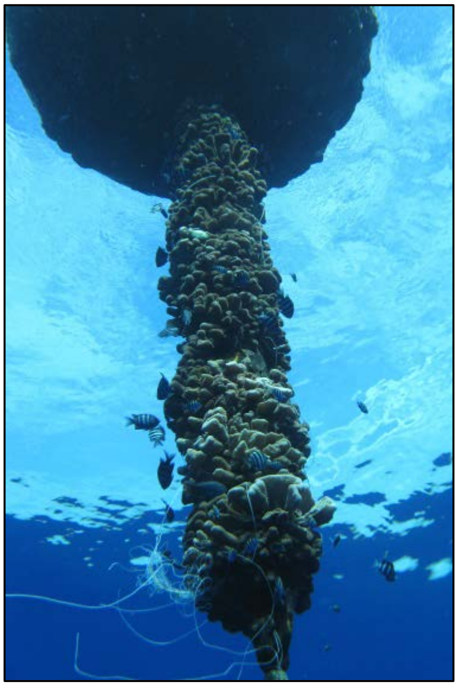

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FINAL TECHNICAL REPORT

Evaluating the Potential for Marine and Hydrokinetic Devices to Act as Artificial Reefs or Fish Aggregating Devices

Based on Analysis of Surrogates in Tropical, Subtropical, and Temperate U.S. West Coast and Hawaiian Coastal Waters

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List of Abbreviations

AR	Artificial Reef (in Tables and Figures)
BOEM	U.S. Bureau of Ocean Energy Management
CA-WA	Central California to Cape Flattery, Washington
DEB	Marine Debris (in Tables and Figures)
DOE	U.S. Department of Energy
EMF	Electromagnetic fields
FAD	Fish Aggregating Device; Also refers to purpose-built FADs (in Tables and Figures)
FL	Drift Kelp (in Tables and Figures)
FR	Federal Register
HTH	H. T. Harvey & Associates
KE	Attached Kelp (in Tables and Figures)
m	Meter
m/s	Meters per second
MAR	Mariculture Facilities (in Tables and Figures)
MHI	Main Hawaiian Islands
NDBC	National Data Buoy Center
NMFS	National Marine Fisheries Service
NR	Natural Reef (in Tables and Figures)
ODFW	Oregon Department of Fish and Wildlife
OP	Oil and Gas Platform (in Tables and Figures)
PG&E	Pacific Gas & Electric
PM	Piers and Docks (in Tables and Figures)
SCB	Southern California Bight
TEC	Tidal Energy Converter
WEC	Wave Energy Converter

Executive Summary

Wave energy converters (WECs) and tidal energy converters (TECs) are only beginning to be deployed along the U.S. West Coast and in Hawai‘i, and a better understanding of their ecological effects on fish, particularly on special-status fish (e.g., threatened and endangered) is needed to facilitate project design and environmental permitting. The structures of WECs and TECs placed on to the seabed, such as anchors and foundations, may function as artificial reefs that attract reef-associated fishes, while the midwater and surface structures, such as mooring lines, buoys, and wave or tidal power devices, may function as fish aggregating devices (FADs), forming the nuclei for groups of fishes. Little is known about the potential for WECs and TECs to function as artificial reefs and FADs in coastal waters of the U.S. West Coast and Hawai‘i. We evaluated these potential ecological interactions by reviewing relevant information about fish associations with *surrogate structures*, such as artificial reefs, natural reefs, kelps, floating debris, oil and gas platforms, marine debris, anchored FADs deployed to enhance fishing opportunities, net-cages used for mariculture, and piers and docks.

Based on our review, we postulate that the structures of WECs and TECs placed on or near the seabed in coastal waters of the U.S. West Coast and Hawai‘i likely will function as small-scale artificial reefs and attract potentially high densities of reef-associated fishes (including special-status rockfish species [*Sebastes* spp.] along the mainland), and that the midwater and surface structures of WECs placed in the tropical waters of Hawai‘i likely will function as *de facto* FADs with species assemblages varying by distance from shore and deployment depth. Along the U.S. West Coast, frequent associations with midwater and surface structures may be less likely: juvenile, semipelagic, kelp-associated rockfishes may occur at midwater and surface structures of WECs in coastal waters of southern California to Washington, and occasional, seasonal, or transitory associations of coastal pelagic fishes such as jack mackerel (*Trachurus symmetricus*) may also occur at WECs in these waters. Importantly, our review indicated that negative effects of WEC structures on special-status fish species, such as increased predation of juvenile salmonids or rockfishes, are not likely. In addition, WECs installed in coastal California, especially in southern California waters, have the potential to attract high densities of reef-associated fishes and may even contribute to rockfish productivity, if fish respond to the WECs similarly to oil and gas platforms, which have some of the highest secondary production per unit area of seafloor of any marine habitat studied globally (Claisse et al. 2014).

We encountered some information gaps, owing to the paucity or lack, in key locations, of comparable surrogate structures in which fish assemblages and ecological interactions were studied. TECs are most likely to be used in the Puget Sound area, but suitable surrogates are lacking there. However, in similarly cold-temperate waters of Europe and Maine, benthopelagic fish occurred around tidal turbines during lower tidal velocities, and this type of interaction may be expected by similar species at TECs in Puget Sound. To address information gaps in the near term, such as whether WECs would function as FADs in temperate waters, studies of navigation buoys using hydroacoustics are recommended.

Section 1.0 Introduction

1.1 Study Overview and Purpose

This report presents the findings and recommendations resulting from a review of scientific literature and discussions with resource managers and subject matter experts, concerning the potential ecological effects of marine renewable energy devices, specifically wave energy converters (WECs) and tidal energy converters (TECs), in waters off of the U.S. West Coast and Hawai'i. This study was initiated by the U.S. Department of Energy (DOE) and the Bureau of Ocean Energy Management (BOEM) and carried out by H. T. Harvey & Associates (HTH).

More is known about the ecological effects of marine renewable energy devices (i.e., wave, tidal, and offshore wind energy) in regions where these devices have already been installed, such as in Europe (e.g., Royal Haskoning Enhancing Society 2011, Frid et al. 2012, Leung and Yang 2012, Witt et al. 2012, Adams et al. 2014, Bergstrom et al. 2014, Broadhurst et al. 2014, Reubens et al. 2014). However, fish and invertebrate assemblages in coastal waters of the Pacific Ocean differ from those in other regions, so direct inference may not always be appropriate or applicable. In fact, there has not yet been a synthesis of knowledge, regarding waters off the U.S. West Coast and Hawai'i, that could be used to evaluate the potential ecological effects of marine renewable energy projects and facilitate environmental permitting in these regions. This study was conducted to address the growing demand for such information.

The goal of this study is to evaluate the ecological interactions that may result from WEC and TEC installations in waters off the U.S. West Coast and Hawai'i. The specific objective is to evaluate the potential for WECs and TECs (considered *stressors*) to function as artificial reefs or fish aggregating devices (FADs), thereby affecting marine fishes (*receptors*). Because WECs and TECs are only beginning to be deployed along the U.S. West Coast and in Hawai'i, this study extrapolates the relevant information from known fish assemblages and ecological interactions that occur at *surrogate structures*, such as artificial reefs, natural reefs, oil and gas platforms, marine debris, FADs built to enhance fishing opportunities, and net-cages used for mariculture found in coastal tropical, subtropical, and temperate waters, and applies this information to future installations of WECs and TECs located along the U.S. West Coast or in Hawai'i. Specifically, we analyze information so that developers and resource agency staff can evaluate the potential for WECs and TECs to function as artificial reefs or FADs based on the geographic location of the device, the fish and other marine species present, the device's deployment depth and distance from shore, and oceanographic conditions that affect species presence, such as El Niño conditions and proximity to coastal processes (e.g., large river influences).

1.2 Characteristics of WECs and TECs

WECs and TECs are two types of marine renewable energy devices that may be installed in offshore marine or tidal locations, respectively. WECs introduce structure at the water's surface and in the midwater (*midwater/surface structure*), and on or near the seabed (*ocean bottom structure*) in the form of wave power devices, mooring lines, buoys and foundations or anchors (Nelson 2008, Previsic 2010). Wave power devices can range in size and shape, from cylindrical devices a few meters in height and diameter, to long linear-shaped devices that are more than 100 meters (m) in length. Types of wave power devices include those that float on the surface (e.g., attenuators, point absorbers, oscillating water column devices, overtopping devices) and would be anchored in water depths of greater than 40 m (maximum deployment depths would likely depend on distance from shore because of costs associated with transmission cables), and surging flap devices (e.g., Aquamarine Power's Oyster, which is approximately 25 m wide and 10–15 m high) attached to the seabed in nearshore waters 10–15 m deep (Nelson and Woo 2008, Previsic 2010). With the exception of a hinged-flap device that would provide structure throughout the water column to the surface, the midwater structures of WECs are generally limited to mooring lines and, in some types, structure that extends down from the surface into the upper few meters of the water column (e.g., point absorbers). On the ocean bottom, anchors could range from concrete blocks that are several meters (e.g., 5–10 m) in width and height, with little complexity such as holes or crevices, to drag-embedment anchors with little or no hard structure above the seabed (Previsic 2010).

TECs introduce bottom and midwater structure into tidal waters in the form of instream tidal turbines with rigid or flexible mooring, plus a gravity foundation or penetrating anchor to attach it to the seabed (Polagye and Previsic 2010). TECs are generally installed with an overhead clearance of 15–25 m to avoid posing a hazard to vessel traffic (Polagye and Previsic 2010). Working surfaces (e.g., the moving turbines) are generally treated with antifouling coatings because biological fouling by barnacles, algae, and other organisms hampers device performance.

WECs and TECs may be installed as a single-unit demonstration project, a small pilot project with a few devices in an array within a few square kilometers, or a large commercial-scale development with numerous (tens of) devices in a much larger area (Previsic 2010). Test facilities may have several types of devices installed for testing and evaluation (e.g., DOE et al. 2012a, Naval Facilities Engineering Command 2014). Installations may also be scaled up gradually, starting with one device and increasing to a small array, then to a large commercial development (Previsic 2010).

1.3 Potential Ecological Interactions with WECs and TECs

The ocean bottom structures of WECs and TECs, such as anchors and foundations, may function as artificial reefs by adding hard substrate, vertical relief and habitat complexity that becomes colonized by invertebrates and reef-associated fishes (Nelson 2008, Boehlert et al. 2013, Wilhelmsson and Langhamer 2014). Midwater and surface structures, such as mooring lines and wave or tidal power devices, may function as FADs, forming nuclei for the aggregation of pelagic fishes (Nelson 2008, Boehlert et al. 2013, Wilhelmsson and Langhamer 2014). WEC devices and their operation may also generate additional stimuli that may not be present in other types of artificial reef or FAD structures, such as sound or electromagnetic fields (EMF), which could alter fish behavior (Nelson 2008).

The difference between artificial reefs and FADs is not only the position of the structure within the water column (ocean bottom versus midwater/surface), but also the type of response by fish. Artificial reefs function primarily as habitat for demersal, reef-associated fishes or their prey (Nelson 2008). FADs, like other surface or midwater structures, function primarily as a means of orientation for fishes in open water (Hunter and Mitchell 1967, Dagorn 1994, Nelson 1999, Fréon and Dagorn 2000), probably based on the optical reflex that leads a fish to orient to a solid object in moving water (Lyon 1904, Atz 1953), although FADs may also provide habitat for pelagic fishes and juveniles of reef-associated fishes (Nelson 2008). Artificial reefs may simply concentrate existing individuals, or may serve to enhance the regional production of fishes; the latter is more likely if hard-bottom habitat is limiting in the area (Grossman et al. 1997, Pickering and Whitmarsh 1997). FADs may also enhance regional production of fishes by aiding in juvenile dispersal, or by improving the survival rate of juveniles via protection from predators and/or by congregating food sources (Fréon and Dagorn 2000, Castro et al. 2002).

Midwater/surface structures of WEC or TECs with anchors can function as both artificial reefs and FADs and may attract more fish species and individuals than either type of structure alone, at least in shallow (e.g., <200 m depth), tropical and subtropical waters where FAD-associated species occur (Beets 1989, Hair et al. 1994). For example, oil platforms, which provide habitat on the bottom and throughout the water column to the surface, are known to enhance production because they support late larval, juvenile, and adult demersal life stages of reef fishes (Claisse et al. 2014). FADs located adjacent to natural rocky reefs may also attract a greater fish species diversity and abundance and different species assemblage than FADs deployed over sand bottom; in Caribbean waters, the former attracted a variety of resident reef–associated species and extended their habitat into the midwater, while the latter attracted primarily pelagic, more typical FAD-associated fishes (Workman et al. 1985).

Fish that associate with WECs and TECs could include *special-status fish species* (e.g., State- or federally listed species, federal candidate species, federal species of concern, or species designated as "overfished" or requiring special management by the National Marine Fisheries Service [NMFS]), representing a potential constraint to permitting due to potential environmental, economic, or cultural impacts. For example, there are concerns that special-status fish, such as federally threatened or endangered juvenile salmonids, could aggregate at WECs and TECs and be subject to increased predation if large predatory fishes, piscivorous seabirds, pinnipeds, or sea otters (*Enhydra lutris*) are also attracted (e.g., Lyons et al. 2007, Thompson et al. 2008, Boehlert and Gill 2010, Hughes et al. 2014, Russell et al. 2014, Wilhelmsson and Langhamer 2014).

A commercial-scale development with many devices could provide beneficial connectivity and promote migrations of fish and invertebrates between individual devices (Nelson 2008, Thorpe 2012, Krone et al.

2013). WECs and TECs could also serve as *de facto* marine reserves if fishing is limited, prohibited, or managed around the devices, such that they serve as a source for recruitment to adjacent fished and unfished areas, improving fish populations as a whole (DOE 2009, Wilhelmsson and Langhamer 2014). Positive population-level effects resulting from fishing exclusion zones around WECs and TECs are likely to be greatest for heavily fished species, for more residential or stationary fish species (Boehlert et al. 2013, Wilhelmsson and Langhamer 2014), and for those fishes able to use habitat created by the device structure to complete important life history stages and thus facilitate recruitment. This connectivity could also create dispersal pathways for nonnative invertebrates by providing new settlement sites for pelagic larvae that would otherwise be lost offshore (Adams et al. 2014). Marine renewable energy developments are not likely to similarly create supplementary dispersal pathways for nonnative fishes (such as the predatory lionfish [*Pterios volitans* and *P. miles*] which is threatening native reef fish communities in the western Atlantic Ocean [Morris and Whitfield 2009]), given that fish mobility and dispersal can occur in egg, larval, and adult life stages, and therefore is much less limited by habitat availability.

1.3.1 Artificial Reefs

Artificial reefs, formed by human-made structures intentionally or unintentionally situated on the ocean bottom, have been placed in coastal waters along the U.S. West Coast and Hawai'i, mainly to attract and concentrate fish for management, fishing, and/or recreational diving opportunities (e.g., Seki 1983, Cross and Allen 1993, Palsson et al. 2009, Broughton 2012). Artificial reefs generally support similar fish assemblages as natural rocky reefs, although fish densities at artificial reefs tend to be higher because of the higher perimeter-to-area ratio, greater complexity, vertical relief, cover, and diversity of habitats provided (Jessee et al. 1985, Ambrose and Swarbrick 1989, DeMartini et al. 1989, Stephens et al. 1994, Wilhelmsson et al. 2006, Hunter and Sayer 2009). However, artificial reefs are generally much smaller than natural reefs, so the total fish abundance may be trivial in comparison to that found at natural reefs (Broughton 2012). As on natural reefs, the fish and invertebrates that colonize an artificial reef may spend only a portion of their life cycle there; thus, these reefs are ecologically connected to other areas and habitat types, and their presence can have population-level effects (Broughton 2012). The bottom structures (anchors and foundations) of WECs and TECs would likely attract similar fish species as are found at artificial reefs at similar depths and environments, although factors such as complexity and vertical relief of bottom structure, total number of anchors or foundations, and distance to the nearest natural reef or other hard structure may affect assemblages and ecological interactions.

1.3.2 Floating Objects and FADs

Fish in tropical and subtropical waters are known to associate with or aggregate at floating objects, such as buoys, logs, jellyfish, whale corpses, abandoned fishing nets, drift algae (e.g., *Macrocystic pyrifera* paddies, *Sargassum* spp.), and purpose-built FADs, and fish species composition appears to be similar among different types of free-drifting objects (Mortensen 1918, Gooding and Magnuson 1967, Hunter and Mitchell 1967, Helfman 1981, Rountree 1989, Holland et al. 1990, Druce and Kingsford 1995, Parin and Fedoryako 1999, Itano and Holland 2000, Relini et al. 2000, Zárate-Villafranco and Ortega-García 2000, Dempster and Taquet

2004). A review by Castro et al. (2002) found more than 300 fish species from 96 families (Scombridae and Carangidae are most common) associated at least occasionally with floating items, and the majority of the fish were juveniles. There are several theories as to why fish associate with or aggregate at floating objects: they may use the structure to hide from predators (Rountree 1989), to increase their encounter rate with other conspecifics or schools to increase survival (the *meeting-point* hypothesis, typical of adult tunas; Dagorn 1994, Fréon and Dagorn 2000), or to increase the likelihood of being in favorable environments, because floating objects are often found in highly productive frontal zones caused by ocean convergences (the *indicator-log* hypothesis, largely applicable to juveniles; Hall et al. 1999). Smaller fishes tend to aggregate closely to floating objects (i.e., within a few centimeters to meters) and depend on its presence for shelter, protection from predators, and food, and they may remain throughout the most vulnerable stages of development (postlarvae and juvenile; Castro et al. 2002). Larger fishes (mainly migrant tunas– *Thunnus albacares*, *T. obesus*, and *Katsuwonus pelamis*, and dolphinfish, *Coryphaena hippurus*) tend to be loosely associated with floating objects on a scale of a tens to hundreds of meters, and likely use them as a meeting point for school formation to continue on their migration routes (Gooding and Magnuson 1967, Fréon and Dagorn 2000, Castro et al. 2002). Fish associations or aggregations can range from minutes to months and may include repeat visits, and they are generally fleeting or transitional and not residential for a lifetime (Gooding and Magnuson 1967, Hunter and Mitchell 1968, Dempster and Taquet 2004, Dagorn et al. 2007).

FADs are often deployed in tropical and subtropical waters in order to concentrate target species or their prey to improve fisheries catch (Nelson 2003). Free-drifting FADs are generally deployed in the open ocean while anchored FADs are often deployed nearer to shore for inshore local tropical fisheries (Jaquemet et al. 2011). There is some evidence that drifting FADs may provide a *super-normal stimulus*, attracting tuna into lower-quality, less productive habitats and affecting their growth and condition relative to fish captured in free schools (Hallier and Gaertner 2008, Jaquemet et al. 2011, but see Schaefer and Fuller 2005).

Fish associations with FADs and other types of floating objects in tropical and subtropical waters are well known and similar associations would be expected at the midwater and surface structures of WECs and TECs deployed in tropical and subtropical waters. However, fish associations have not been reported for temperate waters, which may be one reason that anchored FADs are rarely placed in temperate waters to improve recreational and commercial fishery yields. FAD-associated fish assemblages are generally composed of tropical or subtropical taxa, and fish associations with FADs may be less likely or less prevalent in colder waters where these taxa are rare or absent (Nelson 1999). Water temperature or clarity may constrain the presence of FAD-associated species; for example, dolphinfish, which are limited to sea surface temperatures of >19°C, occur regularly at FADs offshore of Australia only when temperatures exceed this threshold (Dempster 2004). In the temperate North Pacific Ocean, water clarity generally declines farther north as productivity increases, decreasing the detectability of floating objects as well as reducing the adaptive advantages for pelagic fishes (e.g., protection from predators or access to prey) to associate with floating objects. Nonetheless, the potential for WECs and TECs to function as FADs in temperate waters has not been ruled out, and has been identified as an information gap needing further research (Boehlert et al. 2013).

