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Current ability to assess impacts of electromagnetic fields associated with marine and hydrokinetic technologies on marine fishes in Hawaii

Reef Manta Ray
Manta alfredi

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1. Executive Summary

Marine and hydrokinetic energy (MHK) and offshore wind devices are being developed and deployed in U.S. and international waters. Electric current flowing through subsea transmission cables associated with these devices will generate electromagnetic fields (EMF), which may interact with, and potentially impact, marine fishes. Some marine fishes can detect electric and/or magnetic fields and use them to navigate, orientate, and sense prey, mates and predators. Over the past five years there have been multiple comprehensive reviews and studies evaluating the potential vulnerability of marine fishes to EMF produced by MHK devices. Most documented effects involve sub-lethal behavioral responses of individual fish when in close proximity to EMF (e.g., fish being repelled by or attracted to fields). These reviews reach conclusions that the current state of research on this topic is still in its infancy and evaluations of potential impacts are associated with great uncertainty. A variety of MHK technologies are likely to be considered for deployment offshore of the Hawaiian Islands, and there is a need to be able to better predict and assess potential associated environmental impacts. The goal of this study was to provide a complementary piece to these previous reviews (e.g., Normandeau et al. 2011) by focusing on marine fish species in the Hawaii region. We compiled the relevant available information, then prioritized fish species as candidates for various paths of future research. To address this, we first developed a list of Hawaii Region Focal Species, which included fishes that are more likely to be sensitive to EMF. We then compiled species-specific information available in the literature on their sensitivity to EMF, as well as life history, movement and habitat use information that could inform an analysis of their likelihood of encountering EMF from subsea cables associated with MHK devices. Studies have only documented EMF sensitivity in 11 of the marine fish species in this region. There was also relatively little detailed information on fish movement and habitat use patterns for most of the focal species. Our last objective was to develop recommendations for research needs to close the important knowledge gaps. We describe species-independent baseline research that primarily consists of *in situ* quantification of EMF generated by MHK devices and undersea cables that can occur as pilot and commercial scale MHK devices are deployed in Hawaii. Then we propose a simple approach for prioritizing Hawaii Region Focal Species (ranked relative to each other) as candidates in multiple related research paths. The prioritization approach incorporates EMF sensitivity information with the likelihood of interacting with EMF generated undersea transmission cables associated with MHK devices. Finally, we discuss the types of research needed to help fill gaps in the scientific knowledge base for this region. These involve studies to better define species-specific EMF sensitivity thresholds under various environmental conditions, studies of life history, movement and habitat use patterns to improve our understanding of the likelihood and frequency fishes may be in the vicinity of EMF generated by subsea transmission cables, and studies of the potential for related population, community or ecosystem impacts. Many of these studies can and should occur opportunistically as pilot and commercial scale MHK devices are deployed in Hawaii.

2. Study Objectives

Marine and hydrokinetic energy (MKH) and offshore wind devices are being developed and deployed in U.S. and international waters. These can include wind turbines, wave energy converters, tidal turbines, ocean current turbines and ocean thermal energy converters. Electric current flowing through subsea transmission cables associated with these devices will generate electromagnetic fields (EMF). Some marine fishes can detect electric and/or magnetic fields and use them to navigate, orientate, and sense prey, mates and predators. These fields occur naturally in the marine environment, generated from physical and biological sources. Cables transmitting electricity will produce both magnetic and electric fields, the strength of which depend on both the voltage and current. However, subsea transmission cables typically contain conductive sheathing that blocks the direct electric fields from the external environment. They will however still produce magnetic fields that could be detected by sensitive species. Additionally, induced electric fields are also produced when seawater or an organism moves through these magnetic fields. Both of these field types may interact with marine fishes when they are within meters to tens of meters of the cables and potentially could impact fish populations, communities and biological processes (Normandeau et al. 2011; Gill et al. 2014). However, most documented effects to date involve sub-lethal behavioral responses of individual fish in close proximity to EMF (e.g., fish being repelled by or attracted to EMF). It is possible that the environmental effects of a single MHK device may not be measurable, however larger commercial scale arrays could have more substantial cumulative impacts, and great uncertainty currently exists around predicting impacts (Previsic 2010; Polagye et al. 2011; Shumchenia et al. 2012). There is a need to reduce uncertainty regarding these potential impacts as MHK developments are being planned and then assessed after deployment (Boehlert and Gill 2010; Normandeau et al. 2011; Polagye et al. 2011; Gill et al. 2014).

Normandeau et al. (2011) is a previous study funded by the Bureau of Ocean Energy Management (BOEM) that included a comprehensive literature review of available information up through 2009 on electro- and magnetosensitivity of marine organisms worldwide. They also modeled the EMF strengths generated by subsea transmission cables that are associated with MHK developments. Their project focused on compiling information on fishes and other marine vertebrates found in the contiguous United States and Alaska in an effort to assist with planning and evaluation of MHK developments in US waters.

Our project compliments Normandeau et al. (2011), by first compiling more recently published information on EMF sensitivity in marine fishes worldwide and other environmental impacts of deployment of MHK devices and associated subsea transmission cables. Then we also make a more in-depth assessment of the information currently available to assess potential impacts of EMF on marine fishes that occur in the Hawaii region (as defined by Mundy 2005 to include the 200 mile exclusive economic zone surrounding the State of Hawaii and Johnston Atoll). Finally we make suggestions for future research paths and prioritize Hawaii fish species within them. A variety of offshore renewable energy generation projects are likely to be considered for deployment offshore of the Hawaiian Islands. Due to the steep nature of the bathymetry surrounding these islands, resulting from their volcanic origin, depths of hundreds of meters are possible relatively close to shore. This could result in MHK and offshore wind devices, and associated subsea transmission cables, in Hawaii being deployed in deeper water than has been done elsewhere.

There were three primary objectives for our study:

1. Literature Search and Information Gathering (Task 1)
This objective includes three parts. First, narrow the over one-thousand marine fish species that occur in the Hawaii Region (Mundy 2005) to a Hawaii Region Focal Species List that includes species more likely to be sensitive to EMF. Second, conduct a literature search to compile recently published information on EMF sensitivity of marine fishes occurring worldwide and potential impacts of MHK and offshore wind technologies in the marine environment. This information will be incorporated into DOE's Tethys knowledge management system. This search covered the period from 2010 to March 2015, searching for information that was published after a previous comprehensive literature review had been conducted on this subject (Normandeau et al. 2011). Third, conduct a literature search to compile information specific to the Hawaii Region Focal Species related to their sensitivity to EMF, as well as life history, movement and habitat use information that could inform an analysis of their likelihood of encountering EMF from subsea cables associated with MHK and offshore wind devices.

2. Literature Review and Assessment (Task 2 and 3)
The second objective was to assess the current ability to evaluate potential "effects" and "impacts" (as defined in Boehlert and Gill 2010; see section 4.1 in this report for more detail) of EMF generated by subsea transmission cables associated with MHK developments on marine fishes in the Hawaii Region based on the available published information. This included compiling a matrix of EMF sensitivity metrics, and life history, movement and habitat use information for the Hawaii Region Focal Species. Finally, we developed a Potential Interaction Index as a way to rank the Hawaii Region Focal Species (relative to each other) based on their potential for interacting with EMF generated undersea transmission cables associated with MHK and offshore wind devices.

3. Recommendations for Future Research (Task 4)
The final objective was to develop recommendations for research needs to close important knowledge gaps regarding the potential interaction of fishes and MHK technologies in the Hawaii Region. This included developing and applying an approach to prioritize the Hawaii Region Focal Species as candidates for, and within, multiple paths of related research.

3. Literature Search and Information Gathering (Task 1)

3.1. Identification of Hawaii Region Focal Species

Given the roughly 1150 marine fishes in Hawaii Region (Mundy 2005), an initial objective of this project was to narrow these to a Hawaii Region Focal Species List that included species more likely to be sensitive to EMF. The species on this list were then used to guide the species-specific literature review portion of the project. Given that the research on marine fish sensitivity to electric and magnetic fields has been primarily focused on relatively few species, for most taxa potential sensitivity must be inferred based on data available for related species

(Normandeau et al. 2011; Gill et al. 2014). Therefore, we used the following guidelines to develop our Hawaii Region Focal Species List:
(1) The list included all Elasmobranchs that occur in the Hawaii Region. Fishes in this group all have the anatomical structures ‘ampullae of Lorenzini’ and therefore their ability to detect electric fields is thought to be virtually universal (Normandeau et al. 2011; Gill et al. 2014). Elasmobranchs are potentially the most vulnerability due to their acute sensitivity, their extensive use of EMFs and the threatened population status of many species due to their unique life history characteristics (Gill et al. 2014). To identify what elasmobranch species occur in Hawaii we included any on either the ‘Checklist of the Fishes of the Hawaiian Archipelago’ by Bruce C. Mundy (2005) or a recent Hawaii Elasmobranch Species List that was compiled by Dave Ebert (June 2014) for a IUCN Shark Specialist Group Workshop.
(2) The list also included marine non-elasmobranch fishes that occur in Hawaii (based on Mundy 2005) in which direct evidence of sensitivity to electric or magnetic fields has been reported. Species-specific sensitivity information was drawn from Appendix Table C-5 in Normandeau et al. (2011) and from any additional sensitive species identified in our recent literature review.
(3) Finally, the list included species that occur in Hawaii (based on Mundy 2005) that are in the same family as fishes for which direct evidence of EMF sensitivity has been reported.

