change (Elsner et al. 2008; Webster et al. 2005; Knutson et al. 2010.), after earlier studies indicated that there was a decreasing frequency, at least in the Atlantic Basin (Landsea and Nicholls 1996). One study concluded that there may be a trade-off between frequency and intensity, with fewer cyclones that are more intense (Kang and Elsner 2015). This means that historical data applied to predictions of future hurricane/cyclone frequency and/or intensity may need to be adjusted or applied with a more conservative stance, i.e., assuming an increased frequency of more intense storms than reflected in the historical data.

F.5 Earthquakes

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. Earthquakes will occur mainly in seismically active areas, as shown in Figure F-10.

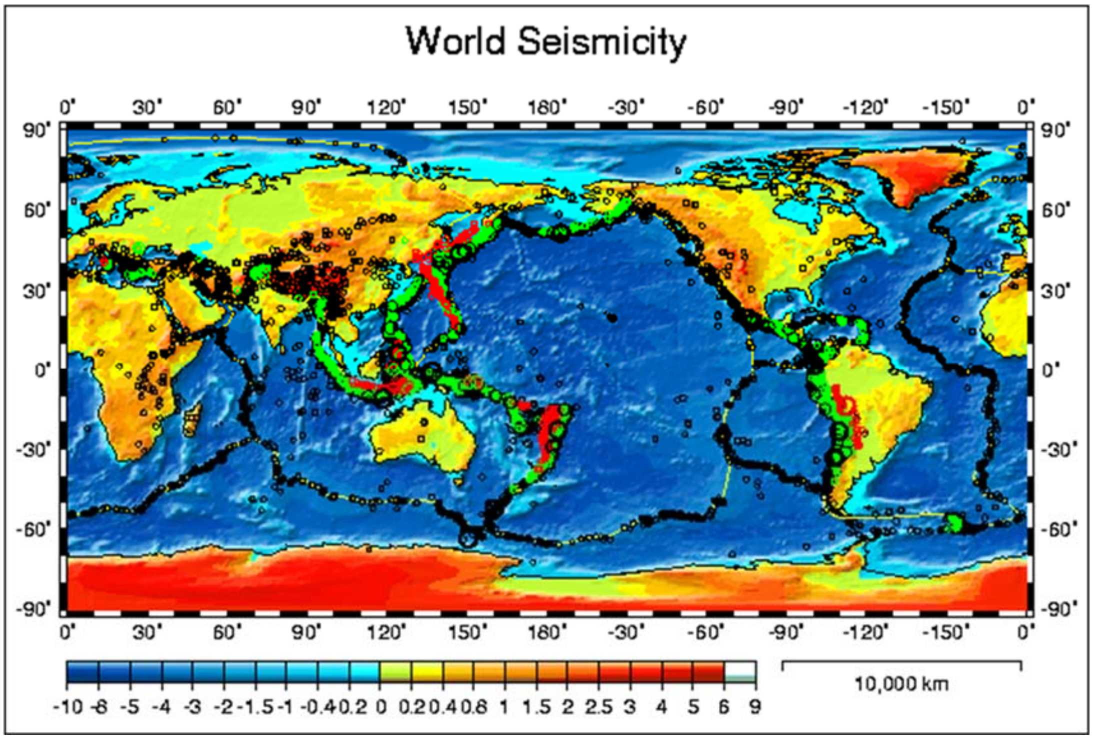

Figure F-10. World Seismic Activity (1977-1992) (Source: Kim 1999)[13]

F.5.1 Categorization of Earthquake Damage

Earthquakes are measured based on Richter magnitude, with potential damage generally described by the U.S. Geological Survey as follows:

- **Less than 3.5**: generally not felt, but recorded.
- **3.5-5.4**: often felt, but rarely causes damage.
- **5.5 to 6.0:** at most slight damage to well-designed buildings, can cause major damage to poorly constructed buildings over small regions.
- **6.1-6.9:** can be destructive in areas up to about 100 kilometers across where people live;
- **7.0-7.9:** major earthquake, can cause serious damage over larger areas.
- **8 or greater:** great earthquake, can cause serious damage in areas several hundred kilometers across.

Because of the logarithmic basis of the Richter scale, each whole number increase in magnitude represents a tenfold increase in measured amplitude; as an estimate of energy, each whole number step in the magnitude scale corresponds to the release of about 31 times more energy than the amount associated with the preceding whole number value.

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

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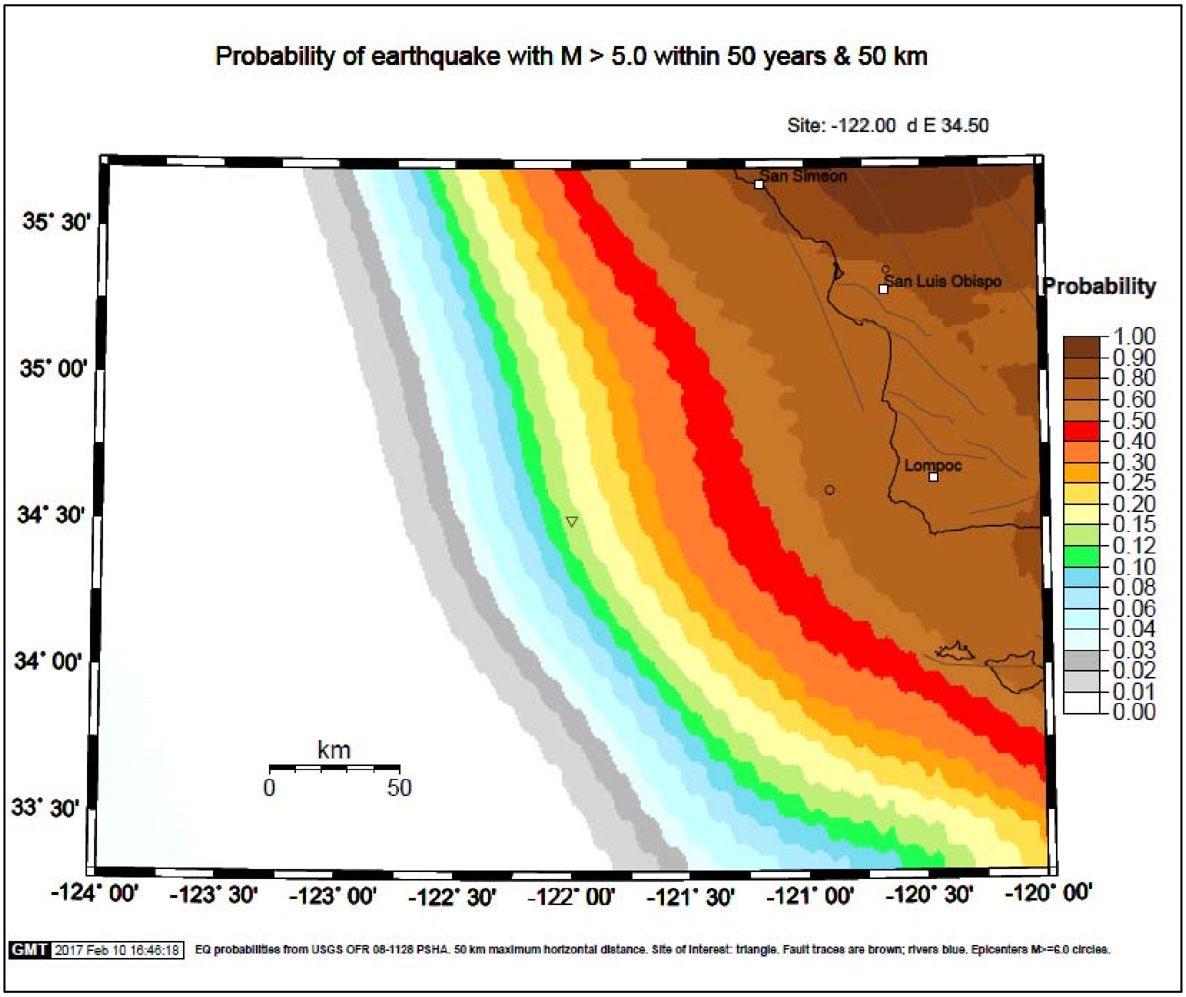
[13] World Seismicity during 1977-1992 are plotted over topography and bathymetry map. Over 10,000 large earthquakes with magnitude (mb) greater than 5.5 are plotted. Notice that majority of the large earthquakes occurs at or close to major plate boundaries (indicated by thick yellow lines). Focal depth of earthquakes are plotted with colors; black = shallow events (0-70 km), green = intermediate depth (70-300 km), and red = deep focus events (300-700 km).