1.4 Research on Existing Marine Renewable Energy Installations

A few studies have examined fish associations and invertebrate colonization of offshore wind projects in Europe during the first few years of device operation. These may help evaluate potential ecological interactions at WECs and TECs in the U.S., especially in temperate waters. In the short term (e.g., <2 years after installation), these studies generally found that fish assemblages at the underwater structures were comparable to those on nearby natural and artificial reefs, and that differences were not easily separated from larger-scale temporal and spatial variability (Kjaer et al. 2006, Langhamer and Wilhelmsson 2009, Langhamer et al. 2009, Degraer et al. 2010, Leonhard et al. 2011, Lindeboom et al. 2011, Stenberg et al. 2012). Wind turbine foundations at some offshore wind projects functioned as artificial reefs, attracting demersal fish such as pouting (*Trisopterus luscus*), Atlantic cod (*Gadus morhua*), goldsinny wrasse (*Ctenolabrus rupetris*), viviparous eelpout (*Zoarces viviparous*), lumpsucker (*Cyclopterus lumpus*), shorthorn sculpin (*Myoxocephalus scorpius*), eel (*Anguilla anguilla*), and gobies (Gobiidae) (Wilhelmsson et al. 2006, Leonhard et al. 2011, Bergstrom et al. 2013, Reubens et al. 2014). In one study, the project foundations provided high-quality habitat for fish by supporting abundant benthic invertebrate prey (e.g., amphipods and crabs), and the fishing exclusion zone around the project likely improved survival of adult fishes (Reubens et al. 2014). At a study offshore of Germany, the majority of mobile fish and crustaceans were reported at the base of a wind turbine foundation (28-m depth), whereas the midwater sections (5–15 m from the surface) of the foundation were only sparsely colonized (Krone et al. 2013). Given that research on existing offshore wind projects has encompassed only the first few years of operations, it is unknown whether these installations will increase the productivity of fish or have other long-term effects on the food web (Bergstrom et al. 2014).

At a tidal turbine in northern Ireland, there was patchy invertebrate colonization of bottom structures (Broadhurst and Orme 2014), and pollack (*Pollachius pollachius*) were associated with the structures only during low tidal velocities (e.g., <1.8 meters per second [m/s]) (Broadhurst et al. 2014). At a tidal energy test site in Maine, individual pelagic fishes (species not identified) were more likely to remain around or pass through the turbine when it was not moving, and schools of fish rarely passed through the turbine area whether or not it was moving (Viehman and Zydlewski 2014). Another study, conducted in Mozambique, indicated that reef fish (wrasses [*Thalassoma* spp.]) kept a minimum distance of 0.3 m from the tidal turbine rotor, and trevallies (*Caranx* sp.) never moved closer than 1.7 m from the rotor during operation (Hammar 2014). At two river instream hydrokinetic devices in Alaska, salmonids were observed to move freely around the turbines without any apparent negative effects, and were more abundant along the edges of the river suggesting no attraction to the devices (Nemeth et al. 2014). These studies suggest that fish may associate with TECs, but only during times of lower tidal velocities and/or when turbine components are not moving, and fish are unlikely to be injured by underwater moving turbines.

1.5 Surrogate Structures

Surrogate structures that function as artificial reefs and/or FADs can be used to assess the fish assemblages and ecological interactions that may occur at WECs and TECs. Because WECs and TECs have ocean bottom structures that may function as artificial reefs as well as midwater/surface structures that may function as FADs, surrogate structures that contain both may be most relevant. Midwater/surface structures that are anchored in place rather than drifting (e.g., anchored FADs or mariculture facilities versus drifting FADs, drift algae, or floating debris) may be most relevant to WECs and TECs because they are anchored or have stationary foundations. The types of surrogate structures considered in this study are briefly discussed below, in terms of the relevance of their structural characteristics.

- **Natural rocky reefs** are rocky outcrops on the ocean bottom of varying relief and complexity, creating a variety of habitats for reef-associated fishes and invertebrates, and substrate for macroalgae (including kelp) and other habitat-forming organisms (e.g., corals; Stephens et al. 2006, Kaplan et al. 2010).
- **Artificial reefs** have been created from a variety of materials placed on the ocean bottom such as concrete, rocks, stone, boulders, steel, metal, tires, automobiles, and shipwrecks (Baine 2001). Artificial reefs generally attract similar fish and invertebrate species assemblages as natural reefs (Love and Yoklavich 2006).
- **Attached and drift kelps (brown algae: Phaeophyceae).** Attached kelp anchors to hard substrate, including natural and artificial reefs and can be found in dense forests growing in the photic zone (depths <30 m) through the water column to the surface, often forming a canopy (Stephens et al. 2006). Drift kelp is composed of floating mats of detached kelp vegetation that act as a point of orientation and shelter for fish and invertebrates (Allen and Cross 2006). Kelps provide food and habitat for a variety of juvenile and adult fish and invertebrates.
- **Purpose-built, anchored FADs,** placed by fisherman or resource management agencies to attract fish, are generally made with one or several surface or midwater buoys made of steel, polyvinyl chloride, cork, foam-filled tire, bamboo, or coconut or palm fronds, connected to a mooring line and anchored by a concrete block or embedded anchor (Seki 1983, Higashi 1994, Dempster and Taquet 2004).
- **Oil and gas platforms** are constructed of vertical and horizontal steel beams extending from the ocean bottom to above the water's surface. In the Gulf of Mexico, these platforms are known to provide habitat for reef-associated species, such as red snapper (*Lutjanus campechanus*) and amberjack (*Seriola dumerili*; Wilson et al. 2003, Shipp and Bortone 2009), and to function as FADs and attract yellowfin tuna (*Thunnus albacares*) and their predators (e.g., sharks and blue marlins [*Makaira nigricans*]) (Hoolihan et al. 2014). Offshore of southern California, oil and gas platforms are known to function as an artificial reef and provide habitat for many species of rockfish (*Sebastes* spp.) (Claisse et al. 2014); however, associations with pelagic fishes are less clear.
- **Marine debris, floating or submerged**, such as plastic, metal, glass, wood, fabric, rubber debris, shipping containers, and lost commercial and recreational fishing gear (e.g., fishing nets, lines, pots, traps), are widely distributed throughout the world's oceans and along the U.S. West Coast (Allen

and Cross 2006, Keller et al. 2010). This debris may act as a drifting FAD or as benthic habitat and attract marine organisms.

- **Mariculture facilities** include floating net-cages, mooring lines, and anchors, and pelagic and demersal fishes are known to be attracted to these facilities (Dempster et al. 2004, 2010, Sanchez-Jerez et al. 2011, Riera et al 2014, Wang et al. 2015). Although unused feed, fish waste, and caged fish attract fish to the net-cages, the net-cages alone play a minor role in attracting fish. For example, in subtropical waters of the Canary Islands, some fishes (bentho-demersal macro- and mesocarnivorous fish species) remained beneath empty net-cages while other fish species left after cessation of farming operations (Tuya et al. 2006). In temperate waters off the east coast of China, reef fishes (primarily Scorpaenidae) were associated with empty net-cages (Wang et al. 2015).
- **Piers and docks** consist of vertical pilings embedded in the seafloor and posts extending to the water surface that become colonized by invertebrates, which serve as a food source for fishes. Shade provided by accompanying overwater structure can either attract or deter fishes (Helfman 1981, Toft et al. 2007).

Section 2.0 Methods

We used existing studies of surrogate structures to assess the potential ecological interactions and fish assemblages at WECs or TECs in the following four subregions[1]: Southern California Bight (SCB); Central California to Cape Flattery, Washington (CA-WA); Puget Sound, and Hawai‘i. For each of the four subregions, we reviewed available studies on surrogate structures and assessed the following factors:

- Morphological characteristics of the surrogate structure (type, structural complexity, and vertical relief)
- The location of the surrogate structure (depth and distance from shore)
- Duration in the water of the surrogate structure
- Fish assemblages and special-status fish species associated with the structure
- Environmental/physical factors that may affect fish assemblages and ecological interactions (the presence of kelp and invertebrates, and physical factors like water quality, temperature, turbidity, currents, and inputs)

Where information was lacking on surrogate structures in each of the subregions, we contacted resource managers and subject matter experts and obtained relevant personal observations and judgments to assist with our assessment.

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[1] Assessment was conducted only for WECs (not TECs) in the SCB, CA-WA, and Hawai‘i subregions and for TECs (not WECs) in the Puget Sound subregion

Section 3.0 Results

3.1 Southern California Bight

The SCB extends from Point Conception to northern Baja, Mexico, and to about 200 km from shore (Dailey et al. 1993). Point Conception is recognized as the center of a transition zone for species occurrence: it represents a known northern biogeographic barrier to some tropical and subtropical fish species, and a southern barrier to some northern temperate species (Horn et al. 2006). The SCB provides a wide variety of habitats for benthic and pelagic fishes, with shallow and deep rocky reefs, kelp beds (dominated by giant kelp [*Macrocystis pyrifera*]), soft-bottom sediments, nine islands (the Channel Islands), and a complex bathymetry that includes 11 deep-water basins, three major banks and seamounts, and 13 major submarine canyons (Dailey et al. 1993). It is located within the California Current that stretches from British Columbia, Canada, to southern Baja California, Mexico; this current carries subarctic waters southward and is characterized by wind-driven upwelling of cold, nutrient-rich waters. The SCB also has incursions of warmer, less productive waters carried by the northwesterly inshore Davidson Current. During the spring upwelling, there are seasonal migrations of temperate fishes into the area, and of subtropical fishes during the warmer temperatures of summer and fall (Dailey et al. 1993). Tropical fishes become prevalent during the warm-water El Niño events that occur every 5–7 years, when the California Current is weakened and warmer equatorial waters flow farther northward (Lluch-Belda et al. 2003). A greater proportion of colder-water species tend to reside in this region during the cold-water La Niña events that generally occur every 4–10 years (Horn et al. 2006). In addition, there are longer-term warm and cool water cycles (e.g., 20–25 year periods), termed the *Pacific Decadal Oscillation*, that may influence fish assemblages (Lluch-Belda et al. 2003): a warm cycle from 1977 to the early 2000s favored subtropical fishes in the SCB, and a cooler cycle may result in the return of more temperate fishes (Allen et al. 2006). In short, there could be seasonal, interannual, and even decadal variability in fish assemblages at WECs in this subregion.

3.1.1 Special-Status Fish Species

Table 1 lists the special-status fish species known to occur in the SCB within approximately 50 km of shore that could be affected by WECs. For each surrogate structure described in Section 3.1.2 below, we noted whether any of these special-status species were reported at the structure (Table 2), and assessed the likelihood that they would occur at WECs (Section 3.1.3).

Table 1. Special-Status Fish Species Known to Occur in the Southern California Bight Subregion

Common Name[1]	Scientific Name	Status[2]
Bocaccio, southern DPS	*Sebastes paucispinis*	FSC
Canary rockfish	*Sebastes pinniger*	O
Yelloweye rockfish	*Sebastes ruberrimus*	O
Cowcod	*Sebastes levi*	FSC
Pacific Ocean perch	*Sebastes alutus*	O
Steelhead, southern California DPS	*Oncorhynchus mykiss*	FE
Pacific bluefin tuna	*Thunnus orientalis*	O

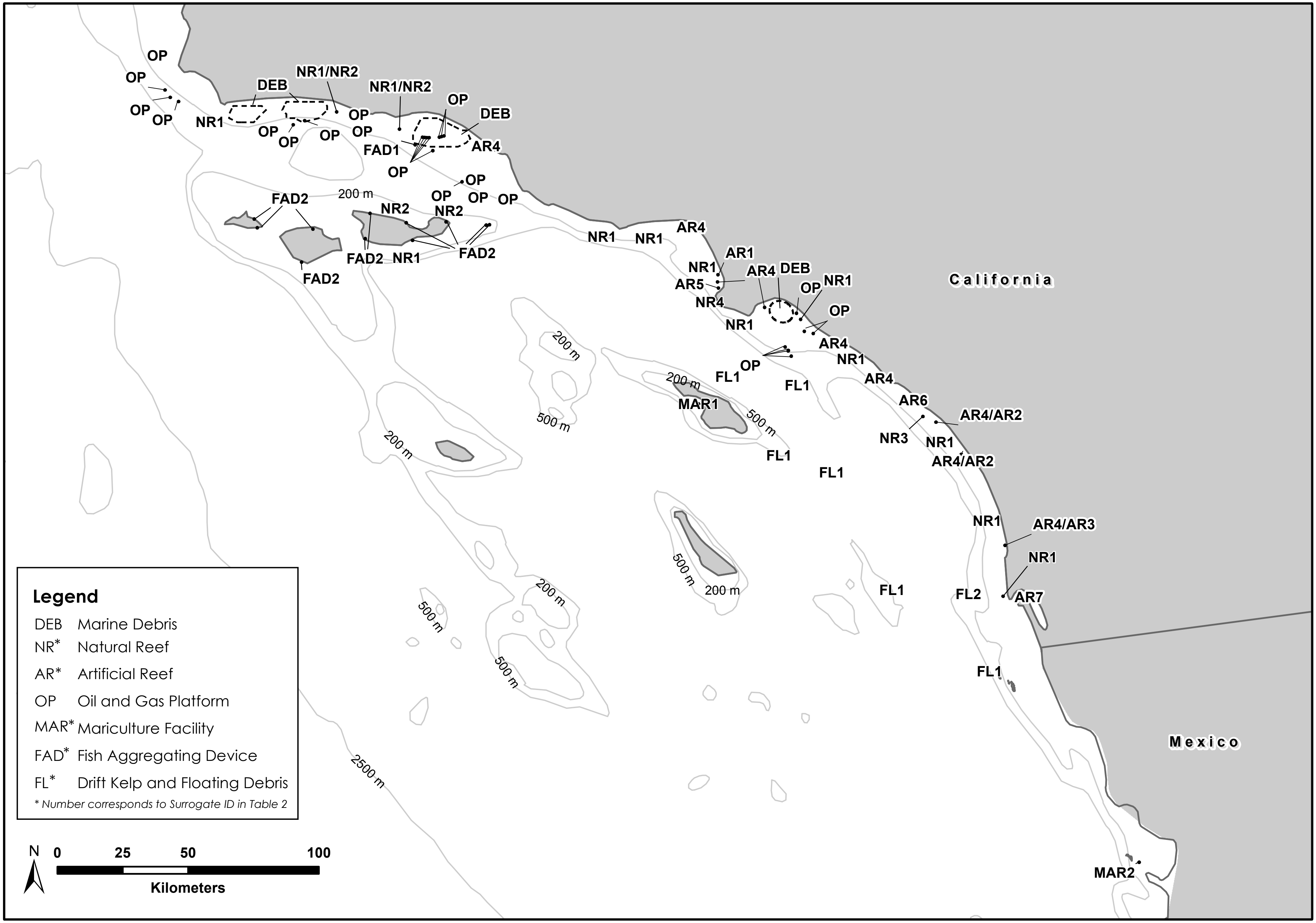
Notes:

[1] DPS = Distinct Population Segment

[2] Status designations: FE = federally listed as endangered; FSC = federal species of concern; O = overfished (NMFS 2013)

3.1.2 Fish Assemblages and Ecological Interactions at Surrogate Structures

In the SCB, bottom-oriented surrogate structures (natural reefs, artificial reefs, and marine debris), combined bottom- and midwater/surface-oriented structures (natural reefs with kelp beds, oil and gas platforms, mariculture facilities, and purpose-built FADs), and midwater/surface-oriented structures (floating drift kelp and debris) were evaluated to examine the types and probabilities of fish species interactions with WECs deployed in this subregion (Figure 1; Table 2).



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Ecological Consultants

Figure 1. Southern California Bight: Locations of Surrogate Structures

Table 2. Southern California Bight: Characteristics of Surrogate Structures (Locations of Surrogate Structures Displayed in Figure 1)

Surrogate Placement	Surrogate Characteristic	Surrogate Depth (m)	Duration in Water at Time of Study	Special-Status Fish Species	Fish Assemblage	Other Organisms/Physical Factors	Surrogate ID[1]
Ocean Bottom + Midwater/Surface	***Natural Reefs*[2]**						
	85 nearshore rocky reefs of varying relief and complexity, giant kelp at some sites	6–14	n/a	None	Southern kelp bed/rocky reef assemblage[3]	–	NR1
	Island reefs: high complexity; high-relief, steep, rocky bottom ending 50 m from shore Mainland reefs: low complexity; high-relief, broad sand flats between outcrops Giant kelp at some sites	1.5–17	n/a	None	Southern kelp bed/rocky reef assemblage[3]	–	NR2
	Low relief, cobble bottom with giant kelp, 100 ha total area	8–18	n/a	None	Southern kelp bed/rocky reef assemblage[3]	–	NR3
	High-relief reefs with giant kelp	3–13	n/a	None	Southern kelp bed/rocky reef assemblage[3]	–	NR4
Ocean Bottom	***Artificial Reefs*[2]**						
	6 high-relief (1.2–4.6-m height), artificial reefs (2 intake structures, 1 sunken barge, 1 quarry rock, 1 hollow concrete tube, 1 small cobble); 150–750 m² total area	10–24	Unknown	None	Southern, northern kelp bed/rocky reef assemblage[3] ,flatfishes (Pleuronectiformes)	–	AR1
	Quarry rock artificial reef in 8 high-relief modules (3.7–4.9 m), 18 m apart; 1.4 ha total area	13	0–5 yrs	None	Southern, northern kelp bed/rocky reef assemblage[3]	Algae, barnacles, encrusting organisms	AR2
	Quarry rock artificial reef with low complexity, high relief (7 m); 0.18 ha total area	14	14 yrs	None	Southern, northern kelp bed/rocky reef assemblage[3]	Algae, crustaceans, echinoderms, mollusks, polychaetes	AR3

Surrogate Placement	Surrogate Characteristic	Surrogate Depth (m)	Duration in Water at Time of Study	Special-Status Fish Species	Fish Assemblage	Other Organisms/Physical Factors	Surrogate ID[1]
Ocean Bottom + Midwater/Surface	10 high-relief (2–11-m height) artificial reefs of rock, boulders, and/or concrete with giant kelp canopy on 4 of the reefs; 0.18–5.81 ha total area	9–24	Unknown	None	Southern, northern kelp bed/rocky reef assemblage[3]	–	AR4
	Breakwater with high complexity, high relief (4.6 m)	13	30+ yrs	Bocaccio	Southern, northern kelp bed/rocky reef assemblage[3]	Near ocean water intake/discharge for steam electric generating station	AR5
	Quarry rock and concrete rubble in 42, 40 x 40-m low-relief modules with giant kelp; 9 ha total area	13–16	0–5 yrs	None	Southern kelp bed/rocky reef assemblage[3]	–	AR6
	4 low-relief reefs (2 quarry rock, 2 concrete block) with low densities of giant kelp	4–8	0–5 yrs	None	Southern kelp bed/rocky reef assemblage[3]	–	AR7
	Oil and Gas Platforms						
	27 oil and gas platforms, high structural complexity with horizontal and vertical beams from bottom to above water's surface; up to 1 ha total area	11–363	~20 yrs	Bocaccio, canary rockfish, cowcod, yelloweye rockfish	Southern, northern kelp bed/rocky reef assemblage[3]; southern CA midshelf, deep shelf rock reef fish assemblage[4]; jack mackerel (*Trachurus symmetricus),* northern anchovy (*Engraulis mordax*) in surface water; juv. rockfishes in midwater; larger rockfish at bottom	Shell mounds, crabs beneath platforms	OP
	Mariculture Facilities						
	Four 555-m^3 mariculture net-cages for white seabass (*Atractoscion nobilis*) over sandy bottom with interspersed low-relief reef (<0.5-m)	17	Unknown	None	Southern kelp bed/rocky reef assemblage[3] , queenfish (*Seriphus politus*), northern anchovy, Pacific chub mackerel (*Scomber japonicas*)	Whelks, sea whips, sea cucumbers, snails, bryozoans, algae under net-cage	MAR1