3.2. Literature Search Methods

3.2.1. Recent Literature

Normandeau et al. (2011), a previous study funded by BOEM (then known as Bureau of Ocean Energy Management, Regulation and Enforcement), reviewed all available information up through 2009 on electro- and magnetosensitivity of marine organisms to evaluate the potential effects of their exposure to subsea power cable EMF. Our general literature search continued from there, focusing on relevant literature published worldwide from 2010 to the present (March 2015). Topics included electro- and magneto-sensitivity of elasmobranchs and marine teleost (bony) fishes, EMF emissions from existing and proposed offshore energy projects, ecological impacts related to offshore energy structures, and fisheries impacts related to offshore energy structures. Literature was identified primarily using online literature search tools, but in a few cases literature was received directly from professionals in the field. Online search tools used included Google Scholar, Web of Science (ISI Science Citation Index), WorldCat and Google Books. In-house libraries from the Vantuna Research Group were also utilized. Key search terms and phrases were used to conduct searches. All fields (e.g., title, abstract) were searched using the following terms and phrases: ‘electromagnetic fields’; ‘EMF’; ‘direct current’; ‘magnetic fields’; ‘electric fields’; ‘electrosensitivity’; ‘magnetosensitivity’; ‘impact’; ‘effect’; ‘offshore renewable energy’; ‘impacts from offshore wind power’; ‘impacts from subsea/undersea cables’; ‘impact assessment’; ‘risk assessment’; ‘power lines’; ‘transmission lines’; ‘subsea/undersea cables’; ‘submarine power lines’. In addition, these search terms were re-searched combined with the search words: ‘fishes’; ‘fish’; ‘elasmobranchs’; ‘shark’. Also, papers that cited an original reference of interest were identified using links to these references that are provided within electronic databases. Published, peer-reviewed, English language studies that are indexed in scientific databases were the primary focus of the review. However, government and industry technical reports, as well as a few relevant book chapters, theses and dissertations were also included in the database.

3.2.2. Hawaii Region Focal Species Characteristics

We started with reviewing sources in Normandeau et al. (2011) for information specific to the Hawaii Region Focal Species, however they relied primarily on Fishbase (original sources not provided) or editions of the Compagno Sharks of the World books. Next we included any relevant information from the 'Checklist of the Fishes of the Hawaiian Archipelago' by Bruce C. Mundy (2005). We added the original published sources references to our database and located as many of the full-text copies as possible. Google Scholar was used primarily in our search through the primary literature for data on fish species-specific sensitivity to EMF and life history, movement and habitat use information related to their likelihood of encountering EMF from subsea cables associated with EMF devices. In-house libraries from Occidental College and the Vantuna Research Group were also utilized. Key search terms and phrases were used to conduct searches of databases and the Internet. All fields (title, abstract, etc.) were searched for a term that referenced the exposure of interest and the taxa or area of interest. We first searched for any available species-specific information, using both the common and scientific names, and then used the following terms and phrases to narrow our search: 'migration'; 'seasonal migration'; 'movement'; 'home range'; 'site fidelity'; 'nursery habitat'; 'habitat use'; 'tagging'; 'behavior'; 'reproductive behavior'; 'egg laying'; 'spawning aggregation'; 'aggregation'; 'juvenile'. Also, papers that cited an original reference of interest were identified using links to these references that are provided within electronic databases. Additionally, some species present different movement, migration and habitat use patterns in temperate regions (the focus in Normandeau et al. 2011) than in tropical regions (what we would expect for the Hawaii Region). Therefore, we also searched for species-specific information for the Hawaii Region and then, more generally, tropical waters. If there was no information specific to these geographical regions, we added available information regardless of geographical location. Published, peer-reviewed, English language studies (or those that provided English language abstracts) that are indexed in scientific databases were the primary focus of the review, however, government and industry technical reports, relevant book chapters, theses and dissertations were also included in the database.

3.2.3. Database Methods

Endnote™ reference management software was used to develop and manage the project database. Once references were selected by project team members (based on relevance to the project objectives), bibliographic data for the reference was imported directly to the project database. Standard bibliographic data was collected for each reference (e.g., author, date, title, publisher, volume, pages, reference type). References were then categorized into Endnote™ database groups based on whether they were used within a specific table or the main text of this report.

3.3. Recent Literature Search Results

The search of recent (2010 to March 2015) literature resulted in the identification of 92 references that are included in our Endnote database. These references are separated into categories by subject matter. These categories included: 1) species-specific information on sensitivity to and effects of EMF for elasmobranch and teleost fish found worldwide (section 3.3.1.), 2) existing and proposed offshore energy projects including the design of, or emissions from, subsea cables (section 3.3.2), 3) ecological impacts related to offshore energy structures (section 3.3.3), and 4) fisheries impacts related to offshore energy (section 3.3.4). An additional category called 'Other' (see section 3.3.5 below) included literature that did not fit into one of the above categories, but had relevant information on the search topics. These references included mainly peer-reviewed journal publications and technical reports, however there were also a few categorized into 'other' which included book chapters, conference proceedings, theses and dissertations, etc. (Table 1). An overview of references selected in the recent literature search is provided in the sections below.

3.3.1. Species-Specific EMF Sensitivity and Effects

A total of 33 references published from 2010-present were found that included species-specific information related to the electrosensitivity or magnetosensitivity of elasmobranchs or teleost fishes or species-specific EMF effects (Table 1, 2, Appendix Table A, B). Twenty-two studies quantified new EMF sensitivity levels and detection distances of 14 elasmobranch species and 15 teleost fishes (Appendix Table A). None of these included new information on any of the Hawaii Region Focal Species directly, but there was information found for a few species that share a family with fish species that occur in Hawaii. Additional studies documented species-specific research on broad range of related topics. For example, the bioelectric field intensity produced by a variety of invertebrate and vertebrate elasmobranch prey items was quantified (e.g., Bedore and Kajiura 2013). Kimber et al. (2011) found that catsharks were either unable to discern or showed no preference for artificial and natural electric fields of the same strength, suggesting they might expend energy "hunting" anthropogenic electric fields associated with subsea power cables. A pair of studies show that salmon may use a "magnetic map" utilizing natural magnetic fields to navigate back to natal areas and that these may explain the long-distance underwater migration abilities of many species (Putman et al. 2013; Putman et al. 2014). Other recent studies investigated the use of strong magnetic fields (e.g., permanent magnets, electropositive metals) as deterrents on fishing gear to lower fisheries by-catch or to potentially act as a non-physical barrier for undesired (e.g., invasive) species (e.g., Robbins et al. 2011; Noatch and Suski 2012; O'Connell et al. 2014a; O'Connell et al. 2014b). Finally, multiple studies examined the developmental impacts of EMF on developing fish embryos (e.g., Woodruff et al. 2012; Lee and Yang 2014).

3.3.2. Offshore Energy Structure and Undersea Cable Characteristics

A total of 8 references from the recent literature search covered topics on offshore energy structure design, including measured or predicted characteristics of EMF emitted from subsea cables used in different scenarios or layouts of offshore energy structures (Table 1, Appendix Table F). Some of these were reviews summarizing the current status (and potential impacts of additional development) of offshore energy along coastlines in different parts of the world. Some included evaluations of the potential of certain areas for future offshore energy development.

3.3.3. Ecological Impacts Related to Offshore Energy Structures

A total of 56 references in the database from the recent literature search were included in this broad category (Table 1, Appendix Table F). Papers or reports with any information on actual or potential ecological impacts related to any type offshore energy structure were included here. This includes the broad range of ecological impacts from construction, operations and decommissioning of energy related structures on a wide range of taxa including elasmobranchs, fishes, birds, marine mammals, and invertebrates, as well as habitat impacts. In most cases the coverage of actual or potential impacts of EMF on fishes is only covered briefly with the authors typically citing one of the major reviews on the topic (e.g., Gill et al. 2005; Normandeau et al. 2011; Gill et al. 2012; Gill et al. 2014).

3.3.4. Fisheries Impacts Related to Offshore Energy Structures

A total of 19 references (Table 1, Appendix Table F) in the database from the recent literature search discussed impacts caused by offshore energy technology or construction specifically related to commercial or recreational fisheries. In many cases these included potential artificial reef effects of MHK structures (e.g., Langhamer 2012) or the exclusion of fishers from grounds around MHKs typically due to safety concerns or risk of fishing gear entanglement (e.g., Jongbloed et al. 2014).