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).

F.5.2 Data Used to Categorize Earthquakes

Earthquake data can be obtained from a number of government sources. The U.S. Geological Survey Earthquakes Hazards Program (USGS 2017a). Probability maps (as in Figure F-11) can be generated. Seismic data can also be accessed by specific state at: https://earthquake.usgs.gov/earthquakes/byregion/.



EQ probabilities from USGS OFR 08-1128 PSHA. 50 km maximum horizontal distance. Site of interest: triangle. Fault traces are brown; rivers blue. Epicenters M>=6.0 circles.

Figure F-11. Probability of Earthquake Greater than 5.0 off Central California (Source: USGS 2017a).

More specific earthquake incident data can be obtained from the NOAA National Centers for Environmental Information, which maintains a global historical tsunami database, the National Geophysical Data Center/World Data Service (NGDC/WDS). This database includes information on earthquakes and damages since 1800 (NOAA 2017d).

Searches on the NGDC/WDS can be conducted on specific parameters or the entire database can be downloaded. The specific parameters that are of relevance to the OFWESA model are the date, location (country, state, latitude/longitude, region), and magnitude. The earthquake events should be filtered by magnitude (magnitude 5.0 and over, and 7.0 and over). This same database includes information on tsunamis, as described below.

F.5.2.1 Application of Earthquake Analysis to California

California is known for its seismic activity, particularly along the San Andreas Fault (Figure F-12). While the emphasis for hazard protection is on land-based locations, the seismic activity would also be felt in offshore areas, including the lease block areas offshore of California.

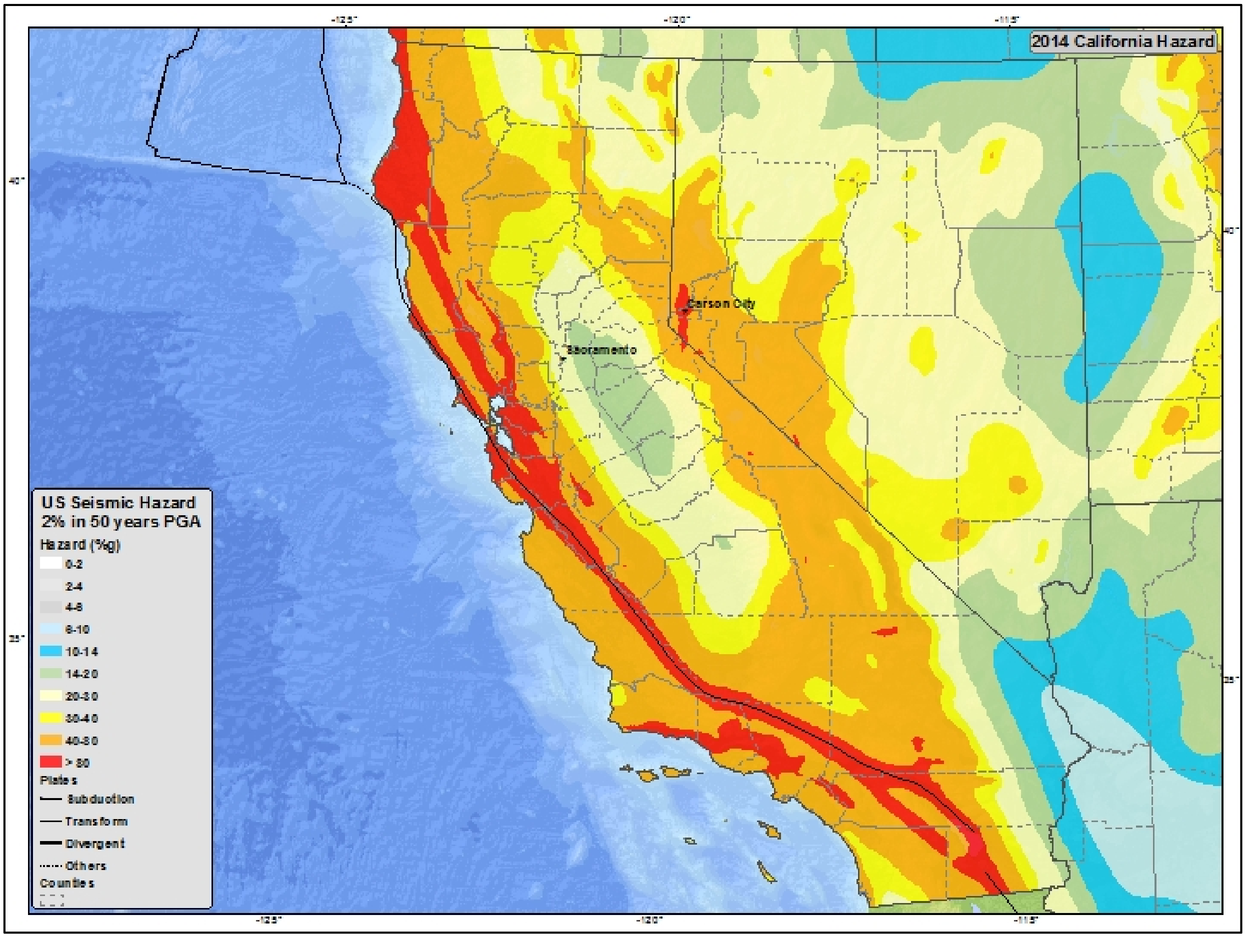


Figure F-12. Seismic Hazard Map for California (Source: USGS 2014)

According to U.S. Geological Survey data, there have been six earthquakes over 5.0 on the Richter scale in California in the last 50 years, or 0.12 per year. There have been no earthquakes over 7.0 in the last 100 years, though there was a 7.9 earthquake in San Francisco in April 1906.