Surrogate Placement	Surrogate Characteristic	Surrogate Depth (m)	Duration in Water at Time of Study	Special-Status Fish Species	Fish Assemblage	Other Organisms/Physical Factors	Surrogate ID[1]
	10–20 mariculture net-cages, 25-m diameter, 11 m deep for striped bass (*Morone saxatilis*) and white seabass Empty cages (once farmed for bluefin tuna) 45–50-m diameter	20–50	4+ yrs	None	Northern anchovy, Pacific chub mackerel, kelp bass (*Paralabrax clathratus*), sardine (*Sardinops sagax*), juv. rockfishes, California sheephead (*Semicossyphus pulcher*),ocean whitefish (*Caulolatilus princeps*)	More fish in warmer years (e.g., El Niño) and in summer/fall	MAR2
Ocean Bottom + Midwater/Surface	***Purpose-Built FADs***						
	6 FADs: 3 FADs moored 7–9 m below water's surface, 3 FADs moored 23–27 m below; each FAD with 1–2 porcupine fish attractors[4] and 1–2 SMURFs[5] in a line	n/a	0–6 months	bocaccio (only 1 individual)	Jack mackerel (95% of individual fish)	–	FAD1
	3-8 SMURFs[5] per location arranged 100–500 m apart, each SMURF moored 3 m below water's surface	15	0–8 yrs	Not reported	Juv. rockfishes	SMURFs placed 50–500 m offshore of rocky reef/kelp beds	FAD2
Ocean Bottom	***Marine Debris***						
	130 objects, e.g., pipes, concrete rubble, truck tires, lobster traps, wellheads of varying size, complexity, and relief	<200	Varied	Bocaccio, canary rockfish	Southern CA midshelf rock reef fish assemblage[6]	–	DEB
Midwater/Surface	***Drift Kelp and Floating Debris***						
	Drifting clumps of primarily giant kelps, 1.4–450 kg wet weight, and floating debris (wood planks, plastic crates, logs)	n/a	Unknown	Juv. bocaccio	Mostly halfmoon (*Medialuna californiensis*), juv. splitnose rockfish (*Sebastes diploproa*); also juv. kelp rockfish (*S. atrovirens*), jack mackerel, blacksmith (*Chromis punctipinnis*), flag rockfish (*S. rubrivinctus*), and sablefish (*Anoplopoma fimbria*)	California sea lions (*Zalophus californianus*) preyed on fish around kelp	FL1
	Drifting clumps of primarily giant kelps	n/a	Unknown	Juv. bocaccio	Mostly juv. splitnose rockfish; also juv. flag rockfish, bocaccio, and treefish (*Sebastes serriceps*)	–	FL2

Surrogate Placement	Surrogate Characteristic	Surrogate Depth (m)	Duration in Water at Time of Study	Special-Status Fish Species	Fish Assemblage	Other Organisms/Physical Factors	Surrogate ID[1]

Notes: – = no data; FAD = fish aggregating device; ha = hectares; juv. = juvenile; kg = kilograms; m = meters; n/a = not applicable; yrs = years

[1] Surrogate citations (Surrogate ID locations displayed in Figure 1):
NR1 = Patton et al. 1985
NR2 = Ebeling et al. 1980
NR3 = DeMartini et al. 1989, DeMartini and Roberts 1990
NR4 = Stephens et al. 1984
AR1 = Helvey and Smith 1985
AR2 = Grant et al. 1982, Carter et al. 1985a, b, Jessee et al. 1985, Anderson et al. 1989
AR3 = Johnson et al. 1994
AR4 = Ambrose and Swarbrick 1989
AR5 = Stephens et al. 1994
AR6 = Reed et al. 2006
AR7 = Pondella et al. 2006
OP = Love et al. 2005, 2006, 2010, 2012, Page et al. 2005, Love and Schroeder 2006, , Nishimoto et al. 2008, Martin and Lowe 2010, Nishimoto and Love 2011
MAR1 = Oakes and Pondella 2009
MAR2 = Pedersen pers. comm.
FAD1 = Nishimoto and Love 2011
FAD2 = Casselle et al. 2010
DEB = Casselle et al. 2002
FL1 = Mitchell and Hunter 1970
FL2 = Boehlert 1977

[2] Low relief = reef structure <1 m in vertical height; high relief = reef structure >1 m in vertical height; mixed relief = overall reef structure has a mix of <1-m and >1-m reliefs; high complexity = crevices, holes, overhangs of varying sizes and shapes throughout the reef; low complexity = few or no crevices, holes, overhangs in the reef

[3] Southern kelp bed/rocky reef fish assemblage, northern kelp bed/rocky reef fish assemblage based on Stephens et al. (2006)

[4] Porcupine fish attractor = 1.5-m-diameter sphere of polyvinyl carbonate rods radiating from central orb

[5] SMURF (Standard Monitoring Units for the Recruitment of temperate reef Fishes) = 1 x 0.25-m-diameter plastic wide-mesh tube loosely stuffed with strips of plastic sheeting

[6] Southern CA (California) midshelf (30–100-m depth) rock reef fish assemblage, southern CA deep shelf (101–200-m) rock reef assemblage based on Love and Yoklavich (2006)

3.1.2.1 Natural Reefs

In general, the rocky reef/kelp bed species assemblage in the SCB is dominated by nearshore reef fishes such as blacksmith, garibaldi (*Hypsypops rubicundus*), halfmoon, opaleye (*Girella nigricans*), basses (Serranidae), surfperches (Embiotocidae), and wrasses (Labridae) (Table 2, NR1–NR4), and these fish species could also be attracted to WECs at shallow depths (e.g., <30 m). Fish will likely be attracted to WEC bottom structures regardless of the amount of habitat complexity: one study indicated that simple, relatively low-relief reefs (0.75–1-m boulders) would likely attract as many fish as high-relief, complex reefs (Table 2, NR1). However, some reef-associated fish species may be absent at bottom structures, such as fish that require caves or interstices (e.g., blacksmith) for breeding (Table 2, NR1).

Because WECs would likely be placed on flat, soft-bottom substrates like those surrounding mainland coastal reefs in the SCB, fish assemblages at the bottom structures may resemble those of mainland coastal reefs (with fewer fish families represented) more than they would resemble the assemblages at steeper, more complex offshore island reefs, which show greater diversity (Table 2, NR2). Assemblages also vary by location in the water column; some species are generally limited to the bottom (e.g., garibaldi, painted greenling [*Oxylebius pictus*], opaleye), water column (e.g., blue rockfish [*Sebastes mystinus*]), or kelp canopy (e.g., kelp surfperch [*Brachyistius frenatus*], halfmoon) (Table 2, NR2), and fish species at WECs may exhibit similar habitat partitioning relative to the available structure.

Rocky reefs with kelp beds have greater fish abundance and diversity than reefs at similar depths lacking kelp, because kelp provides a vertical extension of the substrate as well as canopy habitat (Table 2, NR3, NR4). The presence of kelp has a lesser effect on fish abundance at reefs with a high-relief bottom than at those with a low-relief bottom (Table 2, NR3, NR4), and there are few obligate kelp fish species (Stephens et al. 2006); thus, reef fishes may associate with high-relief WEC bottom structures regardless of the presence of kelp. However, canopy kelp specialists such as kelp surfperch, giant kelpfish (*Heterostichus rostratus*), and halfmoon may not associate with the surface structures of WECs.

3.1.2.2 Artificial Reefs

There are more than 25 artificial reefs in the SCB (not including offshore oil and gas platforms), constructed out of quarry rock, concrete riprap, automobiles, streetcars, and ships to enhance recreational fisheries and to mitigate the impacts of coastal power plants. Most of these artificial reefs are located at depths of less than 20 m (Cross and Allen 1993). Shallow artificial reefs are the second-most valuable habitat in the SCB (kelp beds are the first), based on the diversity of fish guilds that use this habitat type (Bond et al. 1999).

The fish assemblages at WECs deployed in shallow waters (<30 m) could vary in response to oceanographic conditions, as was demonstrated by an 18-year study of the assemblage at a breakwater where warmer-water species (e.g., opaleye, garibaldi, basses, and wrasses) became more abundant during El Niño events (Table 2, AR5). Fish species that use the water column (e.g., blue rockfish, blacksmith) at artificial reefs would likely also occur at the midwater structures of WECs, regardless of complexity or relief; however, many benthic species rely on crevices of varying size to provide cover and protection from predators, and these features may be absent at bottom structures of WECs. Thus, WEC bottom structures may support a lower species richness and abundance of benthic fishes (e.g., sculpin [Cottidae], gobies [Gobiidae], wrasses, and rockfishes) than found at typical high-relief, complex artificial reefs (Table 2, AR1, AR2, AR4). Also, the distance between bottom structures or to the nearest reef habitat may affect fish abundance: in one study, two artificial reefs located 33 m apart had a significantly higher density of fishes than two reefs located farther apart (58 m and 71 m) (Table 2, AR7).

Colonization by some fish species at WECs would be expected to occur rapidly after installation: one artificial reef study reported colonization by surfperches and basses within 1 to 2 days (Table 2, AR2), and another study reported fish densities that were similar to or greater than a nearby reference reef within a few months (Table 2, AR6). Many fishes are attracted to, and feed on, the abundant reef organisms that colonize artificial reefs (e.g., algae, crustaceans, echinoderms, barnacles; Table 2, AR2, AR3), and organisms that colonize the bottom structures of WECs could provide a similar attractant and food source. The sandy bottom habitats between bottom structures may host some larger/adult fishes, whereas juvenile/subadult fishes would likely be found only near bottom structures (Table 2, AR2, AR3).

3.1.2.3 Oil and Gas Platforms

There are 27 oil and gas platforms in the SCB, deployed in a variety of depths (11–363 m), and the habitat created by the complex hardscape structures on the bottom and throughout the water column have the highest secondary fish production (primarily rockfish) per unit area of seafloor of any marine habitat studied globally (Claisse et al. 2014). Many studies have been conducted on the fish assemblages at these platforms (e.g., Love et al. 2005, 2006, 2010, 2012, Love and York 2005, 2006, Page et al. 2005, 2007, Emery et al. 2006, Love and Schroeder 2006, Anthony et al. 2009, Lowe et al. 2009, Martin and Lowe 2010, Nishimoto and Love 2011, Love and Nishimoto 2012). In these studies, researchers examined factors such as the effects of structure complexity, depth, distance to shore, and proximity to natural reefs on fish assemblages and juvenile recruitment. We selected a subset of recent studies to evaluate the fish assemblages and ecological interactions at oil and gas platforms in the SCB (Table 2, OP).

Three distinct fish assemblages were observed around each of the platforms: those associated with the midwater, at bottom, and near the surrounding shell mounds[2] (Love et. al 2010). In general, the upper midwater (from the surface to 30 m) harbored typical nearshore warm-temperate reef fish species, particularly at the inshore platforms (<4.8 km from shore) and those located south of Los Angeles, California (Martin and Lowe 2010). The deeper midwater (>25 m) had extremely high densities of juvenile rockfishes, including large schools of juvenile bocaccio. The platform bottoms were dominated by larger adult rockfishes and lingcod (*Ophiodon elongatus*); whereas the surrounding shell mounds hosted species adapted to living over low

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[2] Composed primarily of encrusting invertebrates (mussels, barnacles) that fall from platform support structures and accumulate on the substratum over time (Love et al. 2010).

relief, such as dwarf rockfishes and other small, juvenile benthic fishes (Love et al. 2010, 2012). Although rockfishes dominated the midwater and bottom structures of the offshore platforms (>14 km from shore), they were generally absent from the three inshore platforms (Martin and Lowe 2010). In the southern half of the SCB, the upper midwater of the offshore platforms also had a strong seasonal presence of schooling jack mackerel in the summer and fall. Similar fish assemblages and habitat partitioning could be found at WECs.

WECs may provide habitat for juvenile rockfishes despite a lack of crevices, caves, and small hiding places, given that the midwater structures of oil and gas platforms, which also lack these features, serve as important nursery grounds and contribute to increased recruitment of bocaccio and other species of rockfish (Love et al. 2006). The platforms may improve juvenile rockfish survival, because in the absence of these platforms, many would have likely been transported by prevailing currents to areas where rocky reef habitat for settlement is uncommon and perished (Nishimoto et al. 2008). Some juvenile rockfishes (e.g., copper [*Sebastes caurinus*] and gopher [*S. carnatus*] rockfishes) hide amongst mussels and anemones when small and depart when they reach a size at which they are unable to use available cover, whereas other species of juvenile rockfishes (including bocaccio) form large schools for protection and remain as adults (Love et al. 2010). Predation rates on small fishes (likely including the special-status juvenile bocaccio) is lower at the platforms than at natural reefs with high-relief profiles (Love and Schroeder 2006), likely because their potential predators tend to occur at the bottom of the platforms while the small fish tend to occur midwater (Love et al. 2006). However, the platforms with greater complexity (e.g., with more vertical/horizontal midwater structure) have higher fish density, species richness, and biomass (Love et al. 2010, Martin and Lowe 2010), so the amount and complexity of structure at the WECs, especially of midwater features, will likely affect the abundance and diversity of associated fishes.

Oil and gas platforms provide a relatively large amount of high-quality, hard-structure habitat for juvenile and adult rockfishes in a small area, and may contribute significantly to biological production of these fishes in the SCB (Love et al. 2006, Claisse et al. 2014), and WECs could create a similar effect in this subregion. As shown by acoustic tagging and experimental translocation, rockfishes are able to move between platforms and nearby natural reefs, and some species (e.g., vermilion [*Sebastes miniatus*] and brown [*S. auriculatus*] rockfishes, and lingcod) tended to home back to the platforms, suggesting a preference for this habitat (Lowe et al. 2009). Transitory and migrating piscivorous fishes that could prey on juvenile fishes at the platforms (e.g., jacks [Carangidae] and barracuda [*Sphyraena barracuda*] and that typically occur around platforms in the Gulf of Mexico; Stanley and Wilson 2000) are not common around platforms in the SCB; in addition, high densities of pinnipeds or seabirds have not been documented around the platforms, thus, predation may be low and the survival rate of juvenile fishes may be relatively high (Love et al. 2006). Also, fishing is generally restricted at most platforms, so the platforms provide marine refugia for adult rockfish, including overfished species such as bocaccio and cowcod (Love et al. 2005). A similar marine reserve effect could occur around WECs, although their contribution to reef fish production in the SCB would depend on their size, depth, and amount of midwater structure.

3.1.2.4 Mariculture Facilities

Mariculture facilities in the SCB attracted fishes whether or not the net-cages contained farmed fish (Table 2, MAR1, MAR2), and similar fish species could be attracted to the bottom and midwater/surface structures of WECs. At a mariculture facility located farther south in northern Baja, California, Mexico, "over a million" baitfish such as anchovy and sardines were associated with the net-cages whether or not the cages contained fish—the fish appeared to be attracted to the shade and shelter (Table 2, MAR2). Installations may attract fish only during periods of warmer waters: most of the fish associations at the net-cages in northern Baja occurred in late spring through fall, when water temperatures were higher (Table 2, MAR2).

3.1.2.5 Purpose-Built FADs

At an anchored, experimental FAD deployed in near-surface waters (7–9 m from the surface), jack mackerel were by far the most abundant species observed, but this species was seen during only 26% of the surveys taken at the structure (Table 2, FAD1). This suggests that the midwater/surface structures of WECs may attract jack mackerel, but that the association would likely be transitory and occasional.

Juvenile rockfishes (e.g. kelp, gopher, black-and-yellow, copper, olive, yellowtail, and black rockfishes) aggregated at FADs placed near rocky reef/kelp beds around the Channel Islands, and settlement of these fishes was positively correlated with regional summer upwelling (Table 2, FAD2). Similar fish species aggregations at WECs could also occur and vary by ocean conditions. However, given that the FADs were constructed out of plastic mesh rolled into a cylinder, providing space inside for small juvenile fishes while excluding larger fishes, it is less certain if similar species would aggregate at WECs that would lack these crevices and small spaces.

3.1.2.6 Marine Debris

The southernmost debris area near Los Angeles had lower species richness, virtually no rockfishes, and barred sand bass (*Paralabrax nebulifer*) and blacksmith were the most common species (Table 2, DEB). In the more productive, cooler waters of the three western debris areas, rockfishes dominated (78% of species observed), and brown, olive (*Sebastes serranoides*), yellowtail (*S. flavidus*), copper, and vermilion rockfishes were the most common species observed (Table 2, DEB). Species richness and abundance was positively related to amount of vertical height and shelter complexity (i.e., number of cracks, crevices, and holes) of the debris. Similar fish species could be attracted to the bottom structures of WECs, and species assemblages and richness would likely vary by location, vertical height and complexity of bottom structures.

3.1.2.7 Drift Kelp and Floating Debris

No fish were observed at floating debris such as wood planks, plastic crates, and logs during studies in the SCB and off the coast of Baja California, Mexico; in contrast, several fish species were associated with drift kelp (Table 2, FL1, FL2). One species, splitnose rockfish, appeared to use drift kelp specifically during its pelagic larval life stage, before settling to a benthic existence in the juvenile and adult stages (Table 2, FL2). Based on observed fish behavior, stomach content analyses, and laboratory experiments, kelp association probably had little effect on diet, and fish were more likely using the kelp for protection from fish predators (Table 2, FL1), a function that could be provided by WECs.

3.1.3 Effects of Structure and Placement on Fish Assemblages and Special-Status Fish Species

3.1.3.1 Ocean Bottom Structure

Based on the studies of natural reefs, artificial reefs, oil platforms, and marine debris there is evidence that the bottom structures (e.g., anchors or foundations) of WECs in the SCB will function as artificial reefs and attract reef fishes. The species assemblage may vary somewhat by latitude and depth, with more subtropical and tropical taxa (e.g., blacksmith, garibaldi, opaleye, halfmoon, basses, and wrasses) ranging from Baja California, Mexico, to the southern half of the SCB and in shallower nearshore waters (<30 m depth), and more temperate taxa (e.g., lingcod, greenlings [Hexagrammidae], and rockfishes) occurring in the northern half and in deeper waters (>30 m depth) (Cross and Allen 1993, Stephens et al. 2006). Oceanographic conditions may also influence the fish assemblage in the SCB. For example, subtropical/tropical species may move farther north or become more abundant in the SCB during periods of warm-water incursions (e.g., El Niño events); this effect occurred at one of the studied artificial reefs (Table 2, AR5).

Several WECs deployed in a limited area would likely form an artificial reef complex and attract a higher density of adult reef fishes per bottom structure than a single device would, as demonstrated by a studied artificial reef complex (Table 2, AR7). Of all the marine habitat types in California, rocky reefs and kelp beds at less than 30-m depth contain the greatest abundance and diversity of fish (Stephens et al. 2006); thus, WECs installed at depths of less than 30 m have the potential to attract a high density and diversity of fishes. Larger, adult rockfishes would likely dominate bottom structures installed at depths greater than 30 m, given that they dominate the bottom structures of oil and gas platforms in the SCB, as well as natural rocky reefs at these depths (Love and Yoklavich 2006, Love and Nishimoto 2012). Bottom structures at depths >30-m could attract high densities of rockfish and even contribute to rockfish productivity, if the structures are comparable to oil and gas platforms, which had some of the highest secondary production per unit area of seafloor of any marine habitat studied globally (Claisse et al. 2014).

Colonization of bottom structures would likely be rapid; surfperches and basses could appear within a few days of installation, at least in shallower waters (<30-m depth)—this occurred at a shallow-water artificial reef (Table 2, AR2). At deeper installations, rockfishes would likely colonize within a year, regardless of distance from the nearest natural reef, given that adult rockfishes are reported to move tens to hundreds of kilometers between reefs (Hanan and Curry 2012). Bottom structures may provide important habitat and escapement capacity for adult rockfishes and allow them to grow larger (in comparison to natural reefs), particularly if fishing is prohibited around the WECs; this effect was observed at the oil and gas platforms (Table 2, OP).

The special-status rockfish species known to occur in the SCB (bocaccio, yelloweye rockfish, cowcod, canary rockfish) are unlikely to occur at bottom structures at depths of less than 30 m (Table 3), because they are uncommon at these depths in the SCB, particularly in their adult life stages (Love et al. 2002). However, based on their presence at the oil and gas platforms, adults of these special-status species could occur at bottom structures of WECs at depths greater than 30 m (Table 3). There is no evidence to suggest that bottom structures would attract any of the other special-status fish species (Pacific Ocean perch, steelhead, Pacific bluefin tuna) that occur in this subregion, because they were not reported by any of the studies of surrogate structures, nor are they reef-associated species.