3.3.5. 'Other' Category

A total of 34 references (Table 1, Appendix Table F) in the database included additional information that did not fall into any of the other four topics categories and were thus put into an 'other' category. For example, some papers included discussions of stakeholder concerns of MHK developments or challenges in marine governance associated with offshore energy.

Table 1. Number of references from recent literature search (2010 to March 2015) in each topic by reference type.

	Reference Type		
Topic	**Journal article**	**Technical report**	**Other (e.g., Book chapter, thesis, dissertation)**
Species-Specific EMF Sensitivity and Effects	26	4	3
Offshore Energy Structure and Undersea Cable Characteristics	0	2	6
Ecological Impacts Related to Offshore Energy Structures	25	13	18
Fisheries Impacts Related to Offshore Energy Structures	13	2	4
'Other' Category	29	3	2

Table 2. Number of references from recent literature search (2010 to March 2015) for each group of marine organisms by subject.

Marine Taxa	Subject: Species-Specific EMF Sensitivity and Effects	Ecological Impacts Related to Offshore Energy Structures	Fisheries Impacts Related to Offshore Energy Structures
Elasmobranchs	14	13	4
Marine teleost fishes	13	36	10
Freshwater teleost fishes	7	3	0
Invertebrates	2	31	1
Marine mammals or birds	0	22	0

3.4. Hawaii Region Focal Species List Results

We identified 99 Hawaii Region Focal Species for this report (Table 3). This included elasmobranch species identified to occur in the Hawaii Region based on Mundy (2005) and a recent Hawaii Elasmobranch Species List that was compiled by Dave Ebert (June 2014) for an IUCN Shark Specialist Group Workshop. Additionally we also included non-elasmobranch fish species that occur in the region for which direct evidence of sensitivity to electric or magnetic fields has been reported, and fishes that share a family with an EMF sensitive species (See Appendix Table C-5 in Normandeau et al. 2011; Appendix Table E this report).

All Elasmobranchs have the anatomical structures ‘ampullae of Lorenzini’ and therefore their ability to detect electric fields is thought to be virtually universal (Normandeau et al. 2011; Gill et al. 2014). Inclusion of all but one teleost fish on the Hawaii Region Focal Species list was based on species occurring in the Hawaii Region that share a family with a sensitive species that occurs elsewhere in the world. The exception was Yellowfin Tuna, *Thunnus albacares*, which does occur in Hawaii and for which there exists direct evidence it can detect magnetic fields and may have a magnetic sense organ (Walker 1984; Walker et al. 1984). There was no other direct evidence of EMF sensitivity for any other members of the Scombridae family that occur in the Hawaii Region (Appendix Table A). Members of the Scorpaenidae family that occur in the Hawaii Region were included based on direct evidence of magnetosensitivity for a species that occurs elsewhere, the Darkbanded Rockfish, *Sebastes inermis* (Nishi and Kawamura 2006). Finally, a single member of the flatfish family Pleuronectidae that occurs in the Hawaii Region was also included based on limited evidence that the European Plaice, *Pleuronectes platessa*, may be able to orientate using the earth’s magnetic field (Metcalfe et al. 1993). A recent pair of studies has shown that salmon, another teleost fish, may make use of a “magnetic map” by sensing natural magnetic fields to navigate back to natal areas. While this may explain the long-distance underwater migration abilities of many species (Putman et al. 2013; Putman et al. 2014), the importance of magnetic sense in the teleost fish families that are included in the Hawaii Region Focal Species list is not well understood. Further examples of research with teleost fishes that discuss evidence of magnetic field orientation or homing capabilities are reviewed in Normandeau et al. (2011).

Table 3. Summary of the 99 Hawaii Region Focal Species by Family.

Elasmobranchs	Family	Total species
	Rhincodontidae	1
	Odontaspididae	2
	Pseudocarchariidae	1
	Megachasmidae	1
	Alopiidae	3
	Cetorhinidae	1
	Lamnidae	4
	Scyliorhinidae	1
	Pseudotriakidae	1
	Carcharhinidae	12
	Sphyrnidae	3
	Chlamydoselachidae	1
	Hexanchidae	1
	Echinorhinidae	1
	Centrophoridae	2
	Somniosidae	2
	Dalatiidae	3
	Etmopteridae	6
	Torpedinidae	1
	Plesiobatidae	1
	Hexatrygonidae	1
	Dasyatidae	3
	Myliobatidae	5
Teleosts	Scorpaenidae	28
	Scombridae	13
	Pleuronectidae	1

3.4.1. EMF Sensitivity Information Available

Currently we have direct EMF sensitivity information specific to 11 out of 99 Hawaii Region Focal Species. For 10 species there are studies available containing specific evidence of EMF sensitivity. Additionally, there is one study indicating no behavioral response in the Tiger Shark, *Galeocerdo cuvier* (Yano et al. 2000) (Table 4). A total of 31 references in the database document these findings.

Table 4. Hawaii Region Focal Species for which we have found studies on EMF sensitivity.

Subclass	Family	Family Common Name	Genus	Species	Common Name
Elasmobranchii	Carcharhinidae	Requiem sharks	*Carcharhinus*	*falciformis*	Silky Shark
Elasmobranchii	Carcharhinidae	Requiem sharks	*Carcharhinus*	*melanopterus*	Blackfin Reef Shark
Elasmobranchii	Carcharhinidae	Requiem sharks	*Carcharhinus*	*plumbeus*	Sandbar Shark
Elasmobranchii	Carcharhinidae	Requiem sharks	*Prionace*	*glauca*	Blue Shark
Elasmobranchii	Carcharhinidae	Requiem sharks	*Triaenodon*	*obesus*	Whitetip Reef Shark
Elasmobranchii	Sphyrnidae	Hammerhead sharks	*Sphyrna*	*lewini*	Scalloped Hammerhead
Elasmobranchii	Lamnidae	Mackerel sharks	*Carcharodon*	*carcharias*	Great White Shark
Elasmobranchii	Lamnidae	Mackerel sharks	*Isurus*	*oxyrinchus*	Shortfin Mako
Elasmobranchii	Dasyatidae	Stingrays	*Pteroplatytrygon*	*violacea*	Pelagic Stingray
Teleostei	Scombridae	Mackerels	*Thunnus*	*albacares*	Yellowfin Tuna
No behavioral response					
Elasmobranchii	Carcharhinidae	Requiem sharks	*Galeocerdo*	*cuvier*	Tiger Shark

3.4.2. Life History, Movement and Habitat Use Information Available

Currently we have some relevant life history, movement and habitat use information specific for all of the 99 Hawaii Region Focal Species (Appendix Table D, E). However, for the majority of these species the information available that is applicable to the objectives of this study is limited. A total of 228 references in the database document these findings. The references and brief descriptions of the information are recorded in two tables. Appendix Table D contains the specific references and information used in the present study to rank a species' potential (relative to each other) for interacting with EMF generated undersea transmission cables associated with MHK devices. See section 4.5.2. for a description of the Potential Interaction Index (PII). Additional references containing geographic range, depth range and general habitat information, not incorporated into the PII, are recorded in Appendix Table E.

4. Literature Review and Assessment (Task 2, 3)

4.1. Current Ability to Assess Potential Effects and Impacts of EMF on Marine Fishes

Over the past five years there have been multiple comprehensive reviews and studies evaluating the potential vulnerability of marine fishes to EMF produced by MHK technologies (e.g., Boehlert and Gill 2010; Isaacman and Lee 2010; Kramer et al. 2010; Hammar and Gullström 2011; Normandeau et al. 2011; Polagye et al. 2011; Lin and Yu 2012; Gill et al. 2014). Gill et al. (2014) summarizes the current state of research on this topic as "still in its infancy" and "associated with great uncertainty", with the most definitive conclusion at this point being "that there appears to be some response to EMF by EM-sensitive fish." Given this limited state of understanding, they present a framework (originally developed in Boehlert and Gill 2010) for considering the potential effects and impacts of marine renewable energy projects on various elements of marine ecosystems (Figure 1). They make a clear and important semantic distinction between "effects" and "impacts." In the context of the present study an effect would include a behavioral or physiological response of a fish (i.e., the "receptor") to EMF (i.e., the "stressor").

Effects however do not indicate the magnitude, direction or significance of the response on the stressor. Therefore, demonstrating evidence of an impact involves documenting whether an effect on individual receptors (in this case individual fish) result in a positive or negative outcome on the population, community or a biological process (e.g., trophic relationships) that the receptor is a component of. Currently researchers have documented effects of EMF on a limited number of fishes under a limited number of conditions, but there are no data available that could be applied to evaluate the potential for impacts of EMF on marine fishes (Boehlert and Gill 2010; Gill et al. 2014). They suggest future research needs to focus on moving from documenting effects to describing impacts to better understand the consequences of EMF associated with MHK projects on the marine environment.