F.5.2.2 Application of Earthquake Analysis to Hawaii

The Hawaiian Islands are known to have a high degree of seismic activity, particularly near the island of Hawaii (Klein et al. 2001). There have been 53 earthquakes over 5.0 (and under 7.0) in the last 100 years, or 0.53 per year, and one earthquake over 7.0, or 0.01 per year. There was one earthquake of magnitude 7.1 in November 1975 centered on the southeastern side of the island of Hawaii near Kalapana (Figure F-13). There have also been earthquakes near Oahu (e.g., magnitude 4.0 earthquakes in 1978, 1980, 1988, and 1990; and magnitude 5.0 earthquakes in 1973 and 2012). Earthquakes on the island of Hawaii have been felt in Oahu (e.g., a 6.7-magnitude earthquake in Kiholo Bay in October 2006 was felt and caused moderate damage in Oahu.)[14] For this reason, the seismic activity of the Hawaiian Islands in general is considered in this analysis.

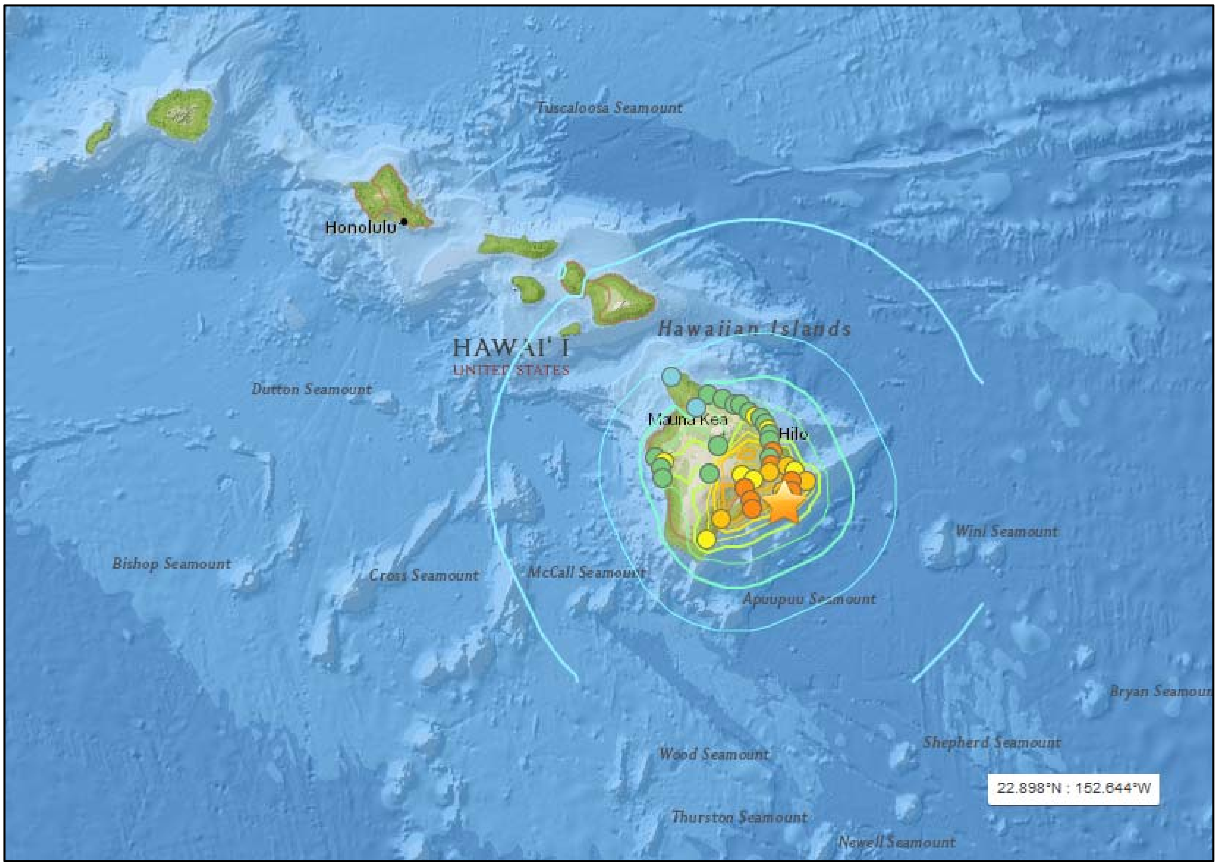


Figure F-13. Seismic Activity around Hawaii Showing 7.1 Earthquake in 1975. Star shows location of 7.1 earthquake (reported in some records as magnitude 7.7 with circles representing smaller earthquake locations) (Source: U.S. Geological Survey Hawaiian Volcano Observatory)

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[14] https://en.wikipedia.org/wiki/2006_Kiholo_Bay_earthquake

F.5.2.3 Process of Earthquake Analysis for Application to Other Locations

For other locations, the annual frequency of earthquakes of 5.0 to under 7.0, and 7.0 and higher should be determined. The former would predict the likelihood of damage causing a partial failure and small spill from an OFW facility structure. The latter would predict the likelihood of damage resulting in major structural failure and a larger spill.

F.5.3 Tsunamis

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.

According to the U.S. Geological Service (USGS 2017b):

> *Tsunami waves are unlike typical ocean waves generated by wind and storms. When tsunamis approach shore, they behave like a very fast-moving tide that extends far inland. Most tsunamis do not "break" like the curling, wind-generated waves popular with surfers. Because of complex interactions with the coast, tsunami waves can persist for many hours.*

F.5.3.1 Categorization of Tsunami Damage

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, as shown in Table F-15. 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.

Table F-15. Magnitude of Tsunami and Average Wave Height

Tsunami Magnitude (Earthquake Magnitude)	Average Wave Height (meters)	Average Wave Height (feet)
4.0 – 4.9	1.44	4.7
5.0 – 5.9	1.34	4.4
6.0 – 6.9	2.43	8.0
7.0 – 7.9	4.04	13.3
8.0 – 8.9	9.79	32.1
9.0 +	40.06	131.0
Based on data in USGS 2017b for global data from 1800 through present. Analysis by ERC.		

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 in the OFWESA model. 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.