Table 3. Predicted Occurrence of Special-Status Fish Species at Wave Energy Converters in the Southern California Bight Subregion, by Water Column Position and Structure Placement

	Position in Water Column[1]		Depth of Bottom Structure[2]		Midwater/ Surface Structure[2]
Common Name	**Juvenile**	**Adult**	**0–30 m**	**30–360 m**	
Bocaccio	WC	B	Y	**Y**	**Y**
Canary rockfish	WC	B	**N**	**Y**	**N**
Cowcod	B	B	**N**	**Y**	**N**
Yelloweye rockfish	B	B	**N**	**Y**	**M**
Pacific Ocean perch	B	B	**N**	**N**	**N**
Steelhead	WC	WC	**N**	**N**	**N**
Pacific bluefin tuna	WC	WC	**N**	**N**	N

Notes: m = meters

[1] WC = water column; B = bottom (Love et al. 2002, Allen et al. 2006)

[2] "Y" = a high likelihood that the species will occur based on studies of surrogate structures (Table 2) and species' biology/habitat; "M" = potential occurrence; "N" = low/no likelihood of occurrence. Bold letters indicate high certainty based on existing information from surrogate structures and species' biology/habitat; regular-font letters indicate low certainty.

3.1.3.2 Midwater/Surface Structure

Based on the studies of oil and gas platforms, mariculture facilities, and purpose-built FADs, the midwater/surface structures of WECs in the SCB could function as FADs and attract rocky reef/kelp bed fishes, juvenile rockfishes, schooling baitfish species, and other tropical migratory fishes. However, fish associations would likely be only occasional, seasonal, and/or transitory: jack mackerel were observed only in summer and fall at oil platforms and at an experimental FAD, and large fish aggregations occurred at the mariculture facility in northern Baja, Mexico only in late spring through fall (Table 2, OP, FAD, MAR2). Pelagic fish associations with surface structures are likely to be most prevalent or likely when waters are warm (>22°C) and clear (Stevenson pers. comm.), such as during summer and fall or during El Niño events, when subtropical and tropical FAD-associated fishes are more likely to be present in the SCB. Fish species may include dolphinfish, which occur in the SCB only during warm-water periods (Norton 1999) and are known to associate with FADs (Dempster 2004). Other fish species that occur in the SCB and are known to associate with drift kelp, such as ocean sunfish (*Mola mola*) (Cartamil and Lowe 2004), jack mackerel, and yellowtail (*Seriola lalandi*) (Allen and Pondella 2006), may be less likely to occur at midwater/surface structures of WECs that are stationary/anchored, as these species were not reported at the stationary oil and gas platforms or the anchored mariculture facilities.

Based on the studies of oil and gas platforms, mariculture facilities, purpose-built FADs, and drift kelp, the midwater/surface structures of WECs in the SCB could attract juvenile, semipelagic rockfishes, including some special-status rockfish species (bocaccio and, occasionally, yelloweye rockfish) (Table 3). WECs installed offshore and in deeper waters (>30 m) could support juvenile bocaccio and other schooling juvenile rockfishes, and even benefit rockfish populations through increased recruitment and juvenile survivorship, if they contain substantial midwater structures similar to the oil and gas platforms. However, it is unlikely that this effect would occur at WECs where the midwater structure is mostly limited to mooring lines.

3.2 Central California to Cape Flattery, Washington

The CA-WA subregion that extends from just north of Point Conception in California to Cape Flattery, Washington, is within the cold-temperate zone (*Oregonian Province*) for fishes (Horn et al. 2006). The CA-WA subregion provides a variety of habitats for benthic and pelagic fishes, with shallow and deep rocky reefs, kelp beds, upwelling zones, banks, seamounts, and riverine influences (Kaplan et al. 2010). Important areas that support reef-associated species include Heceta Bank (55–122-m depth) located 24–48 km offshore of central Oregon; Cordell Bank (≥37 m) located 29 km west of San Francisco, California; and submarine canyons and rocky reefs offshore of central California (Yoklavich et al. 2000, 2002, Kaplan et al. 2010). In shallower waters (<30-m depth) of the subregion, kelp beds are highly productive areas for fish biomass (Kaplan et al. 2010). Two species of canopy-forming kelp occur in this subregion: giant kelp (*Macrocystis pyrifera*), occurs only as far north as central California), which has fronds along the vertical length of the stipe and a year-round closed canopy, and bull kelp (*Nereocystis luetkeana*) (occurs in entire subregion), an annual kelp predominant in shallow, wave-exposed sites, with large fronds only at the surface and an often broken canopy that is only seasonally present (Stephens et al. 2006).

The CA-WA subregion is dominated by the highly productive California Current that stretches from British Columbia, Canada to Baja California, Mexico, and is characterized by a periodic wind-driven upwelling of cold, nutrient-rich waters, particularly strong off northern and central California and Oregon (Allen and Cross 2006, Machias et al. 2012). Upwelling, which occurs in large plumes and eddies, and temperature fronts in which cold and warm surface waters collide, are highly productive and known to concentrate large numbers of pelagic fish, birds, and mammals, and may affect recruitment of some fish species such as rockfishes (Allen and Cross 2006, Ainley et al. 2009, Bograd et al. 2009, Casselle et al. 2010). Warm-water El Niño events occur every 3–8 years, when the California Current is weakened and warmer equatorial waters flow farther northward, and colder-water La Niña events generally occur every 5–7 years (Lluch-Belda et al. 2003). These events influence the distribution and abundance of fish species, often for several years (Horn et al. 2006).

Pacific Decadal Oscillations also influence the subregion, with 20–25-year warm-water and cold-water cycles (Lluch-Belda et al. 2003). Temperate and boreal fishes generally dominate this subregion, although tropical and subtropical species are known to move northward during warm-water events (Lluch-Belda et al. 2003, Allen and Cross 2006).

Central California contains several known, predictable areas of high biological productivity (*hotspots*) and upwelling centers that concentrate fishes, seabirds, and marine mammals, and provide ecologically important areas for juvenile rockfishes and juvenile salmon (*Oncorhynchus* spp.) (Palacios et al. 2006, Nur et al. 2011, Santora et al. 2012). Farther north, hotspots occur off Crescent City in northern California and at Heceta Bank off central Oregon, and fish assemblages include special-status species such as Chinook salmon (*Oncorhynchus tshawytscha*), steelhead, and bocaccio, as well as pelagic species like jack mackerel (Reese and Brodeur 2006). The Columbia River in Oregon, which produces a distinct low-salinity plume that flows southward and out to sea during summer (but is confined to a narrow band along the Washington coast in winter), provides important summer spawning habitat for northern anchovy, which is important prey for other fish, including salmon (Parnel et al. 2008). The coasts of Washington and British Columbia have the highest areas of productivity along the western North American coast because of the nutrient influx from rivers and moderate upwelling; this area supports fish species that occur year-round and migratory species such as sockeye (*Oncorhynchus nerka*), pink (*O. gorbuscha*), and chum (*O. keta*) salmon, in addition to Pacific hake (*Merluccius productus*), sardine, and mackerel, which move into these waters from southern California in spring (Ware and Thompson 2005).

3.2.1 Special-Status Fish Species

Table 4 lists the special-status fish species known to occur in the CA-WA subregion within approximately 50 km of shore that could be affected by WECs. For each surrogate structure assessed in Section 3.2.2 below, we noted whether any of these special-status species were reported at the natural or surrogate structures (Table 5), and assessed the likelihood that they would occur at WECs (Section 3.2.3).

Table 4. Special-Status Fish Species Known to Occur in the Central California to Cape Flattery, Washington, Subregion

Common Name[1]	Scientific Name	Status[2]
Green sturgeon DPSs	*Acipenser medirostris*	
Southern		FT
Northern		FSC
Eulachon, southern DPS	*Thaleichthys pacificus*	FT
Longfin smelt	*Spirinchus thaleichthys*	ST
Pacific lamprey	*Lampetra tridentata*	FSC
Bocaccio, southern DPS	*Sebastes paucispinis*	FSC
Canary rockfish	*Sebastes pinniger*	O
Cowcod	*Sebastes levi*	FSC
Yelloweye rockfish	*Sebastes ruberrimus*	O
Pacific Ocean perch	*Sebastes alutus*	O
Chinook salmon ESUs	*Oncorhynchus tshawytscha*	
California coastal		FT

Common Name[1]	Scientific Name	Status[2]
Central Valley spring-run		FT
Sacramento River winter-run		FE, SE
Lower Columbia River		FT
Upper Columbia River spring-run		FE
Puget Sound		FT
Snake River fall-run		FT
Snake River spring/summer-run		FT
Upper Willamette River		FT
Coho salmon ESUs	*Oncorhynchus kisutch*	
Central California coast		FE, SE
Southern Oregon/ northern California coast		FT, ST
Lower Columbia River		FT
Oregon coast		FT
Chum salmon ESUs	*Oncorhynchus keta*	
Columbia River		FT
Hood Canal summer run		FT
Sockeye salmon ESUs	*Oncorhynchus nerka*	FE
Snake River		FE
Ozette Lake		FT
Steelhead DPSs	*Oncorhynchus mykiss*	
Southern California		FE
South-Central California coast		FT
Central California coast		FT
California Central Valley		FT
Northern California		FT
Pacific-Oregon coast		FSC
Upper Willamette River		FT
Lower Columbia River		FT
Middle Columbia River		FT
Upper Columbia River		FE
Snake River Basin		FT
Puget Sound		FT
Pacific bluefin tuna	*Thunnus orientalis*	O

Notes:

[1] DPS = Distinct Population Segment; ESU = Evolutionarily Significant Unit

[2] Status designations: FE = federally listed as endangered; FT= federally listed as threatened; FSC = federal species of concern; SE = State-listed as endangered (California); ST = State-listed as threatened (California); O = overfished (NMFS 2013)

3.2.2 Fish Assemblages and Ecological Interactions at Surrogate Structures

In the CA-WA subregion, bottom-oriented surrogate structures (natural reefs, artificial reefs, and marine debris), and combined bottom- and midwater/surface-oriented structures (natural reefs with kelp beds, artificial reefs with attached kelp, and purpose-built FADs) were evaluated to examine the types and probabilities of fish species interactions with WECs deployed in this subregion (Figure 2; Table 5).

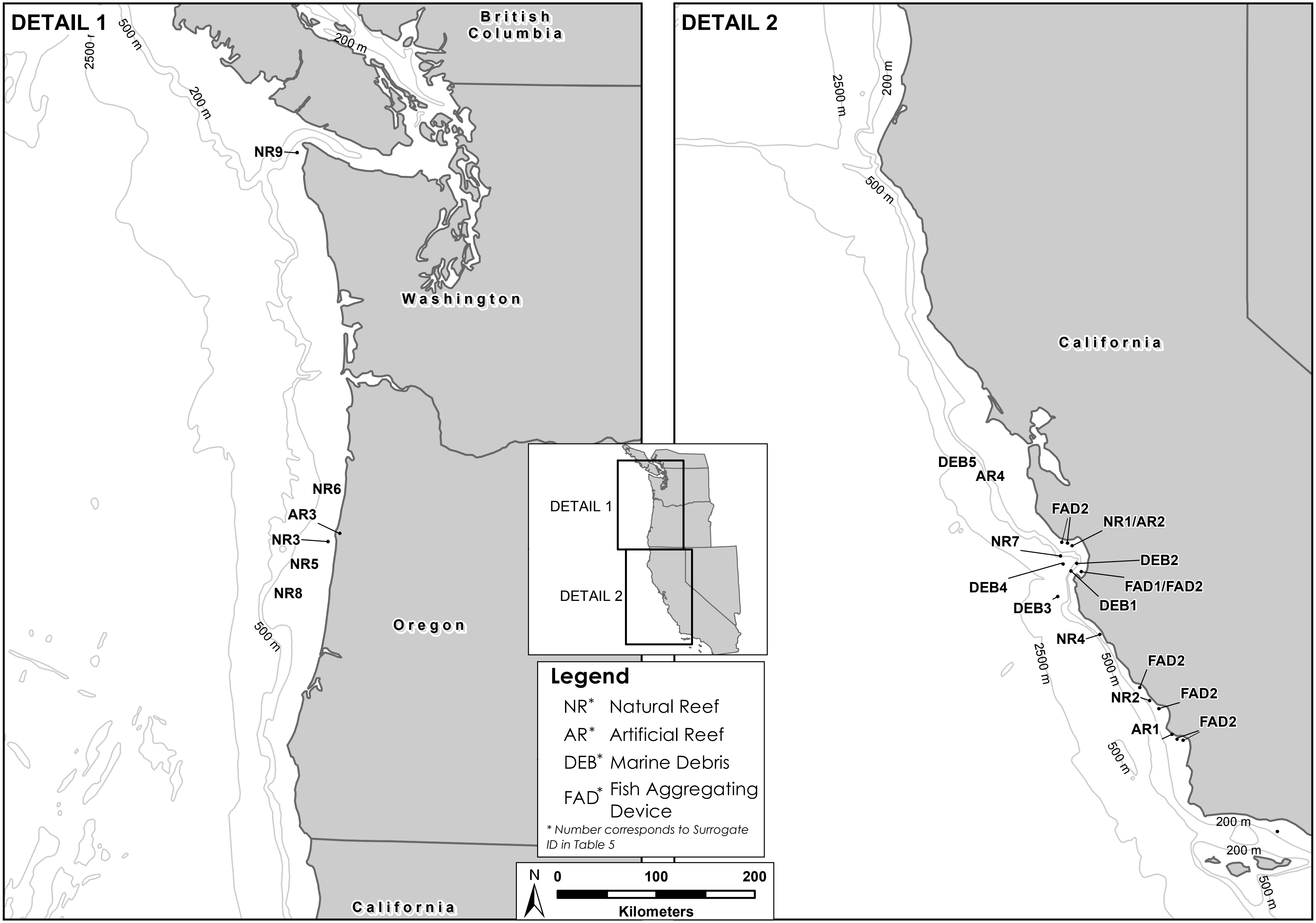

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Figure 2. Central California to Cape Flattery, Washington: Locations of Surrogate Structures

Table 5. Central California to Cape Flattery, Washington: Characteristics of Surrogate Structures (Locations of Surrogate Structures Displayed in Figure 2)

Surrogate Placement	Surrogate Characteristic	Surrogate Depth (m)	Duration in Water at Time of Study	Special-Status Fish Species	Fish Assemblage	Other Organisms/ Physical Factors	Surrogate ID[1]
Ocean Bottom + Midwater/Surface	***Natural Reefs*[2]**						
	4 rocky reefs (2 with high relief of 3 m, and 2 with little vertical relief [0–1.5 m]); 2 of the reefs had giant kelp	7.5–30	n/a	Canary rockfish	Northern kelp bed/rocky reef assemblage[3]; juv. blue and olive rockfishes most abundant	–	NR1
	21-km-long nearshore giant kelp and bull kelp bed	<30	n/a	None	Northern kelp bed/rocky reef assemblage[3]; blue rockfish most abundant	–	NR2
	Rocky patch reefs with large, high-relief (>2-m) boulders; kelp present	10–35	n/a	None	Juv. blue rockfish most abundant, few yellowtail rockfish and widow rockfish (*Sebastes entomelas*)	Sea anemones and sponges present	NR3
Ocean Bottom	Rocky reef complex with outcrops, rock, cobble, and boulders of mixed relief, substrate, and complexity	20–250	n/a	Bocaccio, canary rockfish, cowcod, yelloweye rockfish	20–100-m depth: central/ northern CA midshelf rock reef fish assemblage[4] 100–250-m depth: central/ northern CA deep shelf rock reef fish assemblage[4]	Kelp and understory algae overlaying some rock outcrops	NR4
	5 rocky reef complexes, 1–30 km offshore of mixed relief, substrate, and complexity	<100	n/a	Canary rockfish, yelloweye rockfish	Oregon-B.C. nearshore and shallow shelf rockfish communities[5], kelp greenling (*Hexagrammos decagrammus*), and lingcod	–	NR5
	Rocky reef complex with outcrops, rock, cobble, and boulders of mixed relief, substrate, and complexity	0–70	n/a	Canary rockfish, yelloweye rockfish	Oregon-B.C. nearshore and shallow shelf rockfish communities[5], kelp greenling, and lingcod	–	NR6
	17 km² of an underwater canyon; rocky ridges, boulder, cobble, pebble, and mud bottom with mixed relief	80–360	n/a	Bocaccio, canary rockfish, cowcod, yelloweye rockfish	Central/northern CA deep shelf rock reef fish assemblage[4]	Crinoids, sea anemones, and sponges present	NR7

Surrogate Placement	Surrogate Characteristic	Surrogate Depth (m)	Duration in Water at Time of Study	Special-Status Fish Species	Fish Assemblage	Other Organisms/ Physical Factors	Surrogate ID[1]
	Rock ridges, large boulders, boulder-cobbles, and cobbles with mixed relief, substrate, and complexity	60–360	n/a	Canary rockfish, yelloweye rockfish	60–100-m depth: juv. rockfish, yelloweye rockfish, and lingcod 100–200-m depth: Oregon-B.C. deep shelf rockfish community[5]	Crinoids, sea urchins, sea stars, and sea cucumbers present	NR8
	Pebble, cobble, boulder, and rock ridges with mixed relief and complexity	102–225	n/a	Bocaccio, canary rockfish, yelloweye rockfish	Oregon-B.C. deep shelf rockfish community[5]	Crinoids and sea anemones present	NR9
Ocean Bottom + Midwater/Surface	***Artificial Reefs*[2]**						
	Four modules of high-relief (5–6 m), low complexity concrete rubble, tribar, and quarry stone with canopy-forming bull kelp	16–17	5 yrs	Juv. bocaccio, Juv. canary rockfish	96% YOY blue, yellowtail, and olive (*Sebastes serranoides*) rockfishes	–	AR1
	2 reefs of 240 large concrete pipes (diameters 30–250 cm) with nearby (1.2–1.6 km) reefs/kelp beds; mixed relief (0.5–5 m) and high complexity	13.5	1 yr	Canary rockfish	Northern kelp bed/rocky reef assemblage[3]	–	AR2
	Dock pilings in estuary	<10	Unknown	None	Juv. black rockfish (*Sebastes melanops*) most abundant, few yellowtail and widow rockfishes	Nearby oyster nets hanging 1.8–2.1 m from water's surface	AR3
Ocean Bottom	Coaxial cable (3.2–6.6 cm wide) 0–95 km from shore, on bottom, partially buried in some areas	0–2000	8 yrs	None	Rockfishes, flatfishes	Sea anemones and crinoids present	AR4
	Marine Debris						
	Plastic, metal, rope, glass, and fishing debris	25–3971	Varies	None	Rockfishes	Hydroids, sea stars sea anemones, serpulid worms, crinoids present	DEB1
	Lost fishing gear (e.g., nets, lines, pots, traps)	40–300	Varies	Yelloweye rockfish, cowcod	Wolf eel (*Anarryichthys ocellatus*), ronquil (*Rathbunella* sp.), and rockfishes	Benthic invertebrates present	DEB2
	Debris field of 785-ft dirigible wreckage on the soft-bottom slope between two canyons	>300	71 yrs	Bocaccio	Oregon-B.C. slope rockfish community[5], flatfish, Pacific hake, sablefish (*Anoplopoma* sp.), hagfish (*Eptatretus* spp.)	Anemones, sea stars, basket stars, brittle stars present	DEB3

Surrogate Placement	Surrogate Characteristic	Surrogate Depth (m)	Duration in Water at Time of Study	Special-Status Fish Species	Fish Assemblage	Other Organisms/ Physical Factors	Surrogate ID[1]
	Shipping container on soft-bottom substrate	1280	7–9 yrs	None	Thornyhead rockfish (*Sebastolobus* spp.)	Benthic invertebrates present	DEB4
	Approximately 3600 55-gallon drums of radioactive waste capped with concrete	900	20–23 yrs	None	Thornyhead rockfish, sablefish, deepsea sole (*Embassichythys bathybius*)	Tanner crab (*Chionoecetes tanneri*), sponges	DEB5
Ocean Bottom + Midwater/Surface	***Purpose-Built FADs***						
	24 SMURFs[6] arranged in 3 rows, each row 20-m apart: 16 surface SMURFs (moored 1 m below water's surface),4 mid-depth SMURFs (moored 8 m from bottom), and 4 bottom SMURFs (moored on bottom)	18–19	0–6 months	Bocaccio	Juv. rockfishes	SMURFs placed 100 m offshore of kelp bed/rocky reefs	FAD1
	3-8 SMURFs[6] per location arranged 100–500 m apart, each moored 3 m below water's surface	15	0–8 yrs	Not reported	Juv. rockfishes	SMURFs placed 50–500 m offshore of kelp bed/rocky reefs	FAD2

Notes: – = no data; cm = centimeters; ft = feet; juv. = juvenile; km = kilometers; m = meters; n/a = not applicable; YOY = young-of-the-year; yrs = years

[1] Surrogate citations (Surrogate ID locations displayed in Figure 2):
NR1 = Matthews 1985
NR2 = Bodkin 1986
NR3 = Gallagher and Heppell 2010
NR4 = Yoklavich et al. 2002
NR5 = Hannah and Rankin 2011, Hannah and Blume 2012
NR6 = Easton 2012
NR7 = Yoklavich et al. 2000
NR8 = Pearcy et al. 1989, Tissot et al. 2007, 2008
NR9 = Wang 2005
AR1 = Danner et al. 1994
AR2 = Matthews 1985, Solonsky 1985
AR3 = Gallagher and Heppell 2010
AR4 = Kogan et al. 2006
DEB1 = Schlining et al. 2013
DEB2 = Grimmer et al. 2009, 2010, Grimmer and de Beukelaer 2011
DEB3 = Burton and Lundsten 2006
DEB4 = Monterey Bay Aquarium Research Institute 2013, Taylor et al. 2014
DEB5 = U.S. Environmental Protection Agency 1975
FAD1 = Amman 2004
FAD2 = Casselle et al. 2010

[2] Low relief = reef structure <1 m in vertical height; high relief = reef structure >1 m in vertical height; mixed relief = overall reef structure has a mix of <1-m and >1-m reliefs; high complexity = crevices, holes, overhangs of varying sizes and shapes throughout the reef; low complexity = few or no crevices, holes, overhangs in the reef

[3] Northern kelp bed/rocky reef fish assemblage based on Stephens et al. (2006)

[4] Central/northern CA (California) midshelf (30–100-m depth) and deep shelf (101–200-m depth) rock reef fish assemblages based on Love and Yoklavich (2006)

[5] Oregon-B.C. (British Columbia) nearshore (subtidal to 30-m depth), shallow shelf (30–100-m depth), deep shelf (100–200-m depth), and slope (>200-m depth) rockfish communities based on Love et al. (2002)

[6] SMURF (Standard Monitoring Units for the Recruitment of temperate reef Fishes) = 1 x 0.35-m-diameter plastic wide-mesh tube loosely stuffed with plastic mesh

3.2.2.1 Natural Reefs

The rocky reef/kelp bed species assemblage at less than 30 m depth in this subregion includes juvenile rockfishes, surfperches, greenlings, and sculpins; juvenile blue rockfish tended to be the dominant species at rocky reef/kelp beds located in central California and Oregon (Table 5, NR1–NR3) (Kaplan et al. 2010). Similar fish species could also be attracted to WECs at depths of less than 30 m.