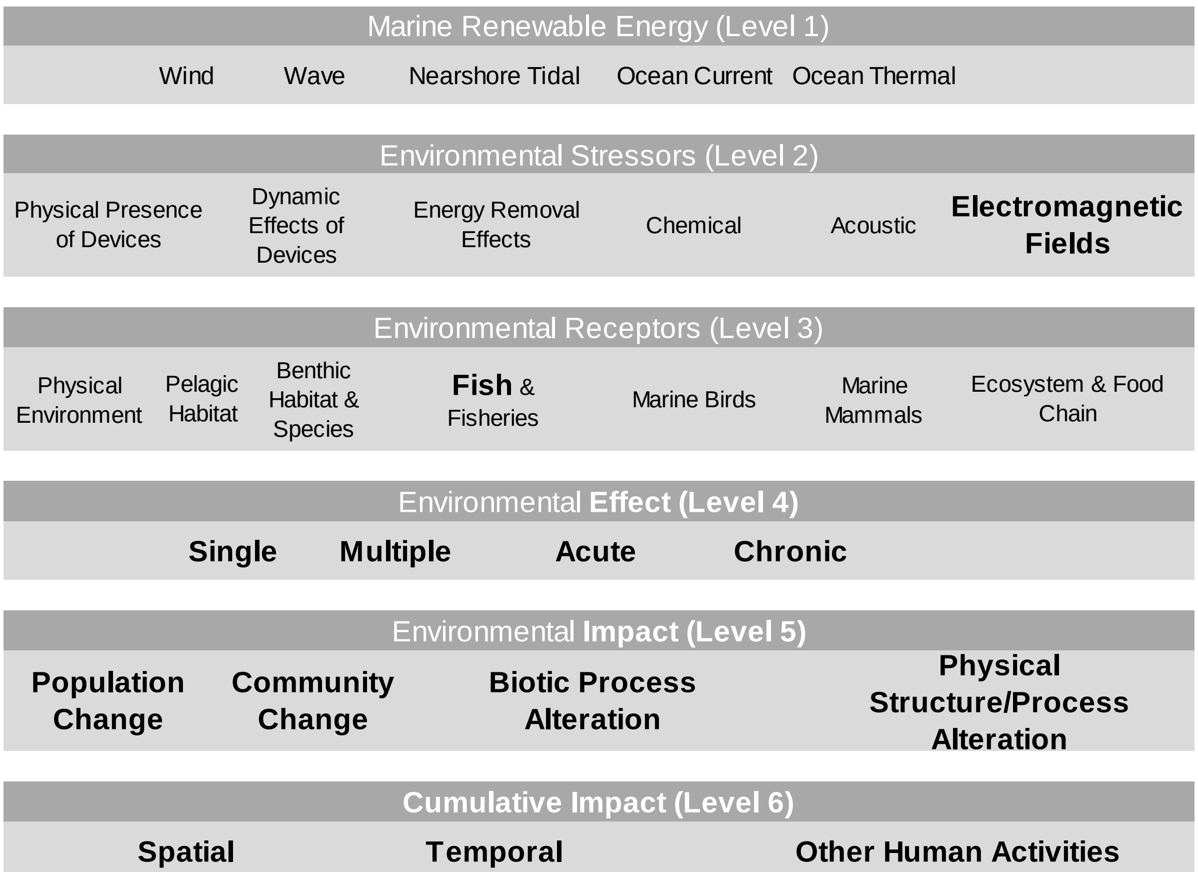

Figure 1. An overall framework proposed by Boehlert and Gill (2010) for assessing environmental impacts of Marine Renewable Energy (including MHK) developments. The figure here is reproduced after Figure 1 in Boehlert and Gill (2010). MHK devices and developments will have specific associated stressors that affect specific receptors depending on the technology, the geography and the local environmental context of the project. Here we highlight (bold text) the Stressor (Electromagnetic Fields) and the Receptors (Fish) that are the focus of the present study. Boehlert and Gill (2010) make a clear distinction between "Effects" (Level 4) and "Impacts" (Level 5 and 6). In the context of the present study an effect would include a behavioral or physiological response of a fish to EMF. Therefore, demonstrating evidence of an impact (Level 5) involves documenting whether an effect on individual receptors (fish) result in a positive or negative outcome on the population, community or a biological process (e.g., trophic relationships) that the receptor is a component of (Boehlert and Gill 2010; Gill et al. 2014). Multiple Level 5 impacts (over space and/or time), potentially including impacts from other non-MHK related activities (e.g., fishing), may also combine to result in Level 6 cumulative impacts.

With only 11 out of the 99 identified Hawaii Region Focal Species having species-specific (i.e., direct) behavioral or physiological evidence of EMF sensitivity, the evidence base, even at Level 4 (EMF effect, response), from which to evaluate the potential impacts of MHK projects on fishes in the Hawaii Region is very limited. A 2010 report that reviewed environmental concerns related to a potential wave energy project in Hawaii identified bottomfishes, scombrids and elasmobranchs as fishes that could serve as indicator species for EMF impacts, a general suite of species that encompass those on our Hawaii Region Focal Species list. However, beyond stating that EMF could result in general behavioral or physiological effects, they classified the specific effect types and overall risk level both as unknown based on the current available information (Kramer et al. 2010). Research published since 2010 has provided little to change these conclusions. Further, while general characteristics of EMF emitted by subsea cables have been modeled under various conditions (Normandeau et al. 2011), predicting specific thresholds where effects, let alone impacts, will occur is highly uncertain because (1) EMF generated will depend on the MHK device and associated transmission cable specifications, as well as the physical environment of the site, and (2) potential effects will vary across species due to (largely undefined) species-specific EMF sensitivity thresholds, as well as site-specific ecosystem characteristics (Boehlert and Gill 2010; Normandeau et al. 2011; Gill et al. 2014). In a case study of potential EMF impacts on the sandbar shark, Normandeau et al. (2011) conclude that while evidence exists that would suggest "sensory thresholds that overlap with expected EMF levels from subsea power cables, the information necessary to understand the nature of any response and resulting consequences to individuals or populations of sandbar shark is lacking." They continue "any potential effects (*and impacts, as defined in Boehlert and Gill 2010*) would depend upon project and site-specific factors related to both the level of EMF and the ecology of shark populations in proximity to the cable."

Given the lack of information available to predict potential effects, let alone impacts, of EMF from subsea power cables on fishes, and more specifically the paucity of this type of information available for the Hawaii Region Focal Species, we propose an approach to prioritize fish species in Hawaii as good candidates for various paths of future research and provide sources for related background information for each species. Below we first briefly summarize the current knowledge on EMF generation from subsea transmission cables associated with MHK devices, characteristics of potential MHK projects in the Hawaii Region, and research documenting sensitivities and effects of EMF on marine fishes. Readers should also refer to more comprehensive recent reviews on these subjects (e.g., Boehlert and Gill 2010; Normandeau et al. 2011; Gill et al. 2014). We then summarize the available information in the literature on EMF Sensitivity for Hawaii Region Focal Species and propose a Potential Interaction Index (PII) that incorporates species-specific life history movement, and habitat use information available in the literature to rank a species' potential for interacting with EMF generated by subsea transmission cables associated with MHK devices. The species-specific EMF sensitivity information and the PII are then used together to rank the Hawaii Region Focal Species (relative to each other) as potential candidates within multiple paths of future research.

4.2. EMF Generation by Undersea Cables

Both natural and anthropogenic EMF generation has been reviewed in detail elsewhere (for a detailed background and review of the current state of knowledge globally see Normandeau et al. 2011; Gill et al. 2014). The primary sources of anthropogenic EMF associated with MHK developments are emitted by the cables which transmit power between individual MHK devices, between devices and a seafloor substation, and those linking offshore power generating developments and mainland power grids. Cable networks have typically consisted of all alternating current (AC) cables. However, larger networks will also likely feature lower voltage AC cables to connect individual MHK devices, with additional DC cables used for the transmission lines spanning longer distances to connect MHK facilities located further offshore with the mainland power grid (Previsic 2010; Normandeau et al. 2011; Gill et al. 2014). Cables transmitting electricity will produce both magnetic and electric fields, the strength of which depend on both the voltage and current. However, subsea power cables contain conductive sheathing that blocks the direct electric fields from the external environment and therefore they are not considered here. We can consider the magnetic fields generated by AC and DC cables, and the induced electric fields that occur when seawater or an organism moves through the magnetic fields. Additionally, while the metallic structure of the MHK devices will also produce EMF, similar to those produced by other metallic objects and associated systems in the marine environment (e.g., metal vessels, anti-corrosion systems, metallic objects associated with ports, marina and shorelines) (Gill et al. 2014), these types of EMF are not considered in the present study.