F.5.3.2 Application of Tsunami Analysis to California

According to the NGDC/WDS data, there have been 25 recorded tsunamis affecting central California since 1800, and eight in the last century – or about one every 12.5 years (NOAA 2017d). The most recent one occurred in November 2000 when a tsunami caused waves of up to 15 feet high near Point Arguello. Waves of this height may cause partial failure and a small spill in an OFW facility. The average magnitude of the tsunamis (based on earthquake magnitude) for the 200-year time frame in central California was 6.4 (for events for which magnitude of the precipitating earthquake was recorded).

For the California lease block area, an annual probability of 0.08 was applied in the risk matrix for partial failures (and smaller spills) based on one tsunami every 12.5 years. There were no recorded tsunami events of magnitude over 8.0.

F.5.3.3 Application of Tsunami Analysis to Hawaii

According to the NGDC/WDS data, there have been 40 recorded tsunamis affecting Hawaii since 1800, and 15 in the last century – or about one every 6.7 years (NOAA 2017d). The most recent one occurred in October 2006 when a magnitude 6.7 tsunami caused small waves near Kiholo Bay, on the island of Hawaii. Waves of this height are unlikely cause partial failure and a small spill in an offshore wind farm, but this event illustrates the fact that wave height can be extremely variable in the event of an earthquake-caused tsunami. However, since an earthquake of this magnitude generally has higher waves, it is assumed that there would be a commensurate risk of a higher wave height. The average magnitude of the tsunamis (based on earthquake magnitude) for the 200-year time frame in Hawaii was 6.75 (for events for which magnitude of the precipitating earthquake was recorded).

For the Hawaiian sites, an annual probability of 0.15 was applied in the risk matrix for partial failures (and smaller spills) based on one tsunami every ~7 years. There was one recorded tsunami events of over 7.9 (in the year 1868), or one in 150 years (0.007 per year).

F.5.3.4 Process of Tsunami Analysis for Application to Other Locations

The process for applying the tsunami analysis to other locations would involve analyzing earthquake and tsunami data and determining:

- the frequency of 6.0 to 7.9 earthquakes, which would predict the likelihood of a partial structure failure and a small spill; and
- the frequency of 8.0 and larger earthquakes, which would predict the likelihood of a major structural failure and a larger spill.

Earthquake data are available from the U.S. Geological Survey (USGS 2017a) or from the NGDC/WDS (NOAA 2017d) as described above. Alternatively, the history of tsunamis in the region can be analyzed to determine the relative frequency of events of this magnitude (USGS 2017b).

The relative frequency of tsunamis can be compared between additional sites to develop a measure of relative risk. Alternatively, the tsunami frequency per square mile of coverage of the OFW facility site can be compared with the overall national average frequency of 117 recorded incidents in 100 years (based on NGDC/WDS data), or 1.17 tsunamis per year across 150,000 square miles[15] or 0.0000078 tsunami per year per square mile.

F.6 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.

F.6.1 Types of Vessel Spills that Could Occur

The various vessel accidents that could conceivably occur and lead to spillage of oil, chemicals, or other substances include:

- vessels allisions[16] 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.[17]

Vessel allisions with OFW structures area a major concern in the prevention of accidents involving ships. An allision may cause significant damage to a vessel either through direct contact or from wind turbine

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[15] Based on a 12-mile territorial water limit and general coastline area of 12,383 miles (U.S. Census data).

[16] 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.

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

parts falling onto the ship causing damage (Kramer 2015). There are no known cases of vessels alliding with OFW structures to cause enough structural damage to cause spillage.

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 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.

An anecdotal example of a vessel allision with an OFW facility occurred on 17 August 2014, when 10 tonnes (70 barrels) of diesel oil spilled into the Irish Sea from the OMS Pollux (247 DWT, 39 meters long dive standby vessel) after the cargo ship allided with a wind turbine at Dong Energy's Walney Offshore Windfarm. One of the ship's fuel tanks was punctured below the water line.[18] The vessel was carrying out routine inspection work when an anchor cable broke. Notably, there was no damage to the wind turbine.[19]

There are risks from both passing vessel commercial traffic, as well as from maintenance vessels servicing the OFW facilities. Allision risks during maintenance are mostly associated with turbines undergoing a corrective maintenance (replacement) (Presencia and Shafiee 2017). Spills from these vessels would tend to be small, as they would be limited to the fuel on board the vessel. In addition, there are risks of spills and accidents from smaller recreational and fishing vessels that transit between or near the wind turbines despite the safety exclusion zone restrictions in place. Recreational and commercial fishing boats could conceivably be in the exclusionary zone because the structures can attract fish and invertebrates (Leonhard et al. 2011, Russell et al. 2014).

Vessel collisions with each other due to the presence of OFW facilities have been raised as a concern in various studies, including those conducted for the EIS for the proposed Cape Wind project off Massachusetts (Etkin 2006b; Etkin 2008). In those studies, the increased risk of an accident due to the presence of the OFW facility was found to be relatively low, though the vessel traffic in the area was also relatively low. An increase in traffic would increase the likelihood of an allision or collision.

One of the indirect effects of particular concern is the potential for radar interference due to the presence of OFW facility structures. The possibility of radar "blind spots, reflections, and shadow areas" created by the Cape Wind structures was raised in The McGowan Group (2004) report. This issue is discussed in

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[18] http://maritime-connector.com/news/security-and-piracy/oil-leaks-into-sea-after-ship-hits-win-turbine-off-barrow-coast/; http://www.maritime-executive.com/article/Ship-Hits-Wind-Farm-Piling-Spills-Fuel-2014-08-14

[19] http://www.ibtimes.com/oil-spill-offshore-triggered-when-maintenance-ship-hits-wind-turbine-generator-1661220

greater detail in the following studies: U.K. Air Warfare Centre 2005a, 2005b, 2005c; Brown 2005; and Howard and Brown 2004. The relevance to the Cape Wind situation is discussed in ESS Group, Inc. (2006). The issue was analyzed for the Virginia Offshore Wind Technology Advancement Project (VOWTAP) in C&H Global Security 2013 and Seifert 2005. There is also evidence that wind farms may cause issues with air traffic control radar, which could possibly contribute to plane accidents.[20]

The proximity of OFW facilities to vessel traffic lanes has been a concern for a number of existing wind parks outside the U.S. For example, collision and allision risk in a wind park in the Baltic Sea off Denmark was analyzed in a paper by Christensen, Andersen, and Pedersen (2001) and a follow-up study that included analyses of oil spillage was conducted by Randrup-Thomsen et al. 2000. A similar study was conducted for the proposed Burbo Bank Wind Park off Liverpool, United Kingdom (Anatek UK Limited 2002).