Juvenile and adult rockfishes dominate rocky reefs at depths greater than 30 m, and many rockfish species move farther offshore and to deeper waters with age (Table 5, NR4–NR9; Love et al. 2002, Love and Yoklavich 2006, Oregon Department of Fish and Wildlife [ODFW] 2006). Similar fish assemblages and life stages could be attracted to WECs, depending on the depth of bottom structures. In Oregon coastal waters, the fish species most likely to be attracted to the bottom structures of WECs include those associated with large, high-relief boulders (e.g., yelloweye and quillback [*Sebastes maliger*] rockfishes, lingcod, and kelp greenling at depths <70 m; yelloweye, rosethorn [*S. helvomaculatus*], tiger [*S. nigrocinctus*], and redstripe [*S. proriger*] rockfishes, lingcod, and greenlings [*Hexagrammos* spp.] at depths >60 m); as well as those using a variety of habitat types (e.g., canary, yellowtail, sharpchin [*S. zacentrus*], and greenstripe [*S. elongates*] rockfishes) (Table 5, NR6, NR8, NR9). Some species may show high site fidelity to WECs (e.g., quillback, vermilion, tiger, china [*S. nebulosus*], and yelloweye rockfishes), whereas others (e.g., black, copper, and canary rockfishes) may show less site fidelity and a wider range of vertical and horizontal movements (Table 5, NR7). In addition, several studies have noted that greenstripe rockfish appears to specialize on mud-bottom areas near scattered boulders (Table 5, NR8, NR9), and this association could occur at soft-bottom areas around WECs. Thus, although a variety of rockfish species would likely be attracted to the bottom structures of WECs, their use of the structures would likely differ.

3.2.2.2 Artificial Reefs

There are few artificial reefs in the CA-WA subregion to use as surrogates for the bottom and midwater/surface structures of WECs; these are located in the coastal waters of central California. Two other types of structures, dock pilings and a coaxial cable on the ocean bottom, were also included as artificial reef surrogate structures for this subregion. There is no artificial reef program in Oregon (ODFW 2006), and those in Washington are limited to Puget Sound (Pacunski pers. comm.).

WECs in shallower waters of central California would likely be colonized rapidly if placed near a natural rocky reef: colonization of an artificial reef placed in an area with several nearby natural reefs (<1 km away) occurred within 6 to 12 months after construction (Table 5, AR2). Bottom structures that have little complexity (e.g., cement-block anchors) would likely attract rockfishes and other benthic fishes; rockfishes and flatfishes were even associated with a single coaxial cable on the ocean bottom (Table 5, AR4). However, a lack of complexity may result in only limited use by fish; fish species diversity and density was much greater at complex artificial reefs (constructed of concrete pipes of differing sizes) than at simple, high-relief artificial and natural reefs (Table 5, AR1, AR2). A low-complexity artificial reef was dominated by juveniles of only three rockfish species (blue, yellowtail, and olive rockfishes); juveniles of these species are generally pelagic and specialize on kelp (Table 5, AR1). Juvenile rockfishes (mostly black rockfish) occurred around docks and pilings in an estuary, and it was suggested that the vertical structure provided by pilings acted as an attractive substitute for habitat provided by giant kelp (Table 5, AR3). Similar fish species could be attracted to the bottom and midwater structures of WECs.

3.2.2.3 Marine Debris

Benthic fish species have been reported at marine debris, including lost fishing gear, the wreckage of a dirigible, a lost shipping container, and 55-gallon drums at a variety of depths (Table 5, DEB1–DEB5). The bottom structures of WECs could attract numerous rockfishes and other fish associated with soft- and hard-bottom habitats and their interface, like those reported at the debris field of a dirigible (Table 5, DEB3). If installed in very deep waters (>900 m), bottom structures may attract very few fish species, such as thornyhead rockfish, sablefish (*Anoplopoma* sp.), and deepsea sole (Table 5, DEB4, DEB5).

3.2.2.4 Purpose-Built FADs

Juvenile rockfishes (mostly black, kelp, yellowtail, copper, gopher, and black-and-yellow [*Sebastes chrysomelas*] rockfishes) aggregated at FADs placed near rocky reef/kelp beds, with the greatest abundance and species diversity at the surface FADs versus the mid-depth and bottom FADs (Table 5, FAD1, FAD2). The species associated with the FADs are also known to associate with kelp, indicating that the FADs provided acceptable alternative habitat for these species. Settlement by some species (e.g., kelp, gopher, black-and-yellow, and copper rockfishes) was positively correlated with summer upwelling, while settlement by other species (olive, yellowtail, and black rockfishes) was highly variable and poorly related to any ocean indices (Table 5, FAD2), and fish assemblages at WECs could also vary by ocean conditions. Given that the FADs were constructed out of plastic mesh rolled into a cylinder, providing space inside for small juvenile fishes while excluding larger fishes, it is less certain if similar species would aggregate at WECs that would lack these crevices and small spaces.

3.2.3 Effects of Structure and Placement on Fish Assemblages and Special-Status Fish Species

3.2.3.1 Ocean Bottom Structure

Based on the studies of natural and artificial reefs, marine debris, and purpose-built FADs, there is ample evidence that the bottom structures (e.g., anchors or foundations) of WECs in the CA-WA subregion will function as artificial reefs and attract various species of rockfishes and other reef-associated species, including the special-status rockfish species bocaccio, yelloweye rockfish, cowcod, and canary rockfish (Table 6). The fish assemblage that would be expected to associate with these bottom structures may vary somewhat by latitude and depth: central California experiences incursions of southern subtropical reef fish species during warm-water events, which may not occur farther north (Stephens et al. 2006), and species diversity generally declines with increasing latitudes (Love et al. 2002).

Table 6. Predicted Occurrence of Special-Status Fish Species at Wave Energy Converters in the Central California to Cape Flattery, Washington, Subregion, by Water Column Position and Structure Placement

	Position in Water Column[1]		Depth of Bottom Structure[2]			Midwater/
Common Name	**Juvenile**	**Adult**	**0–30 m**	**30–360 m**	**360–4000 m**	**Surface Structure[2]**
Green sturgeon	–	B	M	M	**N**	**N**
Eulachon	WC	WC	**N**	**N**	**N**	N
Longfin smelt	WC	WC	**N**	**N**	**N**	N
Pacific lamprey	–	WC	**N**	**N**	**N**	N
Bocaccio	WC	B	**Y**	**Y**	**Y**	**Y**
Canary rockfish	WC	B	**Y**	**Y**	**N**	**Y**
Cowcod	B	B	**N**	**Y**	**Y**	**N**
Yelloweye rockfish	B	B	**N**	**Y**	**Y**	**N**
Pacific Ocean perch	B	B	**N**	**N**	**N**	**N**
Chinook salmon	WC	WC	**N**	**N**	**N**	N
Coho salmon	WC	WC	**N**	**N**	**N**	N
Chum salmon	WC	WC	**N**	**N**	**N**	N
Sockeye salmon	WC	WC	**N**	**N**	**N**	N
Steelhead	WC	WC	**N**	**N**	**N**	N
Pacific bluefin tuna	WC	WC	**N**	**N**	**N**	N

Notes: m = meters

[1] WC = water column; B = bottom; – = life stage not present in marine waters (Love et al. 2002, Allen et al. 2006)

[2] "Y" = a high likelihood that the species will occur based on studies of surrogate structures (Table 5) and species' known biology/habitat; "M" = potential occurrence; "N" = low/no likelihood of occurrence. Bold letters indicate high certainty based on existing information from surrogate structures and species' biology/habitat; regular-font letters indicate low certainty.

It is unknown whether the bottom structures of WECs would serve as nursery habitat for juvenile rockfishes, given that they would likely lack the structural complexity and crevices, but it is highly likely that they would serve as habitat for adult rockfishes. Colonization of bottom structures would likely be rapid (e.g., within 1 year), regardless of distance from the nearest natural reef, given that adult rockfishes are reported to move tens to hundreds of kilometers between reefs (Hanan and Curry 2012). It is difficult to predict colonization times by species because individuals exhibit wide variation in their movements; however, some species (e.g., canary rockfish) may be attracted quickly to bottom structures, whereas more sedentary species (e.g., quillback rockfish) may be less likely to colonize or take longer to show up (Hannah pers. comm.).

There is no evidence to suggest that bottom structures would attract any of the other special-status fish species (e.g., eulachon, longfin smelt, Pacific lamprey, Pacific Ocean perch, salmonids) that occur in this subregion; these were not reported at any of the studied surrogates, nor are they reef-associated species. One special-status fish species, green sturgeon, is highly migratory and wide-ranging, occurring along the entire Pacific coast at depths of less than 110 m (Erickson and Hightower 2007, 74 Federal Register [FR] 52300). After spawning, they typically travel from natal rivers in fall to estuaries or to the ocean, then migrate to concentrated areas off the west coast of Canada in winter and return to U.S. waters in spring (Lindley et al. 2008). When along the U.S. West Coast, they concentrate mostly near San Francisco and Monterey Bays and in the coastal waters of Oregon and Washington (Huff et al. 2012). They stay longer in areas with high seafloor complexity and high relief, especially at boulders at depths of 20–60 m, likely because benthic prey and refuge from predators are available (Huff et al. 2011, 2012). Thus, green sturgeon could occur at the bottom structures of WECs in this subregion, although they are unlikely to take up residence there given their highly migratory behavior.

3.2.3.2 Midwater/Surface Structure

The CA-WA subregion supports many rockfish species with long pelagic juvenile life stages that could be attracted to midwater structures of WECs (Allen pers. comm.). The associations may be only diurnal or temporary, because some of these species (e.g., yellowtail rockfish) tend to move to the bottom at night (Tissot pers. comm.), and many migrate to the bottom as adults. Fishes that aggregated at natural and artificial reefs/kelp beds, and at FADs placed near rocky reef/kelp beds, included juvenile, semipelagic, and kelp-associated rockfishes (e.g., black, olive, blue, and kelp rockfishes), and some special-status rockfish species (bocaccio and canary rockfish; Table 6). However, it is less certain if the midwater/surface structures of WECs in the CA-WA subregion would attract a similar species assemblage given their differences in structural characteristics. Kelp and the FADs from these studies contained spaces for small juvenile fishes to shelter, whereas WECs would be constructed of smooth steel with the midwater structure limited to mooring lines, both of which would be lacking hiding spaces and crevices, unless colonized by algae or invertebrates. However, some of these species, such as bocaccio, canary, and blue rockfishes, were also reported at the midwater structures of oil and gas platforms (also constructed of smooth steel and lacking in crevices) in the SCB (Table 2, OP; Love et al. 2010), suggesting that they could also occur at the midwater structures of WECs in this subregion.

Fish species other than semipelagic rockfishes are not likely to consistently associate with midwater/surface structures in the CA-WA subregion, although transitory and occasional associations may occur. Jack mackerel were sporadically observed at a purpose-built FAD and at oil platforms in the SCB; jack mackerel also occur throughout this subregion (Miller and Lea 1972) and migrate northward from southern California as far as British Columbia in the spring (Ware and Thompson 2005). Floating objects in this region support substantial barnacle growth and small aggregations of baitfish and invertebrates, but larger fish associations are rare, based on observations taken from the north Pacific albacore (*Thunnus alalunga*) troll and pole-and-line fishery along the coasts of Washington, Oregon, and northern California (Childers pers. comm.). In this fishery, albacore will occasionally remain under the boat, even overnight, but not consistently (Childers pers. comm.). Surface structures could attract baitfishes (e.g., capelin [*Mallotus villosus*], northern anchovy, and sandlance [*Ammodytes hexapterus*]) and juvenile fish, including salmonids, but any association would likely be only transitory and occasional (Allen pers. comm, Holland pers. comm.). Fish associations might be uncommon at FADs in cooler (<18°C), low-visibility waters (Stevenson pers. comm.), and both of these conditions are consistently present in this subregion.

No salmonids were reported at any of the surrogate structures in this subregion, suggesting that they would not be attracted to WECs. Although juvenile salmonids were reported at the midwater/surface structures of piers, docks, and artificial reef/kelp beds in Puget Sound (see Section 3.3.2), their presence at these structures in a low-energy, estuarine, nearshore environment during outmigration does not indicate that they would be attracted to structure in the higher-energy, open ocean. Despite their apparent absence at surrogate structures in this subregion, the potential for juvenile salmon to associate with WECs and be subject to increased predation has been raised as an issue of concern during permitting of several proposed wave energy projects (PG&E and HTH 2010, Reedsport OPT Wave Park 2010), warranting a more in-depth assessment of the potential effects of WECs on salmonids. Out of all the special-status salmonid species, juvenile Chinook and coho salmon are most common in the coastal waters of this subregion (Quinn and Myers 2004, Beamish et al. 2005) and therefore, are most likely to encounter WECs. Chum and sockeye salmon generally range south as far as the Oregon-California border, and their ocean migration is northward (Quinn and Myers 2004), so their occurrence may be brief or rare in northern California, Oregon, and Washington. Juvenile steelhead migrate directly offshore and into subarctic north Pacific waters rather than along the coast like other salmonids (Pearcy et al. 1990, Beamish et al. 2005), so their presence at WECs in this subregion is also unlikely.

Both Chinook and coho salmon are more abundant farther north in the CA-WA subregion and thus more likely to be present at WECs installed to the north. In surface trawls taken in central California coastal waters (<200-m depth), juvenile Chinook salmon were common in relatively low densities (compared to other fish species), but coho salmon were rare (Harding et al. 2011). Along the Oregon coast in summer, surface trawls found juvenile coho salmon using the Columbia River plume (northern Oregon waters), whereas juvenile Chinook salmon were more widely distributed along the Oregon coast (Pool et al. 2012). Both species were more abundant in Washington coastal waters than in Oregon (Bi et al. 2008). They generally migrate northward and offshore over the summer, although Chinook salmon are the more migratory species; by September, most juvenile Chinook salmon had migrated out of Washington coastal waters while coho salmon remained (Peterson et al. 2010, Tucker et al. 2011).

Juvenile salmon foraging and the factors driving their prey distribution suggest that it is unlikely that either species would associate with WECs, even though juvenile Chinook and coho salmon in coastal waters of Oregon and Washington generally occur in water less than 100 m deep (Peterson et al. 2010) and within the upper 15 m of the water's surface (Emmett et al. 2004, Walker et al. 2007). The at-sea distribution of juvenile Chinook and coho salmon is highly patchy, and likely reflects the patchy distribution of their prey (Peterson et al. 2010). The first few months at sea for juvenile salmon are marked by intensive feeding and rapid growth, which serves to increase their chance of survival by reducing vulnerability to predation (Pearcy 1992, Daly et al. 2009). They feed on zooplankton (e.g., copepods and euphausiids) and juvenile pelagic fishes (e.g., rockfishes, northern anchovy, Pacific herring [*Clupea pallasii*], sardines, and smelt [Osmeridae]) (Daly et al. 2009), none of which are expected to associate with WECs, and the dynamic ocean conditions of the California Current (e.g., coastal upwelling, ocean temperature/salinity fronts) generally drive the distribution of these highly pelagic organisms (Brodeur et al. 2005, Santora et al. 2012), rather than the presence of any structure. Juvenile salmon occurrence also has been correlated with higher turbidities (Emmett et al. 2004); turbid water may offer some visual protection from predators (Peterson et al. 2010). Thus, juvenile salmon occurrence is most likely affected by prey availability and less by predator avoidance in turbid, highly productive waters. There is no evidence to suggest that midwater structures in the ocean would influence the distribution of these species.

3.3 Puget Sound

Puget Sound is the second-largest estuary in the U.S., covering an estimated 7250 km^2 and bordered to the west and east by the Olympic and Cascade mountain ranges, respectively (Gelfenbaum et al. 2006). A glacial fjord, the Sound contains deep and narrow channels divided by islands and peninsulas, and is supplied with freshwater, nutrients, and sediments by the surrounding rivers and coastal streams. Water depths increase rapidly from shore, averaging 62 m, with a maximum depth of about 370 m (Gelfenbaum et al. 2006). The waters are generally cold (7–13°C) and nutrient-rich, and deeper waters have an average salinity that approaches that of ocean waters (Gelfenbaum et al. 2006). Currents in the Sound are driven primarily by tides and inputs from rivers—velocities generally range from 0.3 to 1.0 m/s, although narrower channels often have stronger currents because flows are restricted (DOE et al. 2012b).

More than 200 species of demersal and pelagic fish have been reported in Puget Sound (Gelfenbaum et al. 2006), including 28 species of rockfish (Palsson et al. 2009), and commercially fished species such as Pacific hake, Pacific cod (*Gadus macrocephalus*), walleye pollock (*Theragra chalcogramma*), Pacific herring, spiny dogfish (*Squalus acanthias*), lingcod, English sole (*Pleuronectes vetulus*), and various rockfish species (Gelfenbaum et al. 2006, DOE et al. 2012b). Eight species of salmonids occur in the Sound: Chinook, chum, coho, pink, and sockeye salmon; steelhead; cutthroat trout (*Oncorhynchus clarkia*); and bull trout (*Salvelinus confluentus*) (DOE et al. 2012b); these species use the Sound during juvenile outmigration and rearing and as adults returning to natal rivers to spawn. Rockfish abundance in general has been declining because of overfishing (Palsson et al. 2009), and salmonids have declined because of habitat degradation, barriers to fish passage, and adverse effects on water quality and quantity resulting from dams, harvest, and artificial propagation (64 FR 14513).

3.3.1 Special-Status Fish Species

Table 7 lists the special-status fish species known to occur in the Puget Sound subregion that could be affected by TECs. For each surrogate structure assessed in Section 3.3.2 below, we noted whether any of these special-status species were reported at the structure (Table 8), and assessed, based on current information, the likelihood that they would occur at TECs (Section 3.3.3).