Normandeau et al. (2011) reviewed the expected EMF levels from various types of subsea cable systems and then produced models of the predicted magnetic field intensity and spatial extent from existing and proposed cable systems. Cables are often buried to protect them against physical damage and therefore their models assumed cables were buried 1 m below the seafloor. Magnetic fields diminish with distance and therefore burial also reduces the exposure of fishes at or above the seafloor to EMF. Based on their models, average AC magnetic field values were highest at the seafloor directly above the buried cable at 7.85 μT and then decreasing with distance to 0.13 μT at 10 m above the seafloor. The average modeled magnetic fields produced by DC cables were stronger than those produced by AC cables at all distances they compared. Average DC magnetic field values ranged from 78.27 μT at the seafloor to 0.83 μT at 10 m above the seafloor. Normandeau et al. (2011) also suggests that magnetosensitive organisms are likely equipped to detect these low intensity (<0.01 μT) DC magnetic fields. However, how or if this detection would interfere with navigation or orientation is currently unknown.

Normandeau et al. (2011) also modeled induced electric fields. The expected induced electric field produced by a 5 knot (2.57 m/sec) ocean current flowing over a DC cable buried 1 m below the seafloor ranged from 1.94E-04 V/m at the seafloor directly above the cable to 8.80E-06 V/m 10 m above the seafloor. They also modeled the induced electric field strength in a small shark (150 cm long and 60 cm high) swimming above and parallel to a buried AC cable which yielded a field strength of 7.65E-04 V/m when swimming at the seafloor directly above the cable, and this decreased to 1.24E-05 V/m at 10 m above the seafloor. Ultimately, the strength of the induced field will be influenced by a variety of factors including the speed and orientation of the current or the organism relative to the field.

It is important to note however that these calculated field strengths can just provide a rough estimate of the fields that organisms may experience in the vicinity of subsea cables. The intensity of the fields produced will vary depending on the cable design, current level and other factors like the burial depth. And the field an organism experiences will change as it moves towards or away from the cable (Normandeau et al. 2011). It has been demonstrated that at least one species of elasmobranch (Small-spotted Catshark, *Scyliorhinus canicula,*) can distinguish between magnetic fields produced by AC and DC (Kimber et al. 2011). Additionally, other authors (Gill et al. 2014) highlight that due to differences in the EMF generated by AC and DC cables, it should not be assumed that effects on marine organisms will be similar. However, given the lack of data available about differences in the behavioral responses (Level 4, effects) to each type of field, the most comprehensive recent review available does not distinguish between the two types of cables when evaluating potential effects on marine fishes (Gill et al. 2014).

The overall scale of an MHK development (e.g., footprint, number and characteristics of MHK devices and cables) is an important consideration for any evaluation of the potential for EMF effects (Level 4) to translate into impacts (Level 5 & 6) (Boehlert and Gill 2010; Shumchenia et al. 2012; Gill et al. 2014). It is possible that while the environmental effects of a single MHK device may not be measurable, larger commercial scale arrays may have significant cumulative impacts (Previsic 2010; Polagye et al. 2011; Shumchenia et al. 2012). Research has primarily focused on evaluating the effects of a single transmission cable, with limited data on the EMF generated by large-scale arrays of devices and cables. Multiple transmission cables located close to each other may have an additive effect resulting in higher EMF being generated, therefore it is critical that this be considered when commercial scale projects are being designed and evaluated (Isaacman and Lee 2010; Normandeau et al. 2011; Gill et al. 2014).

4.3. Potential and Operational Hawaii MHK Project Characteristics

A variety of MHK projects may be considered in the Hawaii Region or are currently operational. Due to the steep nature of the bathymetry surrounding the Hawaiian Islands, resulting from their volcanic origin, depths of hundreds of meters are possible relatively close to shore. This could result in MHK devices and associated subsea transmission cables being deployed in Hawaii in deeper water than has been done elsewhere. A review of the seafloor depth range of offshore wind energy projects in Europe found that all operating or under construction developments were located in 40 m or less water depth. However, new technologies (e.g. large floating offshore wind turbines) are being developed and tested in water depths up to 300 m, and eventually may be deployed up to 700 m depth (Bailey et al. 2014). Scenarios for MHK projects in Hawaii could include (Donna Schroeder, U.S. BOEM, pers. comm.):
(1) A MHK pilot scale test facility (currently operational) near Kaneohe Bay, Oahu. Some types of MHK technologies can be tested here. It is a floating facility, tethered to the seafloor and placed in water less than 200 m depth, with relatively lower voltage rated AC transmission cables.
(2) A commercial scale array of MHK devices including multiple wind turbines, or multiple wave energy converters, or both technologies integrated within an array. These facilities would likely be tethered to the seafloor and floating in waters of less than 500 m depth.

(3) Interisland DC transmission cables, capable of very high transmission loads, running along or buried just under the seafloor connecting the power grids between two or more islands. While these may be associated with MHK projects or traditional power generating facilities located on land, in either case they would present an opportunity to study potential EMF effects and impacts in the marine environment that could be used to inform future MHK developments.

A 2010 report funded by the United States Department of Energy provided characteristics of wave energy conversion project scenarios using a reference site in Hawaii located on a north-east facing coast on Oahu Island near Makapu'u Point, Waimanalo bay and Kailua bay. The device technologies examined would involve EMF generating subsea cables and the report identified and characterized environmental and EMF effects (Previsic 2010). The reference site was located in an area approximately 3-5 km offshore, with a likely deployment seafloor depth of around 50 m. Evaluated scenarios included a range of project scales and technologies from one device, for a pilot scale project, to multiple devices, for a commercial scale project. The footprint of the devices may range from as small as 0.2 km by 0.2 km for single device pilot project to 4.8 km by 0.5 km for a large commercial project scale array of devices. For large commercial scale projects, the number of devices and the overall project footprint would highly depend on the device technology used. Individual devices would be connected with lower-voltage (below 40kV AC) cables to a seafloor substation. The substation would then be connected to the onshore power grid by a single, potentially higher-voltage (AC or DC), transmission cable largely running perpendicular to shore. Further details on specifics of the various individual technologies evaluated can be found in Previsic (2010).

Another 2010 report funded by the United States Department of Energy (Kramer et al. 2010) reviewed environmental concerns related to a small commercial scale wave energy project, one of the potential MHK wave energy projects evaluated in Previsic (2010). They identified bottomfishes, scombrids and elasmobranchs as fishes that could serve as indicator species for EMF impacts, a general suite of species that encompasses almost all of those on our Hawaii Region Focal Species list. There are no federally threatened or endangered fish species in the project area, and the project is located in a bottomfish restricted fishing area (Hawaii Division of Aquatic Resources undated). However, beyond stating that EMF could result in "disorientation or behavioral changes", they classified the specific effect types and overall risk level both as "unknown" based on the current available information. They also suggest that uncertainty warrants further study since the "literature has not reached consensus."

4.4. Summary of EMF Sensitivity and Effects in Marine Fishes

Normandeau et al. (2011) and Gill et al. (2014) provide reviews of the current understanding of EMF sensitivity in marine fishes and associated effects of EMF that would be generated by subsea electrical transmission cables on marine fishes. Here we briefly summarize their findings along with those from other recent published literature (cited throughout), to provide additional context from which to consider potential effects and impacts on Hawaii Region Focal Species.

Due to the presence of the anatomical structures 'ampullae of Lorenzini' in elasmobranchs, it is thought that they have a virtually universal ability to detect electric fields. They have been shown to be both repelled by and attracted to stronger and weaker (respectively) anthropogenic electric fields. A limited number of studies suggest avoidance may occur when encountering field strengths of ~400 to 1,000 μV/m, but avoidance thresholds are likely species-specific. EMF from subsea cables could serve as an impediment to migration or movement for fishes moving near the seafloor (Gill et al. 2012; Noatch and Suski 2012). However, due to the decrease in field strength with distance, fishes that are able to move up off the seafloor could move past the cables, but there is currently no evidence of fish doing so (Normandeau et al. 2011; Gill et al. 2014). Elasmobranchs use electroreception to detect prey, predators and mates. Median sensitivity in various elasmobranchs has been documented at 5-48 nV/cm with maximum detection distances of 22-44 cm (reviewed in Bedore and Kajiura 2013). Kimber et al. (2011) found that catsharks were either unable to discern or showed no preference for artificial and natural electric fields of the same strength, suggesting they might expend energy "hunting" anthropogenic electric fields associated with undersea power cables. Therefore it has been hypothesized that EMF emitted by subsea transmission cables could disrupt migrations, movements, avoidance of predators, and prey and mate locating capabilities. While most teleost fishes are generally assumed to not be electrosensitive, some species including sturgeon and the European eel have shown behavioral responses to electric fields, but multiple authors have concluded that EMF from undersea cables would have minimal and temporary effects on them (e.g., Kropp 2013).