An extensive study conducted for the U.S. Coast Guard (2016), the *Atlantic Coast Port Access Route Study (ACPARS),* concluded that the cumulative effect of multiple wind farms in a region was of major concern to the marine transportation system. This increased risk of collisions and environmental damage would be due to vessel traffic being displaced and funneled into smaller areas. In addition to increased vessel traffic density, it was also concluded that there would be mixing of previously segregated traffic, which would cause increased risk. The APCARS report states:

> *The World Shipping Council (WSC) commented that positioning fixed wind turbines in close proximity to significant maritime transportation corridors and in the pathway of oceangoing ships is not something that an RFI [Request for Interest] should allow to be contemplated. The environmental costs and damage of a single allision between a ship and a wind turbine, as well as the potential loss of life and property could easily exceed any benefits of siting such turbines in the area. Safety of navigation dictates that there should be no circumstance where a lease should be invited in or near the approaches to a commercial shipping channel delineated by a TSS [Traffic Separation Scheme]… We strongly recommend that BOEM adopt as a general policy that the agency will not invite interest in wind farm leases in areas that overlap with a TSS or to the approaches to a TSS* (USCG 2016).

A previous study on the Atlantic Coast concluded that there was a marginal risk increase to vessels from wind farms, with a 12% increase in collisions, and a 0.4% increase in groundings. The risk of allisions was not calculated, though it was concluded that there may be a marginal increase (Copping et al. 2013). These studies did not analyze the probability of spillage from OFW facility components due to a vessel-related accident.

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. A detailed vessel traffic and spill analysis would need to be conducted for a site assessment using the location and development details of a proposed project.

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[20] http://www.windaction.org/posts/46830-navy-study-wind-farms-could-significantly-degrade-air-traffic-control-radar-detection#.WYSZCFGQxhF.

F.6.2 Categorization of Vessel Accident Damage

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).

Based on studies involving allision with offshore petroleum platforms, vessel allisions with OFW facility structures are likely to be relatively rare events (Hassal et al. 2016); although, as concluded in the ACPARS, increasing vessel traffic may potentially increase the likelihood (USCG 2016). The likelihoods of vessel allisions and vessel-vessel collisions (vessel casualties) have been studied extensively for a large variety of purposes. The probabilities vary by traffic density, navigational issues, geographic features, vessel type, and vessel traffic systems in place, among other factors. A review of the literature on general vessel casualty rates is shown in Appendix A.

Determining the likelihood of allisions of vessels with OFW facility structures, as would be completed for a project-specific site assessment or environmental impact assessment, is complex in that it needs to take into account location-specific conditions, which may vary over time and space:

- Ship traffic and navigational routes in the vicinity of the wind facility, as reflected by the quantity of vessels of different types (gross tonnage) and probability distributions in the vessel transit routes (vessel transit routes that are parallel to the ideal transit route but distributed as normal and uniform distributions perpendicular to the ideal route).
- Environmental conditions that might influence deviations from course (e.g., storms, fog).
- The wind park geometry and bathymetry of the study area.
- The range of vessel failure scenarios that might result in an allision (i.e., loss of steering, human error, propulsion failure) (Etkin 2006b; Anatek UK Limited 2002; Randrup-Thomsen et al. 2000).

For example, fault tree analyses incorporating the various failure rates, probabilities of compounding environmental factors, and the likelihood of deviating from vessel traffic lanes were incorporated into determining the frequency of accidents, including allisions, for the proposed Cape Wind project (Figure F-14) (Etkin 2006b; Etkin 2008). This type of approach would be most informative for determining the absolute or incremental risk of vessel accidents and spillage as might be required for an EIS (e.g., MMS 2009).

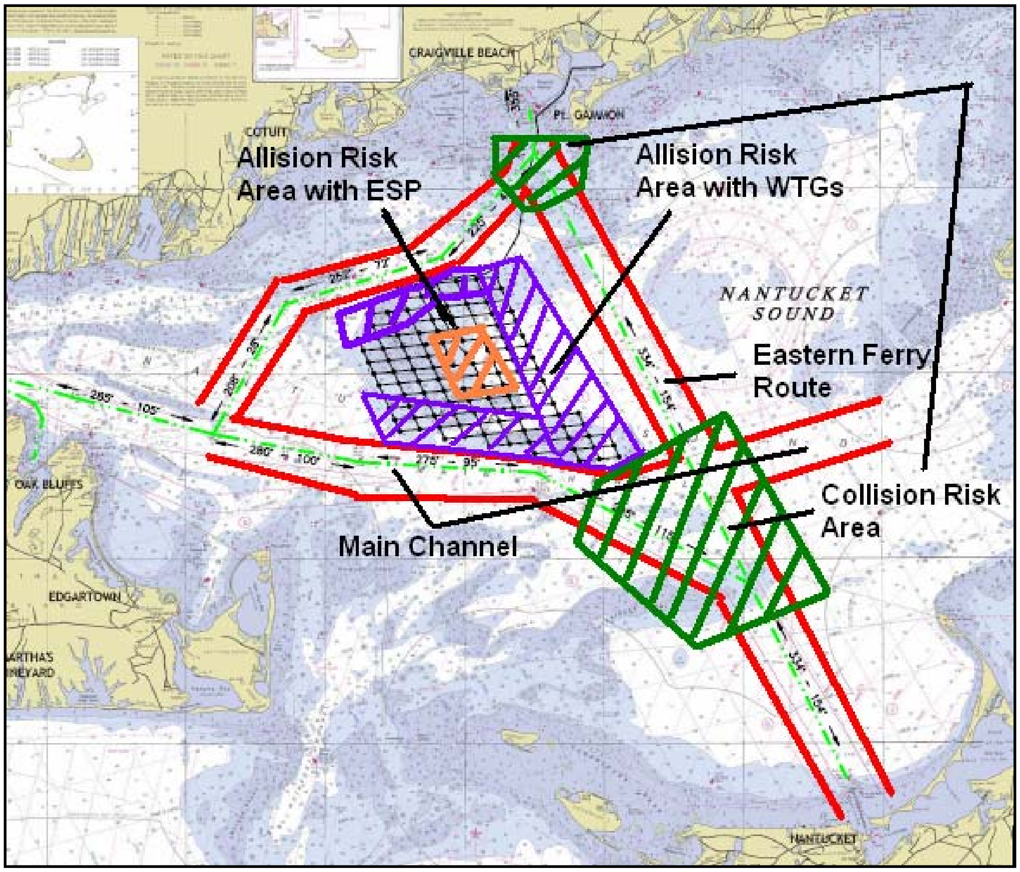

Figure F-14. Approximate Vessel Traffic Risk Zones for Cape Wind (Source: Etkin 2006b)

Documented worldwide vessel accident rates might also conceivably be applied to the OFWESA model. These rates vary greatly and are generally based on frequencies of accidents per vessels operating for a year. If one applies the worldwide allision frequency value of 6.0 x 10^{-4} per ship-year (based on Det Norske Veritas 2011) for the OFWESA analysis, it would be necessary to determine: the length of time that a vessel would transit past the OFW, and the number of vessels that would transit past the OFW in a year. If one assumes that the vessels would pass the OFW in two hours (probably maximized), there might be a 1.37 x 10^{-7} probability of an individual vessel experiencing an allision, based on an hourly allision rate of 1/8,760 times the yearly rate. Likewise, if the worldwide collision rate is 3.0 x 10^{-3} per ship-year (based on Det Norske Veritas 2011), allision rate would be 6.85 x 10^{-7} per vessel during the two-hour passing time.