Table 7. Special-Status Fish Species Known to Occur in the Puget Sound Subregion

Common Name[1]	Scientific Name	Status[2]
Green sturgeon DPSs	*Acipenser medirostris*	
Southern		FT
Northern		FSC
Eulachon, southern DPS	*Thaleichthys pacificus*	FT
Bocaccio, Puget Sound/Georgia Basin DPS	*Sebastes paucispinis*	FE
Canary rockfish, Puget Sound/Georgia Basin DPS	*Sebastes pinniger*	FT
Yelloweye rockfish, Puget Sound/Georgia Basin DPS	*Sebastes ruberrimus*	FT
Chinook salmon, Puget Sound ESU	*Oncorhynchus tshawytscha*	FT
Chum salmon, Hood Canal summer-run ESU	*Oncorhynchus keta*	FT
Bull trout, Coastal/Puget Sound DPS	*Salvelinus confluentus*	FT
Steelhead, Puget Sound DPS	*Oncorhynchus mykiss*	FT
Pacific hake, Georgia Basin DPS	*Merluccius productus*	FSC
Pacific cod, Salish Sea population	*Gadus macrocephalus*	FSC

Notes:

[1] DPS = Distinct Population Segment; ESU = Evolutionarily Significant Unit

[2] Status designations: FE = federally listed as endangered; FT= federally listed as threatened; FSC = federal species of concern

3.3.2 Fish Assemblages and Ecological Interactions at Surrogate Structures

In the Puget Sound subregion, bottom-oriented surrogate structures (natural reefs), combined bottom- and midwater/surface-oriented structures (natural and artificial kelp beds/rocky reefs, mariculture facilities, and piers and docks), and midwater/surface-oriented structures (attached kelp and drift kelp) were evaluated to examine the types and probabilities of fish species interactions with TECs deployed in this subregion (Figure 3; Table 8).

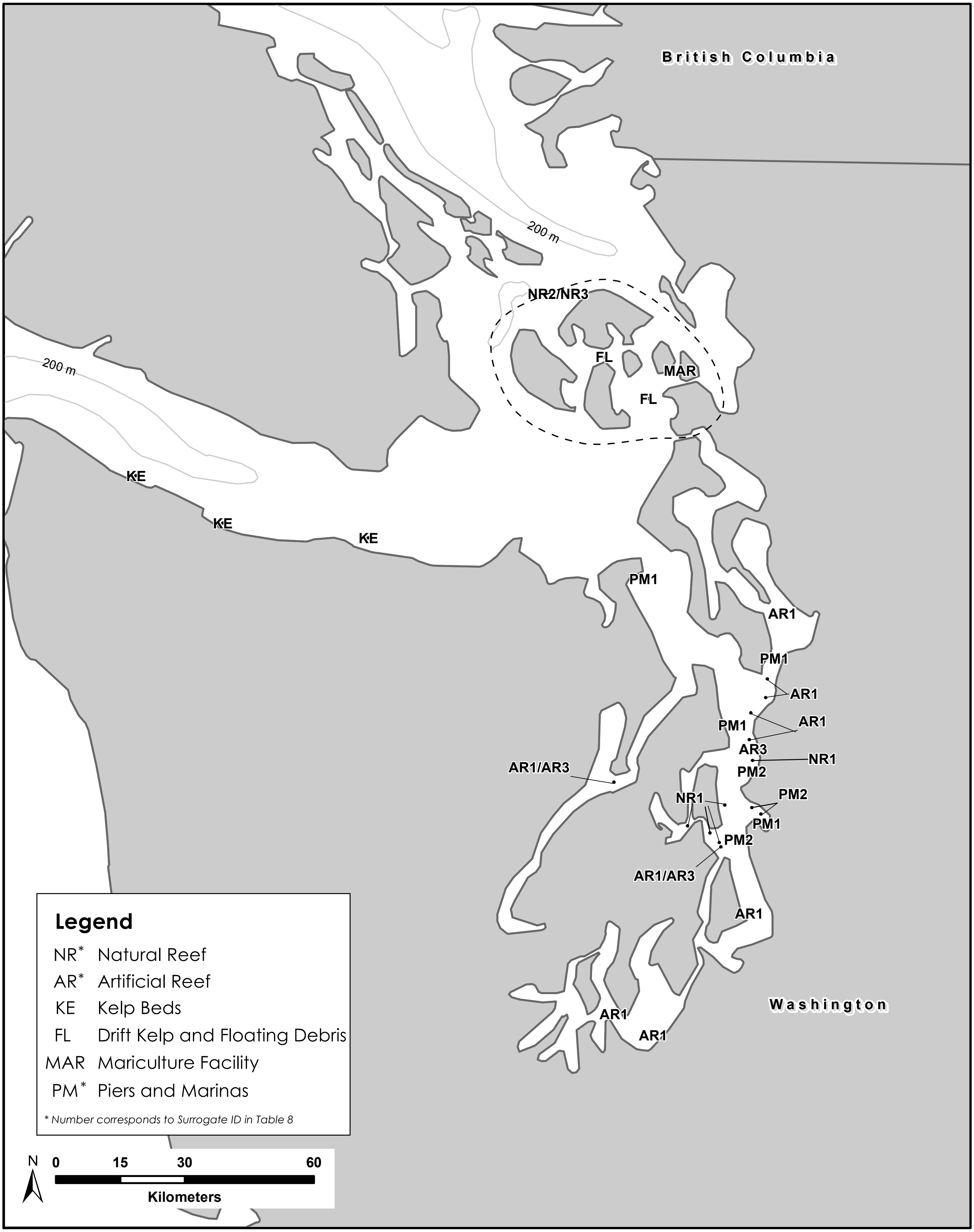

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Figure 3. Puget Sound: Locations of Surrogate Structures

Table 8. Puget Sound: Characteristics of Surrogate Structures (Locations of Surrogate Structures Displayed in Figure 3)

Surrogate Placement	Surrogate Characteristic	Surrogate Depth (m)	Duration in Water at Time of Study	Special-Status Fish Species	Fish Assemblage	Other Organisms/Physical Factors	Surrogate ID[1]
Ocean Bottom + Midwater/Surface	***Natural Reefs*[2]**						
	3 high-relief (<5 m) rocky reefs; 5 low-relief reefs with cobble/rock bottom and a few isolated areas of 1–2-m vertical relief Surface canopies of bull kelp in May–Nov.; perennial kelp (*Agarum firnbriatum, Pterygophora californica*)	0–30	n/a	Not reported	Not reported; only copper, quillback, and brown rockfishes studied	1 reef in a fast-current location (up to 8.1 km/h)	NR1
Ocean Bottom	Rocky habitats, primarily rocks and boulders; 6 ha total area	0–37	n/a	Yelloweye rockfish, Pacific cod	Kelp greenling, copper rockfish, Puget Sound rockfish (*Sebastes emphaeus*), and lingcod most abundant	Areas with kelp not sampled	NR2
	Rocky habitats, primarily rocks and boulders; 4 ha total area	37–234	n/a	Bocaccio, canary rockfish, yelloweye rockfish, Pacific cod	Quillback, Puget Sound, and yelloweye rockfishes, plus codfishes, spotted ratfish (*Hydrolagus colliei*), and lingcod most abundant	–	NR3
Ocean Bottom + Midwater/Surface	***Artificial Reefs*[2]**						
	11 artificial reefs (10 concrete/rock, 1 tire reef); 1600–5580 m^2 area; surface canopy of bull kelp present at 2 reefs	6.1–21.3	2–5 yrs, except one reef 49 yrs	Yelloweye rockfish, Pacific cod, possibly salmonids	Nearshore/shallow shelf Puget Sound rockfish assemblage[3], surfperches, lingcod, cabezon (*Scorpaenichthys marmoratus*); Salmonidae, Clupeidae in upper/midwater of 1 reef	Barnacles and other invertebrates increased quickly for 6 months and stabilized by 20 months	AR1
	8 artificial reefs (4 enlarging existing high-relief reefs, 4 low-relief reefs) of small (15-cm-diameter)quarry rock	4–15	7 months	Not reported	Not reported; study assessed YOY and adult rockfishes	Nearby canopies of bull kelp and eelgrass beds	AR2[4]

Surrogate Placement	Surrogate Characteristic	Surrogate Depth (m)	Duration in Water at Time of Study	Special-Status Fish Species	Fish Assemblage	Other Organisms/Physical Factors	Surrogate ID[1]
	4 high-relief reefs (2 concrete rubble reefs with perennial kelp understories, 1 breakwater with surface bull kelp canopies in May–Nov., 1 anchor system from World War II)	0–20	6–40 yrs	Not reported	Not reported; only copper, quillback, and brown rockfishes studied	1 reef in a fast-current area (≤8.1 km/h)	AR3
Ocean Bottom + Midwater/Surface	***Mariculture Facilities***						
	Fish containment nets for Atlantic salmon (*Salmo salar*) (18,000 m^2 total area), and associated walkway floats and anchor lines; bull kelp on lines near/at water's surface	Unknown	13–14 yrs	None	Northern clingfish (*Gobiesox maeandricus*) fed on invertebrates attached to floats; longnose skate (*Raja rhina*) and spiny dogfish in area	Crustaceans, mollusks, polychaetes on floats, nets, and lines; surf scoters (*Melanitta perspicillata*) fed on benthic invertebrates	MAR
	Piers and Docks						
	Industrial and recreational piers, marinas, docks, and ferry terminals of varying sizes	n/a	Unknown, varies	Salmon	Juv. and adult salmon (*Oncorhynchus* sp.), ratfish, spiny dogfish, rockfishes, sculpin, surfperches, and flatfishes	Shading from structures decreased benthic vegetation and altered benthic assemblages	PM1
	3 piers: 582–4866 m^2 total area 6 riprap sites	<20	Unknown, varies	Salmon	Juv. salmon, sand lance, surf smelt (*Hypomesus pretiosus*), Pacific herring, and surfperches	–	PM2
Midwater/Surface	***Attached Kelp and Drift Kelp***						
	Mixed beds of bull kelp and giant kelp with *Egregia menziesii* and *Alaria* spp. along the inner margin	0–20	n/a	Salmon	Juv. salmon, surf smelt, and sand lance in near-surface water	All sites within 1000 m of a creek mouth	KE
	Floating mats of detached intertidal and subtidal vegetation	n/a	Unknown, varies	Salmon	Juv. splitnose rockfish and other rockfishes, surf smelt, juv. salmon, cod (Gadidae), and cabezon	Mats formed in convergent zones	FL

Surrogate Placement	Surrogate Characteristic	Surrogate Depth (m)	Duration in Water at Time of Study	Special-Status Fish Species	Fish Assemblage	Other Organisms/Physical Factors	Surrogate ID[1]

Notes: – = no data; cm = centimeters; juv. = juvenile; km/h = kilometers/hour; m = meters; n/a = not applicable; YOY = young-of-the-year

[1] Surrogate citations (Surrogate ID locations displayed in Figure 3):
NR1 = Matthews 1990a, 1990b
NR2 = Pacunski et al. 2013
NR3 = Pacunski et al. 2013
AR1 = Buckley and Hueckel 1985, Laufle and Pauley 1985, Hueckel and Buckley 1987
AR2 = West et al. 1994
AR3 = Matthews 1990a, 1990b
MAR = Rensel and Forster 2007
PM1 = Ratte and Salo 1985, Simenstad et al. 1999
PM2 = Toft et al. 2007
KE = Shaffer 2002
FL = Shaffer et al. 1995

[2] Low relief = reef structure <1 m in vertical height; high relief = reef structure >1 m vertical height; mixed relief = overall reef structure has a mix of <1-m and >1-m reliefs

[3] Nearshore/shallow, shelf/deep shelf rockfish assemblages based on Love et al. (2002)

[4] Not mapped; location data not reported

3.3.2.1 Natural Reefs

The fish assemblage at the bottom structures of TECs would likely resemble those reported at rocky reefs in the San Juan Islands (Table 8, NR2, NR3). The presence of rockfishes at TECs may depend on the amount of high vertical relief provided by the structure; in one study, high vertical relief provided year-round habitat for copper, quillback, and brown rockfishes regardless of the presence of kelp, but they departed the low-relief reefs in fall when kelp cover was absent (Table 8, NR1). This study also indicated that rockfishes move between habitats, so rockfishes from nearby habitats could occur at TECs on a seasonal or short-term basis.

3.3.2.2 Artificial Reefs

Artificial reefs have been created in Puget Sound to provide fish habitat and enhance recreational fisheries, and rockfish quickly colonize these habitats soon after deployment (Palsson et al. 2009). Fish would likely be attracted to the bottom structures of TECs rapidly after deployment regardless of their distance from the nearest source reef; at several artificial reefs in the Sound, no "stepping stone" pattern was found in which fishes were attracted to the structures nearest a potential source reef first (Table 8, AR1). In fact, fish showed up at the most distant structure first, suggesting that the source of fish was the surrounding water, not the nearest reef. Colonization followed a similar pattern at all sites: reef aggregators (e.g., striped seaperch [*Embiotoca lateralis*] and pile perch [*Damalichythys vacca*]) showed up within weeks and fed on sand-dwelling invertebrates from the surrounding habitats, whereas reef-foraging species (e.g., copper and quillback rockfishes) became more abundant after the second year, when reef substrate had developed from barnacles to algae mats and reef algae–associated prey had become established. Another study reported immigration and recruitment of juvenile rockfish to an artificial reef within 7 months (Table 8, AR2). Also, the fish assemblage on an artificial reef in its 49th productive year was very similar to that observed in its second year, indicating that, once established, an assemblage may persist over the long term (Table 8, AR1).

TECs lacking crevices are not likely to provide suitable habitat for juvenile rockfishes (Pacunski pers. comm.): at one low-relief artificial reef, juvenile rockfishes only occurred in areas with many crevices (Table 8, AR2). TECs may provide only transitory/seasonal habitat for adult rockfishes, because these fishes are known to move between different habitats. In the summer, many copper, quillback, and brown rockfishes departed a high-relief artificial reef with isolated patches of understory perennial kelp, for low-relief natural rocky reefs with dense kelp coverage, and then returned in fall (Table 8, AR3).

3.3.2.3 Mariculture Facilities

The walkway floats, nets, and anchor lines of a mariculture facility attracted a diverse and well-established assemblage of invertebrates and kelp, plus northern clingfish that fed on the invertebrates (Table 8, MAR). Similar biota could be attracted to the bottom and midwater structures of TECs. The study of this facility focused on invertebrate colonization and not on fish associations, so the fish assemblages at this surrogate were not identified. However, the study underscores the finding that virtually any structure placed in tidal waters of Puget Sound would likely function as habitat for fish and invertebrates.

3.3.2.4 Piers and Docks

Juvenile salmon tend to avoid swimming beneath large, shaded areas such as piers, and these structures may affect their movement and delay migration (Table 8, PM1). However, this alteration of salmonid movement is not likely to occur at TECs because they are lacking large overwater structures. Juvenile salmon were observed scraping biota off the attached log booms of a pier at the water's surface (Table 8, PM1), but not from the pilings on or near the bottom (Table 8, PM2), indicating that juvenile salmon may not feed at the bottom structures of TECs. Also, piers and docks are generally in calm, shallow nearshore waters, limiting their applicability as a surrogate to TECs which would be situated deeper and farther from shore to take advantage of faster tidal currents.

3.3.2.5 Attached Kelp and Drift Kelp

Juvenile salmon and other forage fishes (surf smelt and sand lance) occur in the mid- and surface waters of attached kelp and drift kelp in Puget Sound (Table 8, KE, FL); however these fishes would not necessarily associate with TECs that lack surface structure. Also, kelp beds in the Sound are generally in calm, shallow nearshore waters, whereas TECs would be situated deeper and farther from shore to make use of fast tidal currents.

3.3.3 Effects of Structure and Placement on Fish Assemblages and Special-Status Fish Species

3.3.3.1 Ocean Bottom Structure

Based on studies of natural and artificial reefs, piers and docks, and on the personal observations of R. Pacunski, Groundfish Biologist at the Washington Department of Fish and Wildlife, there is evidence that the bottom structures of TECs in Puget Sound would function as artificial reefs and attract various species of adult rockfishes and other reef-associated species (e.g., surfperches, lingcod, greenlings, cabezon, and sculpins), including the special-status rockfish species bocaccio, yelloweye rockfish, canary rockfish, as well as Pacific cod (Table 9). These fishes are attracted to nearly any bottom structure, and have been observed at a variety of low- and high-relief structures in the Sound, including shipwrecks, tractor tires, fishing gear, large anchors (e.g., 4–8-m blocks), rock armoring, and derelict crab pots and other lost fishing gear (Pacunski pers. comm.). As shown by the artificial reef studies, adult reef fishes would likely be attracted to TECs quickly (within weeks to months), regardless of their proximity to the nearest reef, in part because small-scale habitat features (i.e., low-relief habitat) present throughout the Sound may create habitat corridors, allowing fish to move between areas (Pacunski pers. comm.). Scour around anchors/foundations would likely result in downcutting, creating refuge space for adult lingcod and cabezon; these fish may also use the tops of concrete anchors or foundations of TECs as a foraging base, because they mimic natural ledges (Pacunski pers.

comm.). Although adult reef fishes are likely to associate with TEC bottom structures, juvenile rockfishes are unlikely to occur at TEC bottom structures unless crevices are present (Pacunski pers. comm.). There is also no evidence to suggest that bottom structures would attract any of the other special-status fish species (eulachon, Pacific hake, salmonids) that occur in this subregion—they were not reported by any of the studies of surrogate structures, nor are they reef-associated species.

Table 9. Predicted Occurrence of Special-Status Fish Species at Tidal Energy Converters in the Puget Sound Subregion, by Water Column Position and Structure Placement

	Position in Water Column[1]		**Depth of Bottom Structure[2]**		
Common Name	**Juvenile**	**Adult**	**0–30 m**	**30–250 m**	**Midwater Structure[2]**
Green sturgeon	–	B	M	M	**N**
Eulachon	WC	WC	**N**	**N**	M
Pacific hake	WC	WC	**N**	**N**	M
Bocaccio	WC	B	**N**	**Y**	N
Canary rockfish	WC	B	**N**	**Y**	N
Yelloweye rockfish	B	B	**Y**	**Y**	Y
Pacific cod	WC	B	**Y**	**Y**	Y
Chinook salmon	WC	WC	**N**	**N**	N
Chum salmon	WC	WC	**N**	**N**	N
Bull trout	WC	WC	**N**	**N**	N
Steelhead	WC	WC	**N**	**N**	N

Notes:

[1] WC = water column; B = bottom; – = life stage not present in marine waters (Love et al. 2002, Allen et al. 2006, Lindley et al. 2008)

[2] "Y" = a high likelihood that the species will occur based on studies of surrogate structures (Table 8) and species' known biology/habitat; "M" = potential occurrence; "N" = low/no likelihood of occurrence. Bold letters indicate high certainty based on existing information from surrogate structures and species' biology/habitat; regular-font letters indicate low certainty.

Green sturgeon use Puget Sound at a relatively low rate compared to other west coast estuaries (Lindley et al. 2008), and they were not observed at any of the studied surrogate bottom structures. Off the Oregon coast, green sturgeon stay longer in areas with high seafloor complexity and high relief, especially at boulders at depths of 20–60 m, and this is likely because benthic prey and refuge from predators are available (Huff et al. 2011, 2012). Green sturgeon could occur at the bottom structures of TECs in Puget Sound, but it is highly unlikely because of their low use of Puget Sound and their highly migratory behavior.

3.3.3.2 Midwater/Surface Structure

Based on the studies of natural and artificial reefs/kelp beds (with the kelp serving as midwater/surface structure) and piers and docks, there is evidence that some reef-associated and pelagic schooling fishes could occur at the midwater structures of TECs in Puget Sound. These species include some special-status fish species (yelloweye rockfish, Pacific cod, and juvenile salmonids; Table 9). Benthic and pelagic rockfish have been observed schooling directly over underwater buoys in Puget Sound (Pacunski pers. comm.), and juvenile, semipelagic rockfishes have also been reported at a variety of midwater structures along the U.S. West Coast, such as at oil and gas platforms, mariculture facilities, and natural and artificial reefs/kelp beds. Although juvenile salmonids were reported at the midwater/surface structures of piers, docks, and artificial reef/kelp beds in Puget Sound, their depth distribution and preferred habitat probably would not overlap with that of TECs. Smaller juvenile salmonids (<70 millimeters) generally only occur in nearshore shallow water with low energy (Fresh 2006), whereas TECs would be placed in deeper midchannel waters with high velocity. Larger juvenile salmonids occur in a greater diversity of habitats (Fresh 2006), but their depth distribution still would not overlap with TECs. The majority (80%) of juvenile salmonids sampled in midchannels of Puget Sound occurred in the top 15 m of the water column (Ruggerone and Sweeting pers. comm., as cited in DOE et al. 2012b), whereas TECs likely would have an overhead clearance of 15–25 m to provide safe access for boat traffic.