There is evidence that some teleost fishes have magnetic receptors and orientate to natural magnetic fields, while elasmobranchs may be able to detect magnetic fields by induction of electric fields. Based on field strengths modeled in Normandeau et al. (2011), a magnetosensitive fish may still be able to detect a magnetic field generated by a DC cable at a distance of 20 m. Induced electric fields from this cable could be still be within the sensory range of an electro-sensitive fish a distance of 10 m from the cable. Detection distances will also be dependent on factors such as cable burial depth and the cable's orientation relative to the earth's magnetic field. It is not currently clear if magnetic fields generated by undersea cables would impact a fish's navigational capabilities, but Normandeau et al. (2011) does describe effects (short term deviations from migrations routes) documented in multiple studies.

Finally, a limited number of studies have documented physiological and developmental effects after exposure to EMF (see Gill et al. 2014 for further detail). For example, one study found evidence that exposure to strong magnetic fields caused suppressed melatonin levels in salmon (Woodruff et al. 2012). Another study documented developmental changes in EMF exposed teleost fish embryos, which lead to subsequent behavioral differences in the fish four days after hatching (Lee and Yang 2014). The implications of these results are still uncertain.

4.5. Information Specific to the Hawaii Region Focal Species

4.5.1. Direct Evidence of EMF Sensitivity

Six of the 99 Hawaii Region Focal Species have at least some direct evidence for magnetosensitivity (5 shark species and Yellowfin Tuna) (Appendix Table C). The sensitivity range for all of these species would overlap with the average expected magnetic field strength generated from DC cables and some values modeled for specific AC cable designs (see Normandeau et al. 2011 for specifics). However, it is difficult to draw conclusions based on the current literature because the studies for many of these species did not include estimation of a minimum sensory threshold and there is a high degree of uncertainty associated with predictions of the magnetic field strengths actual cables will generate (Normandeau et al. 2011; Gill et al. 2014). Eight Hawaii Region Focal Species had at least some direct evidence for electrosensitivity (7 shark species and the pelagic stingray), with studies on only 5 of those species including specific electric field strength sensitivity values (Appendix Table C). However, there currently is not sufficient data to define field strength thresholds at which the induced electric fields from undersea cables may either attract electrosensitive species at lower field strengths, or act as barriers to movement (e.g. between feeding, mating and nursery areas) at higher field strengths. Based on the measured or modeled fields generated in close proximity to both AC and DC cables, either of these behavioral effects are possible (Normandeau et al. 2011; Gill et al. 2014).

4.5.2. Potential Interaction Index (PII)

Here we propose a Potential Interaction Index (PII), which provides a simple scoring system that we then used in ranking Hawaii Region Focal Species (relative to each other) as potential candidates within multiple paths of future research. The PII incorporates species-specific life history, movement and habitat use information available in the literature to rank a species' potential for interacting with EMF generated undersea transmission cables associated with MHK devices. The method is based on an approach described in Astles et al. (2009). Their goal was to develop an index that could be used to assess fish species population vulnerability to overfishing. Following a simplified version of their approach we developed a matrix including our Hawaii Region Focal Species in rows and three columns of scored behavioral, movement and habitat use related characteristics based on information available in the literature. Cells within columns are each scored based on column specific categories. Cell scores for different columns ranged from 0 to 1, 0 to 2, or 1 to 3 depending on the number of categories within a column. Lower values are assigned to categories with lower likelihood of encountering EMF associated with MHK developments and transmission cables. Scores are then summed across species (rows) to yield a total PII score. This score is then used (along with information on EMF sensitivity) to rank each species and prioritize them within multiple paths of needed research.

Additional life history, habitat use and geographic range information was gathered during our literature review, but ultimately not deemed relevant or sufficient for inclusion in the PII. It is also reported here in a different table (Appendix Table E) as it may be valuable for managers and researchers to provide additional context when evaluating potential for interaction with EMF associated with specific MHK projects and/or designing future studies.

4.5.2.1. Scored Table Columns and Categories

Here we provide a description of each column included in the PII (Appendix Table D) and the rational for its categorization and scoring.

Behavioral Habitat Type

Species were categorized into one of four behavioral habitat types (BHT) based on the definitions provided in Mundy (2005). These describe a fish's behavior related to habitat space use, rather than specific physical attributes (e.g., benthic substrates) of a preferred habitat.

- **pelagic** (living entirely in open water) (score: 1)
- **benthopelagic** (living primarily in the water column but at times in sensory proximity to substrates) (score: 2)
- **demersal/engybenthic** (living primarily at, but not resting upon, substrates) (score: 3)
- **benthic** (living primarily in contact with substrates) (score: 3)

In cases when the exact categorization terminology was not present in a reference, we made the categorization based on best professional judgment using the information available and these cases are indicated within the Appendix Table D by an "*".

Fishes that reside, feed or move along the seafloor are more likely to interact with EMF generated by MHK power transmission cables which are often buried ~1 m below the seafloor (Gill et al. 2014). Kimber et al. (2011) found that catsharks were either unable to discern or showed no preference for artificial and natural electric fields of the same strength, suggesting they might expend energy "hunting" anthropogenic electric fields associated with undersea power cables. These EMF may also pose an impediment to migration or movement (Gill et al. 2012; Noatch and Suski 2012). Species that live primary in open water or up in the water column will be less likely to interact with these EMF and therefore these categories (pelagic, benthopelagic) received a score of 1 or 2. There is currently no evidence to suggest that species will swim up into the water column to avoid these fields which may extend a few meters or more above the seafloor at relatively high intensities (Normandeau et al. 2011; Gill et al. 2014). Because it is not clear whether they may pose a greater risk for benthic species (e.g., stingrays), as compared to demersal/engybenthic (e.g., Whitetip Reef Shark) species, these categories were both scored the highest value (3).

Movement Pattern

Species that exhibit site fidelity (i.e., remaining in or returning to the same location) are more likely to have repeated and/or prolonged EMF exposures to MHK structures or cables. Here species with evidence of site fidelity were given a score of 1.

- **none identified** (no evidence of site fidelity present in the literature) (score: 0)
- **site fidelity** (some evidence of site fidelity present in the literature) (score: 1)

The limited amount of detailed information available in the literature for most species precluded us from further differentiating levels of site fidelity for categorization and scoring purposes. For most Hawaii Region Focal Species detailed movement pattern information is not available. Therefore, this broad category included species with small home ranges for a specific life stage and those for which there was just some evidence of seasonal/annual fidelity to certain locations.

It was common for a study to report evidence of site fidelity (e.g., repeated observation of a tagged individual at one location), but typically the spatial scale of the home range, nor the reason for returning to or remaining at a site (for example, annual spawning aggregation behavior) was not provided. Best professional judgment was used to evaluate whether the level of evidence in the reference warranted a 1 score. A brief description of the level of site fidelity or movement pattern is provided within the table along with the reference. We also report additional information related to fish movement patterns found during the literature review (not directly indicating or relating to site fidelity) as it may be of interest to researchers or managers.

Vulnerable Habitat Use

Some habitat use patterns, particularly those associated with more vulnerable life stages (e.g., juvenile nursery habitat use) or behaviors (e.g., adult spawning, mating, egg depositing, birthing) could increase the likelihood of EMF effects (behavioral responses) translating into population impacts. Here species with evidence of vulnerable habitat use patterns were given a score of 1.

- **none identified** (no evidence of vulnerable habitat use pattern present in the literature) (score: 0)
- **vulnerable habitat use** (evidence of vulnerable habitat use pattern present in the literature) (score: 1)

Similar to the Movement Pattern column, the limited amount of detailed information available in the literature for most species precluded us from further differentiating habitat use patterns for categorization and scoring purposes. For most Hawaii Region Focal Species detailed these types of habitat use information is not available. For the species it was available for, it included identification of juvenile nursery habitats (typically shallow bays). For sharks this may also involve the females migrating to these areas to give birth. Both cases would result in the potential opportunities for EMF effects (behavioral responses) to result in the disruption of a critical behavior (e.g., juvenile feeding, adult migration to pupping grounds). For example, Scalloped hammerhead (*Sphyrna lewini*) use bays and estuaries in Hawaii as juvenile nursery grounds for around the first 4 months to a year after being born (Clarke 1972; Duncan and Holland 2006) and this could increase the frequency of interactions with EMF associated with transmission cables (Normandeau et al. 2011) at life stage where they may be particularly vulnerable to predation or having benthic feeding behaviors being disrupted. A brief description of the habitat use pattern is provided within the table along with the reference. We also report additional information related to fish habitat use patterns found during the literature review (that may not be considered "vulnerable") as it may be of interest to researchers or managers.