However, for the purposes of the OFWESA model, 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. 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. 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). An example of this relationship is shown in Figure F-15.

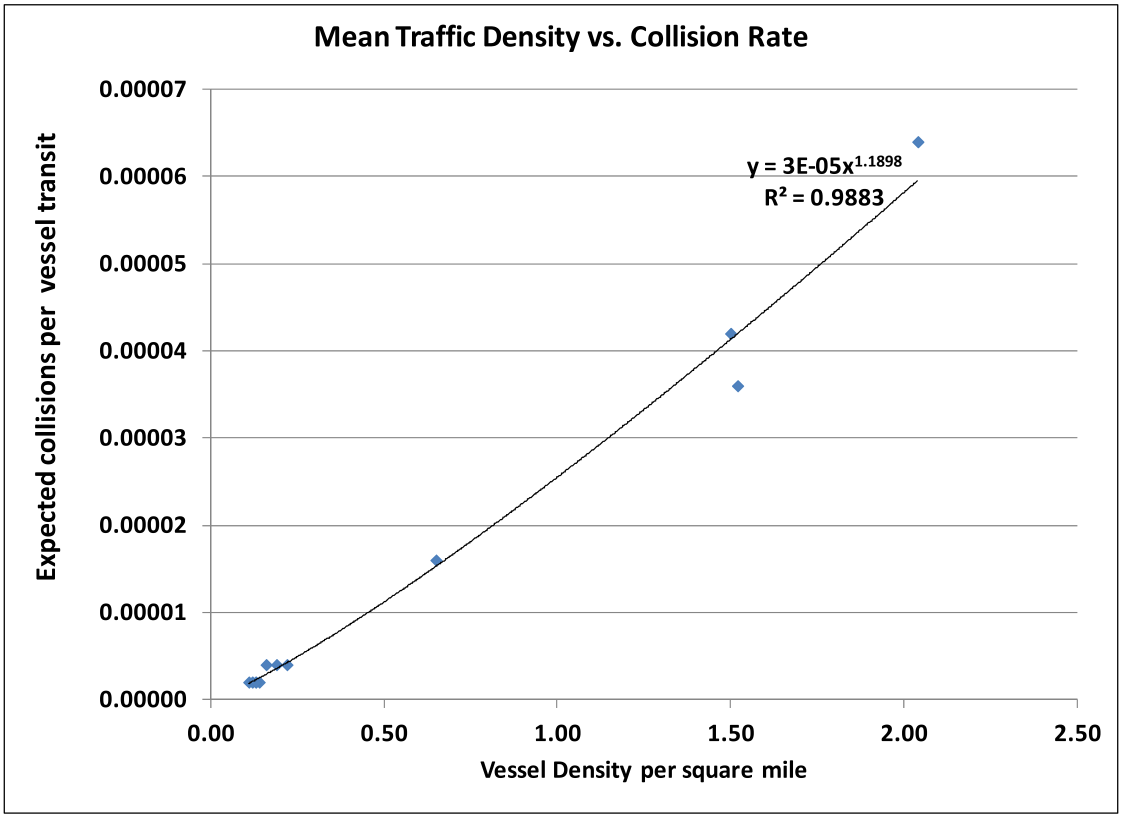

Figure F-15. Expected Collision Rate based on Vessel Density. Data from Judson 1992 for collision rates in the Strait of Juan de Fuca

F.6.3 Data Used to Categorize Vessel Accidents

The approach to determining the relative risk from vessel accidents for the OFWESA model is based on the following assumptions:

- Overall vessel traffic in the general vicinity of the proposed OFW facility site is directly correlated with the probability of allision accidents between vessels and wind facility components.
- Smaller vessels (pleasure craft, recreational vessels, smaller fishing vessels) are unlikely to cause damage, and thus spillage, from wind facility components, though they may experience spills themselves in the event of an allision.
- Medium sized vessels of about 5,000 to 24,999 gross tons (i.e., fish factories, ferries, smaller cargo vessels, passenger ships) are most likely to cause partial structural failure in the event of a direct allision.
- Larger cargo vessels of at least 25,000 gross tons (GT) (i.e., bulk carriers, tankers, tank barges, container ships, etc.) are most likely to cause significant enough damage to cause major structural failure.

For this purpose, vessel traffic data, numbers of vessels, and the distribution of sizes of vessel passing the vicinity of the proposed OFW facility sites are of concern.

F.6.4 Approaches to Vessel Accident Analysis for the OFWESA Model

The most comprehensive data that can be used to determine vessel traffic numbers and density are those coming from the Automated Identification System (AIS). It is a form of geographic position system (GPS) data that allows ships to detect each other in transit.

AIS data, are collected by the U.S. Coast Guard through an onboard navigation safety device that transmits and monitors the location and characteristics of large vessels in U.S. and international waters in real time. The AIS data for the years 2009 through 2014 are available at: https://marinecadastre.gov/ais/.[21]

Alternatively, the data can be accessed at the commercial site www.marinetraffic.com, where more recent data (past 90 days) can be downloaded and density maps of vessel traffic data for the years 2015 and 2016 can be viewed. Specific data searches on vessel numbers by type and size can be conducted, such as the numbers of vessels of different types going to certain ports.

These data would be needed for a comprehensive vessel traffic analysis, as would generally be required in an EIS process for a particular application or proposal for an offshore facility.

However, for the purposes of the OFWESA model, in which a relative comparison between alternative sites as part of an initial screening process is being conducted, a more simplified approach is adequate. The simplified approach involves determining the annual tonnage of vessels and trips going to the key ports in the vicinity of proposed sites. It is also necessary to determine whether the port(s) in question would accommodate large cargo vessels, which would be the ones that could cause a larger spill by causing major structural damage to the facility components in the event of an allision. In some areas, the numbers of larger vessels may be more limited.

Appropriate port data are available from the following sources:

- U.S. Maritime Administration (https://www.marad.dot.gov/resources/data-statistics/)
- US Army Corps of Engineers Navigation Data Center (http://www.navigationdatacenter.us/wcsc/wcsc.htm)

In cases in which the vessel traffic lanes are unclear, reference to the mapping capabilities of the AIS data sites may be instructive. This would assist in determining whether the traffic would conceivably ever be near the proposed OFW facility sites, as shown in Figure F-16.

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[21] The data downloading and conversion process are described in the PowerPoint presentation prepared for BOEM (AIS How to BOEM) that was provided by BOEM to ERC.