TEC placement in channels where strong tidal currents occur may not preclude fish attraction to midwater structures: rockfishes were reported at an artificial and natural reef located in the middle of a passage (400–600 m offshore) with high tidal velocity (up to 2.2 m/s) (Table 6, NR1 and AR3, respectively). However, adult fish associations with TECs may be limited to when tidal velocity is low; for instance, pollock occurred around a tidal turbine (in the United Kingdom) only when tidal velocity was less than 1.8 m/s (Broadhurst et al. 2014). In addition, TECs are not expected to support resident rockfish populations, and fish use of TECs may be only transitory/seasonal, where the devices create stopovers for schools of pelagic rockfishes (e.g., black and yellowtail rockfishes) along movement corridors (Pacunski pers. comm.). A transitory/seasonal effect was observed at some low-relief artificial reefs and natural reefs lacking kelp (Table 8, NR1, AR3).

3.4 Hawai‘i

The Hawaiian Islands situated in the central North Pacific Ocean, are volcanic in origin and form a narrow elongated archipelago comprising 132 distinct islands, atolls, reefs, submerged banks, shoals, and seamounts stretching 2451 km from the southeastern-most island of Hawai‘i northwest to Kure Atoll that are collectively referred to as the Hawaiian Ridge. The main Hawaiian Islands (MHI) include Hawai‘i, Maui, Lāna‘i, Moloka‘i, Kaho‘olawe, O‘ahu, Kaua‘i, and Ni‘ihau. The Northwestern Hawaiian Islands consist of mostly uninhabited atolls, reefs, submerged banks, and seamounts that are separated from the MHI by roughly 250 km of open ocean (between Kaua‘i and Nihoa Islands) and are undergoing subsidence. Nearshore waters harbor coral reefs that colonize the volcanic rock surfaces forming limestone carbonate base features and fringing reef structures; seaward of these fringing reefs, bathymetry descends rapidly to depths exceeding 1000 m. Seamounts and offshore banks that occur along these steep slopes provide important habitat for juvenile and adult deepwater bottom fishes that are closely associated with hard bottom substrates, with the greatest species diversity and richness at depths of 100-400 m. In addition, a diverse assemblage of pelagic fishes, including tropical tuna species, occurs from the surface to 200 m (Carlquist 1980, Ziegler 2002).

Currents are strongly influenced by the presence of the islands and persistent northeast Trade Winds. South of the MHI, the westward-flowing North Equatorial Current forks at Hawaiʻi island, and the northern branch, the North Hawaiian Ridge Current, intensifies near the islands (Flament 1996, Qui et al. 1997). Waters in the lee of the MHI typically contain vigorous eddies and strong flows, and localized fronts form to create favorable habitat for many marine organisms and pelagic fish species (Seki et al. 2001). Water temperatures in the MHI vary between 23°C and 28°C at the surface and drop abruptly to 9–12°C at the thermocline (at depths of 100–300 m) (Struhsaker 1973, Chiswell et al. 1990).

3.4.1 Special-Status Fish Species

Table 10 lists the special-status fish species known to occur in the Hawaiʻi subregion that could be affected by WECs; these fishes are referred to as the *Deep 7 Bottomfish* (Table 10) and receive special management consideration by NMFS because they are vulnerable to overfishing. They occur in relatively deep water (>100 m) and typically associate with seamounts and other natural bathymetric features with high vertical relief and complexity. For each surrogate structure assessed in Section 3.4.2 below, we noted whether any of these special-status species were reported at the structure (Table 11), and assessed, based on current information, the likelihood that they would occur at WECs (Section 3.4.3).

Table 10. Special-Status Fish Species Known to Occur in the Hawaiʻi Subregion

Common Name[1]	Scientific Name	Status[2]
Silverjaw snapper (lehi)	*Aphareus rutilans*	(All) Strictly managed—annual quota system
Squirrelfish snapper (ehu)	*Etelis carbunculus*	
Longtail snapper (onaga)	*Etelis coruscans*	
Pink snapper (opakapaka)	*Pristipomoides filamentosus*	
Von Siebold's snapper (kalekale)	*Pristipomoides sieboldii*	
Brigham's snapper (gindai)	*Pristipomoides zonatus*	
Hawaiian sea bass (hapu'upu'u)	*Epinephelus quernus*	

Notes:

[1] Commonly used names for these species in Hawaiʻi in parentheses

[2] Annual catch limit for commercial harvest established by NMFS (78 FR 52125)

3.4.2 Fish Assemblages and Ecological Interactions at Surrogate Structures

In the Hawaiʻi subregion, bottom-oriented surrogate structures (natural and artificial reefs) and combined bottom- and midwater/surface-oriented structures (mariculture facilities and purpose-built FADs) were evaluated to examine the probabilities of fish species interactions with WECs deployed in this subregion (Figure 4; Table 11).

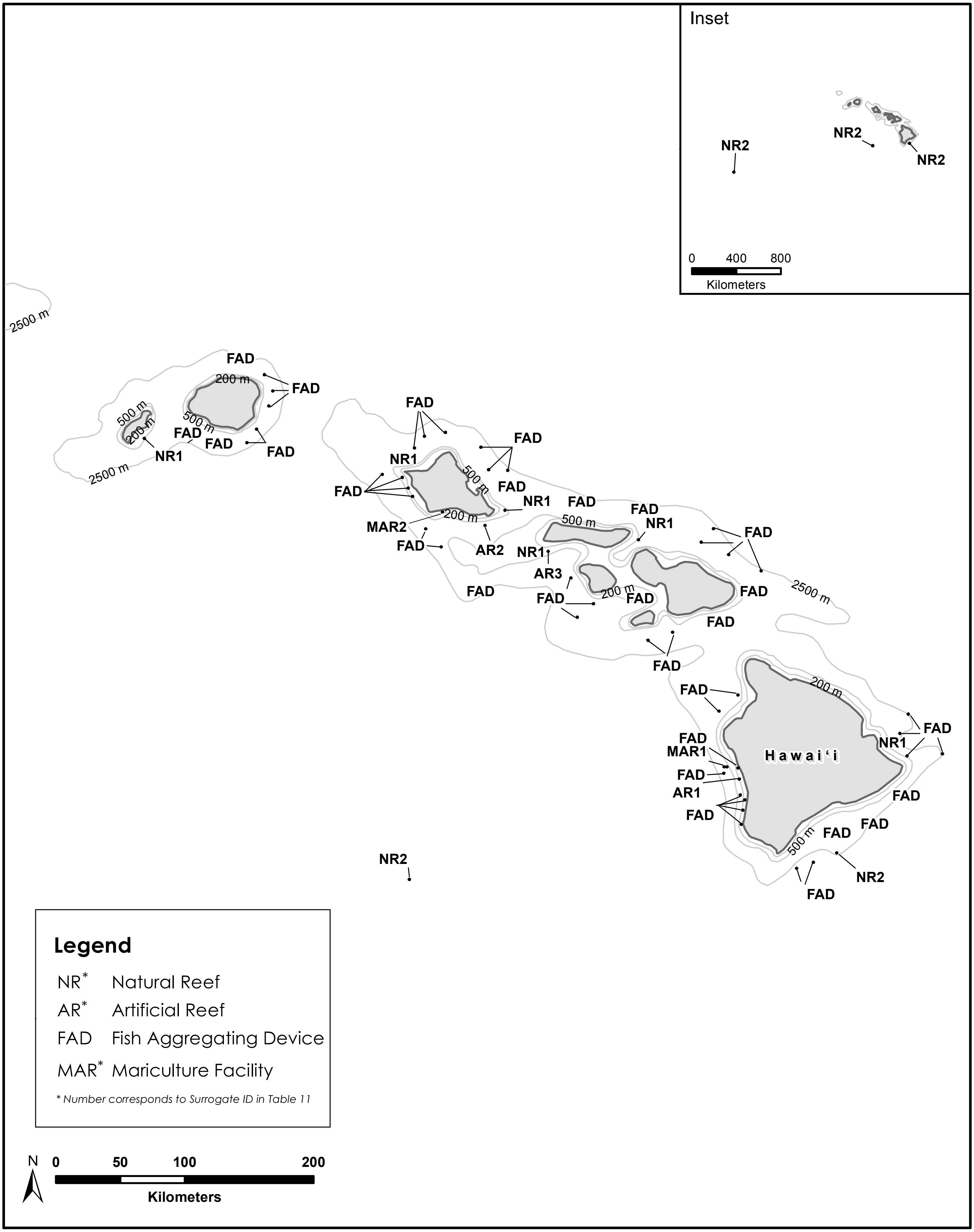

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Figure 4. Hawai'i: Locations of Surrogate Structures

Table 11. Hawai'i: Characteristics of Surrogate Structures (Locations of Surrogate Structures Displayed in Figure 4)

Surrogate Placement	Surrogate Characteristic	Surrogate Depth (m)	Duration in Water at Time of Study	Special-Status Fish Species	Fish Assemblage	Other Organisms/Physical Factors	Surrogate ID[1]
Ocean Bottom	***Natural Reefs*[2]**						
	Mixed relief, often >5 m; moderate to low surge resulting from wave energy	100–300	n/a	Ehu, onaga, opakapaka, kalekale	Deepwater snappers (Lutjanidae), groupers (Serranidae), jacks (Carangidae), and sharks	Not reported	NR1
	Mixed and high relief reefs, slopes, caves, large sand channels and expanses	40–2000	n/a	Lehi, ehu, onaga, gindai, opakapaka, hapu'upu'u	250+ fish species, marked decline in species diversity >200–400-m depth; special-status species only at <400 m depths	Antipathid corals	NR2
	***Artificial Reefs*[2]**						
	6 low-relief reefs (each 164-cm long x 54-cm wide x 81-cm high) of stacked concrete blocks with 13-cm x 18-cm internal openings on sand flats or lava benches	8	2 yrs	None	Common nearshore Hawaiian reef fishes (Acanthuridae, Cirrhitidae, Gobidae, Labridae, Pomacentridae)	Patchy coral	AR1
	>60 concrete pipes (45–150 cm diameter, ≤ 3.7 m long), 1200-m^2 total area 550 auto tire modules; each module 8–10 tires (height ≤ 3-m) partially embedded in concrete base, 1-ha total area 42 open-frame concrete cubes (1.2-m per side), 38 cubes on bottom, 4 cubes on 2nd level	20–35	3–12 yrs	None	Common nearshore Hawaiian reef fishes closely resembling those at nearby natural reefs (Acanthuridae, Scaridae, Labridae, Tetraodontidae, Monacanthidae)	Fouling community of rock oysters, tubeworms, bryozoans, algae and patchy coral on the open-frame concrete cubes	AR2
	8 concrete modules (0.8–1.1-m relief), each module 3–6 pipes (each pipe 30-45 cm diameter) 1 module constructed of 9 fiberglass-reinforced plastic cylinders (5.3-m relief)	60–117	1–4 yrs	Opakapaka	Transient fishes: Acanthuridae, Balistidae, Carangidae, Labridae, Lutjanidae, Mullidae Resident fishes: Acanthuridae, Chaetodontidae, Labridae, Muraenidae, Pomacantridae, Pomacentridae, Scorpaenidae, Serranidae, Tetraodontidae	Antipathid corals	AR3

Surrogate Placement	Surrogate Characteristic	Surrogate Depth (m)	Duration in Water at Time of Study	Special-Status Fish Species	Fish Assemblage	Other Organisms/Physical Factors	Surrogate ID[1]
Ocean Bottom + Midwater/Surface	***Mariculture Facilities***						
	8 interconnected 60 x 60-m surface net-pens stocked with amberjack (*Seriola rivoliana),* anchored on sand-bottom 0.8 km offshore	60	9 yrs	None	Amberjack, ulua (*Caranx* spp.), barracuda (*Sphyraena barracuda*), opelu (*Decapterus macarellus*); sandbar, (*Carcharinus plumbeus*), blacktip (*C. limbatus*), and tiger sharks (*Galeocerdo cuvieri*)	Dolphins, humpback whale (*Megaptera novaeangliae*), Hawaiian monk seal (*Monachus schauinslandi*) visits	MAR1
	7-m-diameter net-pens stocked with amberjack anchored 10 km offshore	1830	14 months	None	Schools of opelu; yellowfin, bigeye (*Thunnus obesus*), and skipjack (*Katsuwonus pelamis*) tunas, pelagic triggerfish (*Canthidermis maculata*); rainbow runner (*Elegatis bipinnulata*); billfish (Istiophoridae), mahi-mahi (*Coryphaena hippurus*), oceanic sharks[1]	Bryozoans and encrusting algae, some marine mammal visits	MAR1
	Free-drifting 7-m-diameter net-pen system stocked with amberjack; ~5–120 km offshore of the Kona Coast	Unreported; probably >1000	8-month deployment cycles	None	5–16 km from shore: opelu, rainbow runner, ulua 16+ km: yellowfin, bigeye, and skipjack tunas; small ahi, billfish, oceanic sharks[3] 32–40 km: mahi-mahi	Occasional cetaceans	MAR1[4]
	Three 25-m-diameter net-pens stocked with moi (*Polydactylus sexfilis*) anchored <1 km offshore	30-50	>4 yrs	None	Schools of amberjack (>100 fish); blue trevally (*Caranx melampygus*); sandbar, blacktip, and tiger sharks	Not reported	MAR2
	Purpose-Built FADs						
	Surface FADs; mostly spherical, moored, and anchored	900–1700	Variable	None	Yellowfin, bigeye, and skipjack tunas, wahoo (*Acanthocybium solandri*), mahi-mahi, billfishes, rainbow runner, opelu, and sharks	Algae, bryozoans, corals, other pelagic invertebrates	FAD

Surrogate Placement	Surrogate Characteristic	Surrogate Depth (m)	Duration in Water at Time of Study	Special-Status Fish Species	Fish Assemblage	Other Organisms/Physical Factors	Surrogate ID[1]

Notes: – = no data; cm = centimeters; km = kilometers; m = meters; ha = hectares; yrs = years; n/a = not applicable.

[1] Surrogate citations (Surrogate ID locations displayed in Figure 4):
NR1= Misa et al. 2013
NR2 = Chave and Mundy 1994
AR1 = Walsh 1985
AR2 = Bailey-Brock 1989, Brock and Norris 1989
AR3 = Moffitt et al. 1989
MAR1 = Keys pers. comm., Sims pers. comm.
MAR2 = Papastimatiou et al. 2010
FAD = Itano and Holland 2000; Dagorn et al. 2007

[2] Low relief = reef structure <1 m in vertical height; high relief = reef structure >1 m vertical height; mixed relief = overall reef structure has a mix of <1-m and >1-m reliefs

[3] Oceanic sharks = e.g., whitetip (*Carcharinus longimanus*), Galapagos (*C. galapagensis*), silky (*C. falciformis*), and whale sharks (*Rhincodon typus*)

[4] Not mapped; net-pens were free-drifting

3.4.2.1 Natural Reefs

Common reef fishes found at depths of less than 30 m in this subregion include herbivorous and carnivorous fishes belonging to families including Acanthuridae, Apogonidae, Cirrhitidae, Labridae, Pomacentridae, Scaridae, and Carangidae (Walsh 1985). Diversity, biomass, and resilience of reef fish communities tend to be greatest where wave energy is minimal, and biomass generally increases with greater habitat complexity and spatial relief (Friedlander et al. 2003).

At depths of greater than 30 m in this subregion, the rocky reef species assemblage includes a variety of deep-water snappers, groupers, jacks, and sharks (Table 11, NR1, NR2), and similar fish species could be attracted to WECs placed in deeper waters. The depth of WEC bottom structures would affect the diversity of fish assemblages at the structures, because markedly fewer species occur at depths of greater than 200 m (Table 11, NR2). Several of the special-status fish species of this subregion (opakapaka, kalekale, onaga, and ehu) were most associated with depths of 90–300 m (Table 11, NR1, NR2).

3.4.2.2 Artificial Reefs

WECs placed in shallower waters (<30-m depth) would likely be colonized rapidly by adult fishes if placed near a natural rocky reef: at an artificial reef placed near a natural reef (<50 m away), fish species equilibrium (when the total number of species stopped increasing) occurred within 10 days of placement, and most of the fishes at the artificial reef were adults (Table 11, AR1). Artificial reefs placed on sand flats exhibited a higher abundance and diversity of fishes than those placed on or near natural reefs; the relative isolation of the sand-flat reefs may have offered a selective advantage in terms of reduced predation, competition, or nest disturbance (Table 11, AR1), and WEC bottom structures placed on soft-bottom substrates could provide similar advantages. However, the low complexity of WEC bottom structures (e.g., cement-block anchors) may limit fish abundance and diversity in comparison to complex artificial reefs: these were greatest at an artificial reef composed of highly complex, open-framework concrete cube modules and lowest at haphazardly dumped automobile shells and tires, and solid concrete pipe (Table 11, AR2). A fouling community (e.g., rock oysters, tubeworms, bryozoans, algae, and corals) developed on the concrete cube modules, providing food for reef fishes, and a similar community would likely develop on WEC bottom structures (Table 11, AR2).

WECs placed in deeper waters (>30 m) would likely attract a mix of adult resident and transient reef fishes, with transient species arriving first (within a few days). Fish species equilibrium likely would be reached within a few months, as was observed at several artificial reefs at depths of 60–117 m (Table 11, AR3). More complex reefs attracted a greater diversity and abundance of resident fishes, because these fishes use the reefs for shelter and foraging. In contrast, shallower (61-m-deep) reefs were associated with a greater biomass of transient fishes. Thus, low-complexity WEC bottom structures would likely see limited use by resident benthic fishes, and total biomass of transient fishes would depend on depth of installation.

3.4.2.3 Mariculture Facilities

Fish assemblages at the midwater/surface structures of WECs in Hawai‘i could resemble those observed amberjack culture operations off the island of Hawai‘i, and those observed at moi culture operations off the island of O‘ahu (Table 11, MAR1, MAR2). Pelagic fishes were associated with one of the anchored net-pens even when it was not stocked with fish, suggesting that WECs would likely attract fishes as well. Sharks were also associated with the moi culture operations, some individual sandbar sharks showed site fidelity to the net-pens over period of up to 2.5 years, as well as transient and sporadic visits by individual tiger sharks, likely due to the persistent availability of prey (Table 11, MAR2).

3.4.2.4 Purpose-Built FADs

Up to 64 purpose-built FADs are permitted in the MHI; most of these are located within 15 km of shore, anchored at depths of 900–1650 m (ranging from a few hundred to 2761 m) (Table 11, FAD). These FADs are known to attract high-value pelagic fishes targeted by recreational fishers, including yellowfin tuna, bigeye tuna, skipjack tuna, mahi-mahi (also known as dolphinfish), wahoo, billfishes, and rainbow runner, as well as nontarget species such as opelu, pelagic triggerfish, and sharks, and fish assemblages vary by depth and proximity to land (Everson pers. comm., Holland pers. comm., Itano pers. comm.). Individual fish exhibit a wide variety of residence times at FADs, staying anywhere from a few days to several months. The midwater/surface structures of WECs could attract a similar assemblage of pelagic fishes if deployed at similar depths and distances from shore.

3.4.3 Effects of Structure and Placement on Fish Assemblages and Special-Status Fish Species

3.4.3.1 Ocean Bottom Structure

Based on the studies of natural and artificial reefs, there is evidence that the bottom structures (anchors or foundations) of WECs in the Hawai‘i subregion would function as artificial reefs and attract various reef-associated fish species, including special-status fish species if placed at depths of 100–400 m (Table 12). Adult fishes probably would colonize bottom structures rapidly (e.g., within a few days), and species equilibrium would be reached within weeks to months (Table 11, AR1, AR3). The low complexity of WEC bottom structures (e.g., cement-block anchors) may limit fish abundance and diversity, which was indicated by comparisons between low-complexity and high-complexity artificial reefs (Table 11, AR2, AR3).