4.5.2.2. Additional Habitat Use, Geographic and Depth Range Information

Our literature review also was used to populate four additional columns (Appendix Table D) of general species-specific information that were not scored as part of the PII.

General Habitat

Any additional habitat descriptions (e.g., near shelf breaks, reef associated, prefer sand bottom) obtained in the literature review were reported in this column. It was not scored because we assume the most relevant habitat use information was already accounted for in the scores associated with the Behavioral Habitat Type and Vulnerable Habitat Use columns. Further, in many cases these descriptions were vague and inconsistent making further classification and scoring unfeasible.

Global Geographic Range

The species global geographic distribution was included where available. While species that only occur in Hawaii (endemics) may be more vulnerable at the population to species level impacts (Following Astles et al. 2009), this does not provide additional information with respect to their potential for interacting with MHK associate EMF at the local scale of a particular MHK project. However, it is still useful background information gathered during literature review.

Hawaii Region Geographic Range

Further details were reported about the species' distribution within the Hawaii Region. While MHK projects are likely to only occur in the Main Hawaiian Islands (and thus might suggest excluding those that have only been observed in the Northwest Hawaiian Islands and/or Johnston Atoll), most of the species not observed in the Main Hawaiian Islands were pelagic or deep-water species that have rarely been observed in the entire region. Therefore, it is possible they may occur in the Main Hawaiian Islands and could be observed there with further sampling.

Depth Range (m)

Here we reported the depth range for each species in the literature. Due to the possibility that MHK devices and transmission cables (from both devices to shore and spanning between islands across the seafloor) could occur across all ocean depths in this region, this column was not scored. A review of the seafloor depth range of offshore wind energy projects in Europe found that all operating or under construction developments were located in 40 m or less water depth (Bailey et al. 2014) and one report describing a potential MHK project in Hawaii listed the likely deployment water depth of around 50 m (Previsic 2010). These projects would likely involve buried transmission cables connecting the devices to the mainland power grid. However, new technologies (e.g. large floating offshore wind turbines) are being developed and tested in water depths up to 300 m, and eventually may be deployed up to 700 m depth (Bailey et al. 2014). Further, due to the steep nature of the bathymetry surrounding the Hawaiian Islands resulting from their volcanic origin, depths of hundreds of meters are possible relatively close to shore providing further potential for MHK projects in deep water.

4.5.2.3. Hawaii Region Focal Species PII Score Results

The PII scores (row totals) for the Hawaii Region Focal Species fell into three ranking groups (ranked relative to each other) (Figure 2): Low (total score: 1-2), Medium (total score: 3), High (total score: 4-5). Species in the Low group included pelagic or benthopelagic sharks and rays, and all of the pelagic teleost fish (e.g., mackerel, tuna), with almost all having no other Movement Pattern or Vulnerable Habitat Use information identified (Appendix Table D). Fishes in the Medium group included sharks and pelagic or benthopelagic rays, and all of the benthic teleost fish. The benthic teleost fish are primarily scorpionfish, with one lionfish species and one flatfish. It is important to note that some species are currently in these Medium and Low categories because there is very limited life history, movement and habitat use information available in the literature for them. For example all of the scorpionfish species had a Behavioral Habitat Type of classification as benthic (score 3) with no other Movement Pattern or Vulnerable

Habitat Use information identified. Only 11 species were in the High PII score group. These included demersal and benthic sharks and one benthic ray. In the case of the hammerheads, while adults were benthopelagic, juveniles were demersal. The highest scored fishes in this group were demersal or benthic, with evidence of both site fidelity and juvenile nursery habitat use (Appendix Table D).

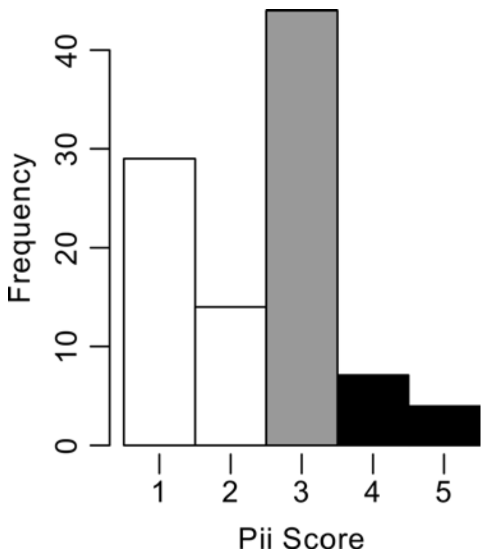

Figure 2. The Potential Interaction Index (PII) scores (row totals) for the Hawaii Region Focal Species. The PII incorporates species-specific life history, movement and habitat use information available in the literature to rank (relative to each other) a species' potential for interacting with EMF generated undersea transmission cables associated with MHK devices. Scores were grouped as: Low (white bars; total score: 1-2), Medium (gray bars; total score: 3), and High (black bars; total score: 4-5).

5. Recommendations for Future Research (Task 4)

5.1. Approach

The final objective of this project is to develop recommendations for research needs to close important knowledge gaps regarding the potential interaction of fishes and MHK technologies in the Hawaii Region. Our recommendations are based on a framework for considering the potential effects and impacts of marine renewable energy projects on various elements of marine ecosystems (originally developed in Boehlert and Gill 2010; discussed here in section 4.1). This framework is considered further within the specific context of effects and impacts of EMF on sensitive marine species in Gill et al. (2014) and research needs are presented. Here we first discuss species-independent baseline research needs. These primarily consist of *in situ* quantification of EMF generated by MHK devices and undersea cables once pilot and commercial scale MHK devices are deployed in Hawaii. Then we propose a simple approach for prioritizing Hawaii Region Focal Species (ranked relative to each other) as candidates in multiple related research paths. The prioritization approach incorporates EMF sensitivity information currently available with a species likelihood of interacting with EMF generated undersea transmission cables associated with MHK devices (i.e., the PII score). It is important to note that the species prioritization presented here is based on current knowledge, and the intent is that it could be updated as more species-specific EMF sensitivity, life history, movement and habitat use information becomes available. We then provide details of the types of research needed within each of three research paths: (A) Level 4 (effect, EMF response) focused research, (B) Level 5 & 6 (EMF impact) focused research, and (C) additional life history, movement and habitat use focused research. Finally, we discuss additional concepts that could be considered either as additional metrics that could be incorporated into the proposed approach for species prioritization or as additional standalone research paths.

Finally, there are additional concepts not considered here that could be used in future evaluations. If the intent went beyond ranking species based on their likelihood to interact with EMF, these could also be incorporated into a species ranking approach for future research. These could include: commercial and recreational fisheries importance (Normandeau et al. 2011; Woodruff et al. 2012), fish species cultural relevance (e.g., Taylor 1993) or non-fisheries value to specific stakeholders (Kramer et al. 2010), and/or public perceptions and safety concerns (e.g., will EMFs attract sharks and increase rate of shark attacks on humans).

5.2. Species Independent Baseline Research

There is a particular need for *in situ* measurements of the strengths and geometries of EMF generated by undersea cables, as much of the current estimates are based on modeling EMF based on actual and proposed cable characteristics (Kramer et al. 2010; Normandeau et al. 2011; Polagye et al. 2011; Gill et al. 2014). As MHK devices are being designed and deployed in larger developments and/or located further offshore and in deeper water, this will involve the development and use of higher kV DC transmission cables. These cables will likely generate EMF of greater magnetic field intensity with different characteristics than AC transmission cables that are used more commonly with smaller developments located closer to shore. Therefore, the assessment of EMF generation will need to continue as this technology continues to develop (Gill et al. 2014). Multiple transmission cables located close to each other, more likely in a commercial scale development, may have an additive effect resulting in higher EMF being generated (Isaacman and Lee 2010; Normandeau et al. 2011; Gill et al. 2014). All pilot and commercial scale MHK developments in Hawaii would provide an opportunity for *in situ* characterization of the EMF generated by active devices and transmission cables. This research path may then continually inform the EMF effect and impact research paths, providing guidance on expected EMF characteristics associated with specific types of MHK developments deployed in various habitats and environmental conditions.