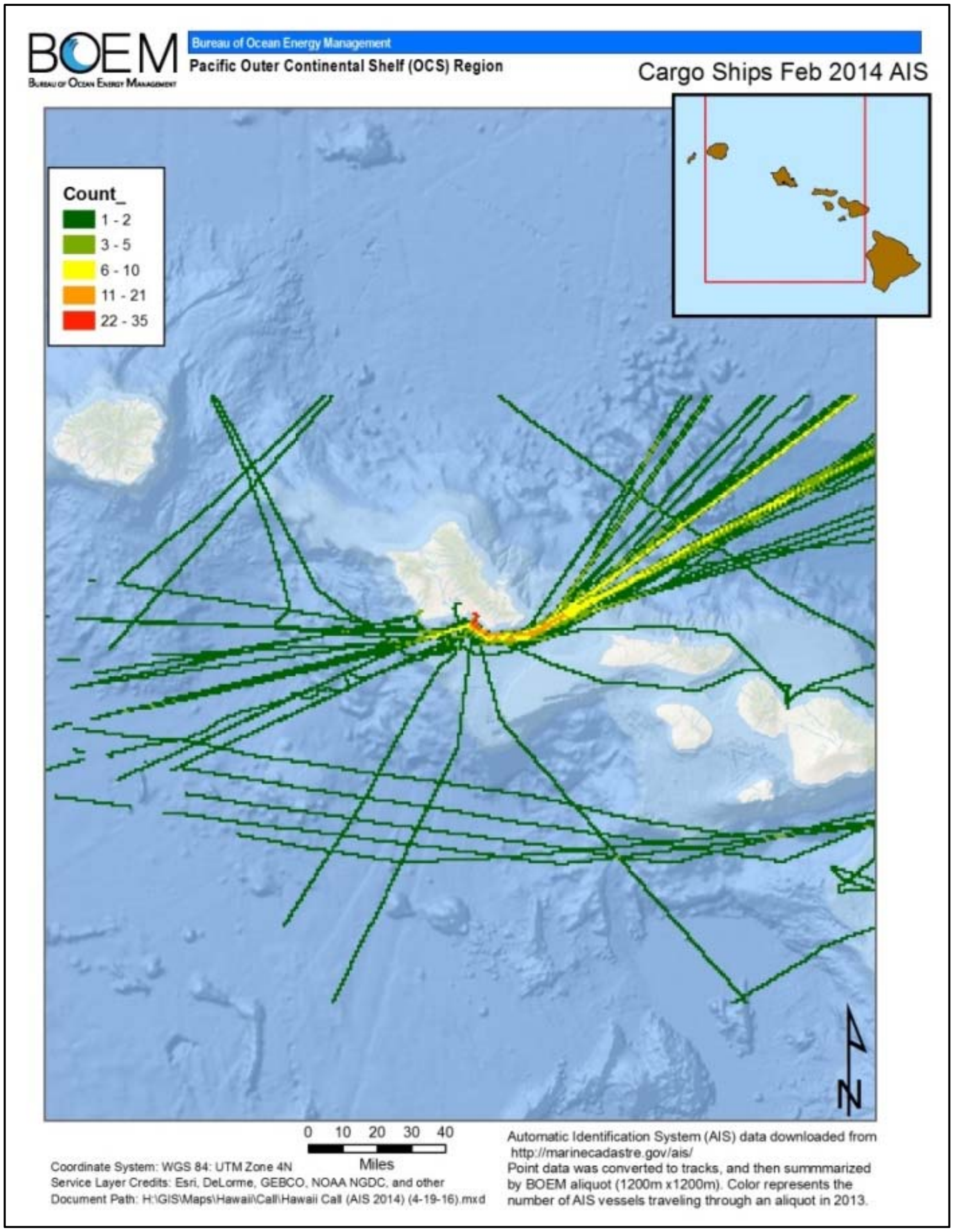

Figure F-16. Example AIS Map: Cargo Ships in February 2014 (Source: From BOEM PowerPoint, "AIS How to BOEM)

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.

F.6.4.1 Application of Vessel Accident Analysis to California Sites

For the California wind energy lease block area, the major concern would be the large amount of traffic that would be going to the Port of Los Angeles/Long Beach, which is the busiest port in the U.S., handling a combined 138.4 million short tons of traffic annually (U.S. Army Corps of Engineers 2015). Potentially, traffic going to San Francisco might also pass by this area. This port has a large volume of larger vessels and tonnage. There is also a much smaller port, Port Hueneme, which handles 1.71 million short tons of freight traffic annually where vessel traffic that passes the lease block area may originate. Port Hueneme is the only deep-water port between the Port of Los Angeles and the Port of San Francisco, and the only U.S. Navy-controlled harbor between San Diego Bay and Puget Sound in Washington State. Besides being a Navy base, it also receives goods destined for the Los Angeles area. This is the reason for the relatively large proportion of larger vessels.

The summary of vessel traffic for the central California ports of concern is shown in Table F-16.

Table F-16. Summary: Annual Freight Vessel Traffic for Central California Ports

Port	Annual Tonnage (Short Tons)	Annual Trips		
		All Vessels	Tows/Tugs	Larger Vessels
Long Beach	78,165,000	21,750	8,461	13,289
Los Angeles	60,188,000	19,985	8,877	11,108
San Francisco	73,697,000	6,779	500	6,279
Port Hueneme	1,710,000	1,424	68	1,356
Total	213,760,000	49,938	17,906	32,032

(Source: U.S. Army Corps of Engineers 2015)

The types of spills that might occur in this area are dependent on the cargo types in the waterborne commerce, which currently includes such commodities as crude oil, petroleum products, plastics, chemicals, pulp and paper, fabricated metal products, iron and steel scrap, agricultural products, and fertilizers. In addition, fuel oils (diesel and intermediate or heavy fuel oil) could also potentially spill from vessels.

F.6.4.2 Application of Vessel Accident Analysis to Hawaii Sites

For the Hawaii wind energy lease block areas, the concern would be vessel traffic going to the island of Oahu, which would include the Ports of Honolulu and Barbers Point. The vessel traffic data are summarized in Table F-17.

Table F-17. Summary: Annual Freight Vessel Traffic for Oahu, Hawaii Ports

Port	Annual Tonnage (Short Tons)	Annual Trips		
		All Vessels	Tows/Tugs	Larger Vessels
Barbers Point	10,570,000	2,327	1,265	1,062
Honolulu	13,832,000	8,435	4,839	3,596
Total	24,402,000	10,762	6,104	4,658

(Source: U.S. Army Corps of Engineers 2015)

The types of spills that might occur in this area are dependent on the cargo types in the waterborne commerce, which currently includes such commodities as petroleum products, plastics, chemicals, fabricated metal products, manufactured goods, iron and steel scrap, agricultural products, and fertilizers. In addition, fuel oils (diesel and intermediate or heavy fuel oil) could also potentially spill from vessels.