Table 12. Predicted Occurrence of Special-Status Fish Species at Wave Energy Converters in the Hawai‘i Subregion, by Water Column Position and Structure Placement

Common Name	Position in Water Column[1] (Juvenile and Adult)	Depth of Bottom Structure[2]			Midwater/ Surface Structure[2]
		0–100 m	100–400 m	400–2000 m	
Silverjaw snapper (lehi)	B	**N**	**Y**	**N**	**N**
Squirrelfish snapper (ehu)	B	**N**	**Y**	**N**	**N**
Longtail snapper (onaga)	B	**N**	**Y**	**N**	**N**
Pink snapper (opakapaka)	B	**N**	**Y**	**N**	**N**
Von Siebold’s snapper (kalekale)	B	**N**	**Y**	**N**	**N**
Brigham’s snapper (gindai)	B	**N**	**Y**	**N**	**N**
Hawaiian sea bass (hapu'upu'u)	B	**N**	**Y**	**N**	**N**

Notes:

[1] B = bottom (Merritt et al. 2011, Misa et al. 2013)

[2] “Y” = high likelihood that the species will occur based on studies of surrogate structures (Table 11) and species’ known biology/habitat; “N” = low/no likelihood of occurrence. Bold letters indicate high certainty based on existing information from surrogate structures and species’ biology/habitat; regular-font letters indicate low certainty.

3.4.3.2 Midwater/Surface Structure

Based on the studies of mariculture facilities and purpose-built FADs, there is evidence that the midwater/surface structures of WECs in the Hawai‘i subregion would attract tropical pelagic fishes, sharks, and other top predators (Table 11, MAR1, MAR2, FAD). Given their benthic habitat, none of the special-status fish species are likely to associate with the midwater/surface structures of WECs (Table 12). Pelagic fish assemblages would likely vary by proximity to land and anchored depth: in very nearshore waters (<1 km of shore, <100 m depth), assemblages may be dominated by amberjack, ulua, opelu, barracuda, blue trevally, sandbar and tiger sharks (Table 11, MAR1, MAR2); within 3 km of shore, assemblages may be dominated by opelu, akule (*Selar crumenophthalmus*), ulua, and small mahi-mahi; and farther offshore (>10 km), by yellowfin tuna, bigeye tuna, skipjack tuna, marlins (*Makaira* and *Tetrapterus* spp.), wahoo, larger mahi-mahi, opelu, and oceanic sharks (Table 11, MAR1, FAD; Everson pers. comm., Holland pers. comm., Itano pers. comm.).

Other special-status marine organisms that occur in Hawai’i, such as sea turtles (listed as federally threatened), have not been observed at anchored FADs, so their presence at WECs is unlikely (Itano pers. comm.). Marine mammals (protected by the Marine Mammal Protection Act and some federally threatened or endangered) may occur at WECs, but based on anecdotal observations from mariculture net-pens, they are unlikely to be negatively affected by midwater structures of WECs. For example, a humpback whale was observed moving “carefully and deliberately” within a mariculture net-pen grid without touching any mooring lines (Table 11, MAR1), suggesting that humpbacks could avoid entanglement with the mooring lines of a WEC installation. Dolphins were also reported at mariculture net-pens (Table 11, MAR1), but they were likely attracted to fish escaping from the pens, an attraction that would be lacking at WECs.

Section 4.0 Conclusions

In this study, the predictability of fish assemblages and ecological interactions at WECs and TECs relies in part on the resemblance of the surrogate structures to WEC and TEC structures, as well as on the distribution and quantity of surrogate structures in each of the subregions. In general, there were enough bottom-oriented surrogate structures to evaluate potential ecological interactions at WECs and TECs in all four subregions, but there were not enough midwater/surface-oriented surrogate structures in the temperate-water subregions (CA-WA and Puget Sound; Table 13).

Table 13. Resemblance of Surrogate Structures to the Bottom and Midwater/Surface Structures of Wave and Tidal Energy Converters, and Distribution of Surrogate Structure Studies in Each Subregion

	Resemblance of Surrogate Structure to WECs/TECs[1]		Distribution and Quantity of Surrogate Structures[2]			
Surrogate Structure	**Bottom Structure**	**Midwater/ Surface Structure**	**SCB**	**CA-WA**	**Puget Sound**	**Hawai‘i**
Natural reef	Low	n/a	High	High	High	High
Natural reef/kelp bed	Low	Low	High	High	High	None
Artificial reef	Low	n/a	High	Low	High	High
Artificial reef/kelp bed	Low	Low	High	Low	High	None
Oil and gas platform	High	Low	High	None	None	None
Marine debris	Low	n/a	Low	Low	None	None
Mariculture net-cage	High	High	Low	None	Low	Low
Purpose-built FAD	High	High	Low	Low	None	High
Drift kelp and floating debris	n/a	Low	Low	None	Low	None
Piers and docks	High	Low	None	Low	High	None

Notes: WEC = wave energy converter; TEC = tidal energy converter; SCB = Southern California Bight subregion; CA-WA = Central California to Cape Flattery, Washington, subregion; FAD = fish aggregating device

[1] Resemblance categories: High = Surrogate structure has comparable relief, complexity, and size as WECs/TECs; Low = Surrogate structure has substantial differences in relief, complexity, and/or size as WECs/TECs; n/a = No structure at this position in the water column

[2] Distribution categories: High = Several studies of surrogate structures were available, and were well-distributed throughout the subregion; Low = Few studies were available and covered only a small portion of the subregion; None = No studies of surrogate structures were identified in this subregion

4.1 Ocean Bottom Structure

The bottom-oriented surrogate structures (natural reefs, artificial reefs, oil and gas platforms, anchors for mariculture net-cages and purpose-built FADs, marine debris, and piers and docks) varied in their resemblance to the bottom structures of WECs and TECs and in their distribution in the subregions (Table 13). Anchors used for mariculture net-cages and purpose-built FADs probably most closely resembled the anchors that would be used for WECs, but the studies for those structures and guided discussions with experts did not provide information on benthic fishes. Natural reefs were present in every subregion, but had a low resemblance to the bottom structures of WECs and TECs, because they generally provided more diverse habitat types and complexity and covered much larger areas than would anchors or foundations. Artificial reefs, which were present in all the subregions but scarce in the CA-WA and Hawaiʻi subregions, also had a low resemblance, because they generally provided greater complexity than anchors or foundations and were located in shallower waters than where most WECs or TECs would be placed (<30 m versus >40 m depth). Although there was abundant information on fish assemblages at oil and gas platforms and these structures had a high resemblance to the bottom structures of WECs and TECs, they occurred only in the SCB subregion. Piers and docks and marine debris likely occur in all of the subregions, but there was little information on fish assemblages at these structures, and marine debris also had a low resemblance to the bottom structures of WECs and TECs. Despite these shortcomings of varying resemblance and distribution, all the bottom-oriented surrogate structures within each subregion hosted similar fish assemblages, suggesting that the studies of these surrogate structures provided adequate information for evaluating the bottom structures of WECs and TECs, and indicating a high level of certainty about the assemblages, regardless of the size and shape of the bottom structures. In addition, there was a general lack of potentially significant negative ecological interactions for fishes, including special-status species, noted at the surrogate structures.

Reef-associated fishes were reported at every type of bottom surrogate structure, which indicates that the bottom structures of WECs or TECs installed in any of the subregions are likely to function as artificial reefs and attract fish. Bottom structures will likely attract fish regardless of their distance from the nearest natural reef habitat; rockfishes have been reported to move tens to hundreds of kilometers between reefs (Hanan and Curry 2012), between natural reefs and oil and gas platforms in the SCB (Lowe et al. 2009), and between natural and artificial reefs in Puget Sound (Matthews 1990a, 1990b). Also, sparse, low-relief habitats (e.g., sand waves, biogenic habitat) that are usually overlooked by humans because they do not show up on bathymetric maps (Prall pers. comm.) may provide connectivity between natural reefs and bottom structures and facilitate colonization.

Both juvenile and adult fish may be attracted to bottom structures, but the low complexity of anchors/foundations may limit species richness, preclude use by crevice-associated juvenile fish or contribute to high levels of recruitment mortality or predation (Pickering and Whitmarsh 1997). If this occurs, the bottom structures may provide habitat for mainly adult reef-associated fishes but not enhance production of these fish, unless a prohibition on fishing succeeds in providing important refuge habitat for adults. If there is a desire to create habitat for a variety of fish and life stages at bottom structures, complex anchors could be installed in lieu of standard concrete-block anchors (Hannah pers. comm.). For example, holes were incorporated into the concrete foundations of WECs in an installation in Sweden; the added complexity provided additional habitat for crabs (*Cancer pagurus*) (Langhamer and Wilhelmsson 2009).

Single or pilot projects with few devices are not likely to have much of an impact on populations or recruitment (Pacunski pers. comm.), but a commercial-scale development with tens to hundreds of devices in a limited area could form a biologically connected artificial reef complex and attract or produce a higher density of fish per device than a single device would. Bottom structures placed in soft-bottom habitats, especially where rocky structure is rare, would likely affect community structure by attracting hard structure–associated fish and invertebrates. However, this effect on soft-bottom communities is not likely to occur on a large scale, given the small area of hard-bottom structure created by WECs and TECs relative to the large amount of available soft-bottom habitat in most areas (Prall pers. comm.).

Based on artificial reef studies from the U.S. West Coast subregions (SCB, CA-WA, and Puget Sound), fish likely would be attracted quickly to WEC or TEC bottom structures (e.g., within days to months), although the assemblage may change over time as new food sources become established. For example, in Puget Sound, surfperches showed up initially on an artificial reef and fed on sand-dwelling invertebrates, whereas rockfishes were more abundant after the second year, once reef algae–associated prey had become established (West et al. 1994).

The bottom structures of WECs are likely to attract and provide habitat for some special-status fish species, particularly adult rockfishes in the U.S. West Coast subregions and snappers in Hawaiian waters, and negative effects on special-status fish species, such as increased mortality of adults, were not indicated by any of the studies of surrogate structures. Reef-associated fishes (including special-status species) have the ability to move between artificial and natural reefs, so if the habitat quality of bottom structures were poor, they would likely depart for higher-quality habitat. The bottom structures of WECs installed in California, especially in the SCB, have the potential to attract high densities of reef-associated fishes and contribute to rockfish productivity, if the structures provide habitat that is comparable to oil and gas platforms, which had some of the highest secondary production per unit area of seafloor of any marine habitat studied globally (Claisse et al. 2014).

4.2 Midwater/Surface Structure

4.2.1 WECs

The midwater/surface-oriented surrogate structures (kelp attached to natural and artificial reefs, drift kelp, floating debris, oil and gas platforms, and the mooring lines and floating structures of mariculture net-cages and purpose-built FADs) varied in their resemblance to the midwater/surface structures of WECs and in their distribution in the subregions (Table 13). The best midwater/surface-oriented surrogates for WECs were probably purpose-built FADs and mariculture net-cages (empty of farmed fish) because they have mooring lines and floating structures; however, there were few of these structures in the CA-WA and SCB subregions. In addition, the net-cages excluded larger fishes (through mesh or cages), and both types of structures generally provide more sheltering space for small fishes than WECs. Although there were many purpose-built FADs to use as surrogate structures of WECs in the Hawaiʻi subregion, their value as a surrogate was tempered by their placement at greater distances from shore and at greater water depths than are likely for commercial WECs of current design. Kelps, which generally provide dense, three-dimensional structure, has little resemblance to the mooring lines and steel midwater or floating devices of WECs, and attached kelps are generally found in waters shallower (<30 m depth) than where WECs would be installed. Oil and gas platforms have only a low resemblance to WECs because of their more complex horizontal and vertical structure throughout the water column, and these surrogates were present only in the SCB subregion. Despite these shortcomings of surrogate structure resemblance and distribution, both kelp and oil and gas platforms may have some value as midwater/surface-oriented surrogate structures for WECs, because there were similar fish assemblages at the midwater structures of oil and gas platforms, kelp beds, and at high-relief reefs lacking kelp in the SCB, which is evidence that these fishes can occur at a variety of structures.

Based on the studies of surrogate structures, and on existing knowledge of fish associations with floating objects, WECs would certainly function as FADs and attract coastal and pelagic fishes in the tropical waters of Hawaiʻi, especially if placed in similar locations and depths as purpose-built FADs, and pelagic fish associations would likely be occasional, seasonal, and/or transitory in the subtropical/temperate transition zone of the SCB subregion. However, potential associations in the temperate waters of the CA-WA subregion are less clear because studies of appropriate surrogate structures were lacking. Juvenile, semipelagic, and kelp-associated rockfishes did associate with kelp vegetation, dock pilings, and purpose-built FADs in this subregion, which suggested that kelp-associated fishes could occur at WECs structures as well, especially if placed in close proximity to rocky reef/kelp beds. Kelp-associated rockfishes may also be more likely to be attracted to the structures if algae or biofouling becomes established on anchors and mooring lines. Studies of midwater/surface structures in other temperate waters suggested potential fish associations for this subregion: relevant fish associations were documented at offshore oil and gas platforms in the SCB (many of those rockfish species also occur in the CA-WA subregion), at empty mariculture net-cages in offshore waters of China (Wang et al. 2015), and at the midwater structures of offshore wind turbine foundations in the Baltic Sea (Wilhelmsson et al. 2006). However, it is less certain whether fish would associate with WECs where the midwater structure is limited to mooring lines.

Special-status rockfish species, such as juvenile bocaccio and canary rockfishes, could occasionally associate with the midwater/surface structures of WECs, although negative effects on these species, such as increased predation, were not indicated by any of the studies of surrogate structures. Association with the midwater/surface structures of WECs by special-status juvenile salmonids (of concern for environmental permitting along the U.S. West Coast), were also not indicated by any of the studies of surrogate structures, nor by their biology and habitat. It is important to note that a risk to salmonids would occur only if they and their predators were attracted to WECs, and if the predators consumed substantial numbers of juvenile salmonids, and this scenario is highly unlikely. Although known predators of juvenile salmonids, such as piscivorous seabirds (e.g., cormorants [*Phalacrocorax* spp.], brown pelicans [*Pelecanus occidentalis*]) and pinnipeds (e.g. California sea lions, northern elephant seals [*Eumetopias jubatus*]), could roost or haul out on above-surface structures of WECs, and some fish predators could occasionally associate with the midwater/surface structures, these predators generally rely on more locally abundant prey types such as northern anchovy, Pacific hake, Pacific herring, rockfishes, jack mackerel, and squid (*Logilo* sp.) (Anderson et al. 1980, Antonelis and Fiscus 1980, Ainley et al. 1981).

4.2.2 TECs

The potential for the midwater structures of TECs in the Puget Sound subregion to function as FADs and attract pelagic fishes is less than certain based on the studies of drifting and attached kelp, and piers and docks, because none of these surrogate structures resembled moving tidal turbines (Table 13). These surrogates also have surface-oriented structure that could attract fishes, and surface structure would be absent from TECs. Observations of TECs in cold-temperate waters off Europe and Maine have indicated that some pelagic fish associate with tidal turbines at lower tidal velocities (Broadhurst et al. 2014, Viehman and Zydlewski 2014), so similar use is likely to occur at tidal turbines in Puget Sound. Negative interactions at the midwater structures of TECs, such as increased predation on special-status juvenile salmonids or rockfishes, were not indicated by any of the studies of surrogate structures.

4.3 Recommendations to Address Important Knowledge Gaps

In our review of ecological studies of surrogate structures, we identified two important knowledge gaps. First, little is known about the potential for fishes to be attracted to the midwater structures (tidal turbines) of TECs in the Puget Sound subregion. Second, additional research is needed to characterize the potential for the midwater/surface structures of WECs in the temperate waters of the CA-WA subregion to function as FADs and attract coastal and pelagic fishes. These knowledge gaps are discussed below.

1. We do not recommend additional studies using surrogate structures to evaluate the potential associations of fish with the midwater structures of TECs in the Puget Sound subregion, because we were unable to identify any surrogate structures that are truly comparable to tidal turbines for TECs, and because negative effects on species as a result of TEC installations seem unlikely judging from the habitat and biology of special-status species in Puget Sound. In addition, reported observations of fishes at tidal turbines during slow tidal currents in cold-temperate waters of Europe and Maine (Broadhurst et al. 2014, Viehman and Zydlewski 2014) provide some relevant information on the potential fish associations and behaviors that may occur around TECs in the Puget Sound. Further studies of the interactions between fishes and tidal turbines in Puget Sound would most likely need to be conducted after TECs are deployed.

2. To address the potential for the midwater/surface structures of WECs to attract pelagic fishes in temperate waters of the CA-WA subregion, we recommend that additional surrogate structures be studied. Based on our review of surrogate structures and from anecdotal observations, there is some evidence that fish may associate with midwater/surface structures of WECs seasonally, transitorily, and/or occasionally, but that a strong and persistent attraction is unlikely. Fish associations with WECs may depend on variables such as latitude or proximity to river mouths, headlands, or highly productive hotspots, but because pertinent information was lacking from the surrogate structures we reviewed, we were unable to evaluate the influence of these variables. This important data gap could be evaluated using navigation buoys, oceanographic buoys, and/or similar types of moorings in the CA-WA subregion.

   Navigation buoys are 1.5-m to 12-m disc-shaped or boat-shaped aluminum or steel floats anchored to the ocean bottom by chain, nylon, or polypropylene mooring lines (National Data Buoy Center [NDBC] 2014). These buoys are deployed and maintained by the U.S. Coast Guard, but fish assemblages at these buoys are not currently documented (Parker pers. comm.). The anchoring and mooring systems of navigation buoys strongly resemble those of most types of WECs, and the size and structure of navigation buoys also strongly resemble some types of WECs (i.e., point absorbers). Based on evaluation of the NDBC's station mapper, which contains mapped locations of 1,250 buoys worldwide, there are approximately 100 navigation buoys evenly distributed along the California, Oregon, and Washington coasts at 4–17 km from shore (the approximate distance from shore at which WECs would be installed) (NDBC 2014), and fish use could be evaluated at these buoys at different latitudes, distances to shore, water depths, and proximities to known coastal or oceanic processes (e.g., river mouths, headlands, natural rocky reefs, ecological hotspots). Other types of buoys and moorings present in the CA-WA subregion could also be evaluated with cooperation and approval from the owner/operators.

   We recommend a phased approach to evaluating potential fish associations WECs in the CA-WA subregion. The first step would be to use hydroacoustic methods to evaluate whether there are any fishes associating with the existing buoys/moorings as surrogates for WECs (Wilson et al. 2003, Lowe and Bray 2006, Horne et al. 2013). Hydroacoustic monitoring equipment can include single-frequency and multichannel-frequency echosounders, and acoustic cameras; these can be either mounted to the buoys or moored to the bottom (autonomous, fixed hydroacoustics), or surveys can be conducted by boat or autonomous underwater vehicle (Lowe and Bray 2006, Jaques 2014). Single-frequency echosounders are traditionally used to locate fish and determine relative densities. However, multichannel frequencies improve fish density estimates and can sometimes identify species (for example, where there are few species), because each fish species has unique acoustic responses, in part related to size and swim bladder volume. Acoustic cameras convert sound pulses into digital images/video and are used mostly for enumerating fish in low-visibility water. Thus, a combination of acoustic cameras and echosounders could be used to determine if fish associate with the buoys, and if so, to identify the sizes of fish and the frequency and duration of visits. If fish are detected at the buoys, a second step could include conducting additional surveys to determine fish species composition and size using fishing methods such as multimesh gill nets, hook and line, and other capture methods; captured specimens could also provide information on condition and food habits (Pacific Energy Ventures 2012). These methods could be used to evaluate potential negative effects on special-status species, such as to determine whether both special-status species and their predators are associated with the buoys, and if predation on special-status fish is occurring.

There are some limitations to using surrogate structures to evaluate potential fish interactions with commercial installations of WECs or TECs. A study of existing buoys/moorings would increase understanding of potential fish interactions with individual or small numbers of WEC devices; however, scaling up to larger arrays would require evaluating fish interactions after installation of a commercial-scale development. In addition, potential fish interactions as a result of indirect effects, such as from EMF or sound emitted by WECs or TECs, could only be evaluated after devices are deployed and operational.

Section 5.0 References

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