F.6.4.3 Vessel Sinking

It is not likely that a large vessel would sink as a result of an accident involving an allision with an OFW facility structure. Even if this were to be the case, the greatest impact would be from the released fuel and/or cargo. These effects are outside of the scope of the OFWESA model.

Conceivably, a smaller vessel, such as a fishing or recreational vessel, that allides with one of the OFW facility structures might suffer such damage that it would founder (sink). If a foundering were to occur, the vessel would most likely be one that contains diesel fuel, or possibly gasoline. If the accident that caused the sinking does not completely puncture the fuel tank of the vessel causing an instantaneous spill, it is possible that there may be leakage from the vessel after it sinks. The quantity of spillage or slow release would be relatively small (likely less than 500 gallons) and its effects would be relatively localized. These types of smaller-vessel events would be correlated with weather activity and correlated with the numbers of small vessels, which are difficult to determine as they generally do not participate in AIS. The presence of the OFW facility structures would likely have relatively little bearing on these events. The presence of the sunken vessel could cause some localized impacts depending on its size, its condition, and the sensitivity of the ocean bottom at that location. The wreck could eventually become an attractant to fish.

F.7 Summary

The large-scale event factors that could cause spills from the floating OFW facilities were analyzed for the central California and Hawaii locations, with the results shown in Table F-18.

Table F-18. Summary OFWESA Risk Matrix for Large-Scale Events Causing Spills

Location	**Hurricane**		**Earthquake**		**Tsunami**		**Vessel Allision with Damage to Wind Facility Structures**	
	Partial Structure Failure	**Major Structure Failure**	**Partial Structure Failure**	**Major Structure Failure**	**Partial Structure Failure**	**Major Structure Failure**	**Partial Structure Failure from Medium Vessel Allision**	**Complete Structure Failure from Larger Vessel Allision**
Data Applied	**Annual Frequency of Hurricanes in Region by Category**		**Annual Frequency of Earthquakes in Region by Magnitude**		**Annual Frequency of Tsunamis in Region by Magnitude**		**Vessel Traffic Data Annual Tonnage**	
							Annual Vessel Trips by Size	
Factor Magnitude	4	>5	5	>7	6	>7.9	Medium *Tows* *Tugs*	Larger *Tankers* *Bulkers* *Containers*
Hawaii	0.095	0.108	0.53	0.01	0.15	0.007	24.4 M tonnage	
							6,104 trips	4,658 trips
California	0.011	0.006	0.12	0.008	0.08	0.00	213.8 M tonnage	
							17,906 trips	32,032 trips

This analysis was based on a comparison of the frequencies of natural events (hurricanes, earthquakes, and tsunamis) and the density of vessel traffic for offshore wind energy lease block areas in two regions, California and Hawaii. The derivations of risk values for hurricanes are explained in Section F.3.4; for earthquakes in Section F.3.5; for tsunamis in Section F.3.6; and for vessel allision events in Section F.3.7. If additional sites are to be considered for the OFWESA model in the future, the comparison should incorporate national data or the range of values for all the alternative sites. Relative to each other, the highest-risk factors are colored in red, the moderate-risk factors are colored in yellow, and the lower-risk factors are colored in green in Table F-18.

For natural events (hurricanes, earthquakes, and tsunamis), the annual frequencies are applied. The frequencies can be compared relative to each other. For example, for hurricanes the Hawaii lease block areas have nine times the frequency of Category 4 hurricanes and 22 times the frequency of Category 5 hurricanes when compared to the central California lease block area. These frequencies reflect the probability that there may be a hurricane, earthquake, or tsunami that could cause sufficient partial or major structural failures to cause 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 would depend on the specific circumstances of each event.

For the vessel allision probabilities, the approach is somewhat different. No complex vessel casualty analysis has been conducted with respect to the probability of allisions of vessels with the OFW facility structures, as that would require detailed information about the locations of wind turbine generators and other structures for a specific proposal. Instead, 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 proxy for the likelihood of an allision incident. The annual tonnage and numbers of vessel trips were applied. 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. In the case of the Hawaii and central California lease block area comparison, it is clear that there is nearly nine times the tonnage in California and thus a higher risk of vessel allision in that region.

The vessel trip numbers by medium and larger vessel size were applied to provide a relative probability of the likelihood of allisions that might cause either partial or major structural failure. The vessel numbers are reflective of the nature of vessel traffic. In some port areas, such as the ones in the vicinity of the Hawaiian lease block areas, there may be relatively fewer larger vessels compared to other locations, due to draft restrictions, lack of terminal infrastructure to accommodate larger deep-draft vessels, or regional economic and industry trends. However, there may be a large number of medium-sized vessels (e.g., tugs and tows), that would increase the likelihood of those types of partial structural failure allisions relative to major incidents. In the comparison between the Hawaiian and central California lease block areas, the total numbers of vessels are much greater in California. It can clearly be seen that the vessel traffic risk for the Hawaii locations are about an order of magnitude less than that for the central California lease block area. Because of the greater proportion of larger vessels in the California ports, the likelihood of a major allision is relatively greater there than in Hawaii. Note that the analysis for the central California lease block could be expanded to other areas off California by adjusting the included vessel traffic data from other ports that may be closer to the particular lease area of concern and eliminating that traffic that may not pass by a certain area (e.g., adding San Diego traffic and eliminating San Francisco traffic for a more southern region).

The data in Table F-18 provides a means to compare the Hawaii and central California lease block areas with respect to the relative probabilities of large-scale natural events and vessel accidents that might cause spillage from OFW facility structures. The absolute likelihood of spillage events was not calculated, but rather the likelihood of spills at each location relative to the other. If absolute probabilities of spills need to be determined, as would be expected as part of an EIS process for a specific proposal or application (e.g., MMS 2009), a more detailed analysis of spill probabilities, particularly with regard to vessel allisions, would need to be conducted. An EIS would also involve the analysis of spills from vessels themselves due to accidents that are attributable to the presence of the offshore facility, as well as spills from the facility structures.

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Department of the Interior (DOI)

The Department of the Interior protects and manages the Nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors the Nation’s trust responsibilities or special commitments to American Indians, Alaska Natives, and affiliated island communities.

Bureau of Ocean Energy Management (BOEM)

The mission of the Bureau of Ocean Energy Management is to manage development of U.S. Outer Continental Shelf energy and mineral resources in an environmentally and economically responsible way.

BOEM Environmental Studies Program

The mission of the Environmental Studies Program is to provide the information needed to predict, assess, and manage impacts from offshore energy and marine mineral exploration, development, and production activities on human, marine, and coastal environments. The proposal, selection, research, review, collaboration, production, and dissemination of each of BOEM’s Environmental Studies follows the DOI Code of Scientific and Scholarly Conduct, in support of a culture of scientific and professional integrity, as set out in the DOI Departmental Manual (305 DM 3).