5.3. Prioritizing Hawaii Region Focal Species as Candidates for Future Research

There is a limited amount of information available to predict potential effects, let alone impacts (as defined by Boehlert and Gill 2010; see section 4.1 in this report for further detail), of EMF from undersea power cables on marine fishes. Given the even greater paucity of this type of information available for the Hawaii Region Focal Species, we propose an approach to prioritize fish species in Hawaii as candidates for various paths of future research. We also provide references for related background information for each species (Appendix Table E). The approach involves two steps to categorize and rank Hawaii Region Focal Species within one of three paths (Categories A-C) as candidates for future research (Figure 3). The first step (1) asks is there direct evidence of EMF sensitivity for a fish on the Hawaii Region Focal Species list (Appendix Table C)? This is followed by (Step 2) using the PII score (Appendix Table D) to further categorize species among research paths. The three research path categories (Figure 3) are:

(A) No Direct Evidence of EMF Sensitivity, High or Medium PII Score: The Hawaii Region Focal Species List includes fish species that are more likely to be sensitive to EMF. Given that the research on marine fish sensitivity to electric and magnetic fields has been primarily focused on relatively few species, for most fishes on this list, sensitivity is inferred based on data available for related species. Therefore an initial prioritization is for **(Category A)** level 4 (EMF effect, response) focused research for those species with no direct evidence of EMF sensitivity. This research path involves documenting behavioral (e.g., repulsion, attraction or confusion) or physiological responses to EMF Species (details on various potential approached provided in Section 5.3.1.). Within this category species can then be ranked relative to each other based on the PII score, prioritizing those with species with relatively greater potential (Medium or High PII Scores) for interacting with EMF generated by undersea transmission cables associated with MHK devices (based on currently available information). Given limited resources, those fishes with a low PII Score are not included in this (or any other) priority research category.

(B) Direct Evidence of EMF Sensitivity, High PII Score: If there is direct evidence of EMF sensitivity, and they have a High PII Score (i.e., based on the currently available life history, movement and habitat use information, and relative to the other Hawaii Region Focal Species, they have the highest likelihood of interacting with EMF generated by undersea transmission cables associated with MHK devices) then they may be candidates for **(Category B)** level 5 & 6 (EMF impact) focused research (Figure 1). This research path involves demonstrating whether observed species-specific effects of EMF on individuals may result in positive or negative outcomes on populations, communities or ecosystems (see section 5.3.2. for more detail). Given the logistical challenges and amount of associated data involved with these types of studies (Boehlert and Gill 2010; Gill et al. 2014), well studied species with established EMF sensitivities and the greatest potential for interacting with MHK generated EMF should be prioritized.

(C) Direct Evidence of EMF Sensitivity, Medium PII Score: If there is direct evidence of EMF sensitivity, but the PII score was in medium group, then we suggest that, based on the currently available life history, movement and habitat use information, the likelihood of interacting with EMF generated by undersea transmission cables associated with MHK devices is not currently justified to be high enough to commit the investment associated with level 5 & 6 (EMF impact) focused research. However, these species may be prime candidates for **(Category C)** additional life history, movement and habitat use focused research. In most cases these species had a Behavioral Habitat Type of demersal or benthic (score 3), but had no other Movement Pattern or Vulnerable Habitat Use information identified that would have resulted in them receiving additional points and moving them up to a High PII score. Additional life history, movement and habitat use focused research may reveal such characteristics.

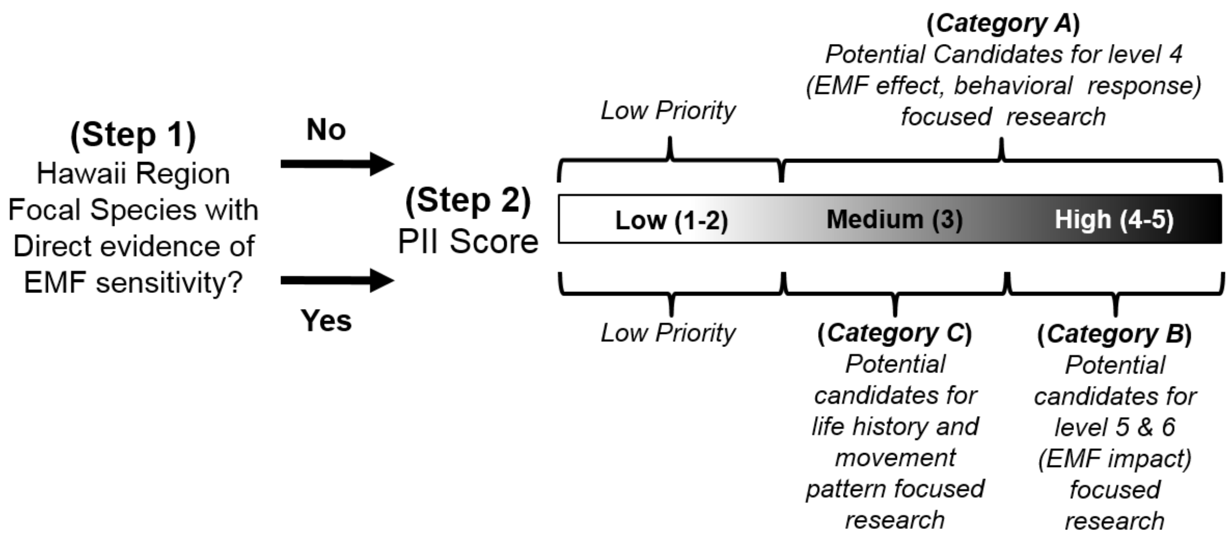

Figure 3. Our proposed two step approach to categorizing and ranking Hawaii Region Focal Species within multiple suggested future research categories includes (Step 1) whether or not direct evidence of EMF sensitivity exists for the species, and then (Step 2) ranks the species based on the PII score (i.e., relative species potential for interacting with EMF generated undersea transmission cables). Species without direct evidence of EMF sensitivity (No) and a High or Medium PII score are (Category A) potential candidates for Level 4 focused research [EMF effect, behavioral response as defined in Boehlert and Gill (2010)]. Species with direct evidence of EMF sensitivity (Yes) and a High PII score are (Category B) potential candidates for Level 5 & 6 focused research [EMF impact as defined in Boehlert and Gill (2010)]. Species with direct evidence of EMF sensitivity (Yes) and a Medium PII score are (Category C) potential candidates for additional life history, movement and habitat use focused research. All Hawaii Region Focal Species are fishes with an increased likelihood of EMF sensitivity, but given limited resources, those with a low PII Score are not currently included in any priority research category. When more information becomes available from future research a species would be moved between categories accordingly.

5.3.1. (Category A) Level 4 (EMF Effect, Response) Focused Research

There is still a primary need for EMF effect level species-specific research documenting behavioral and physiological responses to EMF for fishes globally. This is especially the case for Hawaii Region Focal Species where only 11 out of 99 have direct evidence of EMF sensitivity (Appendix Table C). Forty-six Hawaii Region Focal Species were prioritized as candidates for Level 4 research (Category A, Table 5, Appendix Table D), which include those with no direct evidence of EMF sensitivity, and Medium to High PII score. Within this category, species could be further ranked relative to each other based on their PII score, prioritizing those with species with relatively greater potential for interacting with EMF generated by undersea transmission cables associated with MHK devices (based on currently available information). *Dasyatis lata*, Brown Stingray, is an example a of high priority species in the research path. It has no direct evidence of EMF sensitivity (Appendix Table C) and has a PII score of 5. It is an abundant benthic predator in Hawaii nearshore ecosystems, with some evidence of site fidelity and juveniles using shallow bays as nursery habitat (Appendix Table D). Additional factors not considered in this study such as fishery, cultural or ecological importance could also be used to prioritize species within this category. It should also be noted that even for fish species with documented EMF sensitivity, studies have been performed under a limited range of EMF characteristics and intensities, as well as a limited set of environmental conditions (Normandeau et al. 2011; Polagye et al. 2011; Gill et al. 2014). This suggests that researchers could also consider species with some direct evidence of EMF sensitivity to be candidates for this research path if they conclude that previous research does not provide an adequate understanding of its sensitivity characteristics.

The focus of this research path is to understand the species-specific effects of EMF on individuals. This involves documenting behavioral (e.g., repulsion, attraction or confusion) or physiological responses to EMF. Here we summarize types of studies described in Gill et al. (2014) and elsewhere that would be applicable for Level 4 research. These studies would focus on species and life-stage specific effects.

Lab based studies:

- Characterize sensitivity thresholds to expected EMF types and intensities (Kramer et al. 2010; Polagye et al. 2011; Woodruff et al. 2012).
- Behavioral response (e.g. attraction, repulsion) studies to expected EMF types and intensities (Kramer et al. 2010; Kimber et al. 2011).

In situ studies at sites of active MHK developments or similar subsea transmission cables:

- Observational (e.g., baited or drop-down cameras) of fish behavioral response
- Active or passive tracking of tagged fishes or capture studies to document fine scale movements and more general spatial distribution patterns (Gay 2012).

Mesocosm approach studies:

- Fishes are held within large enclosures situated over subsea cables permitting controlled experiments in semi-natural conditions (Gill et al. 2009).

The strengths and geometries EMF generated by subsea cables can vary based on the habitat, oceanographic and equipment and installation specifications. Therefore, an operating pilot or commercial scale MHK facility should be viewed as an opportunity to conduct *in situ* EMF effect research (Kramer et al. 2010; Normandeau et al. 2011; Polagye et al. 2011; Gill et al. 2014). Additionally, because research so far as focused on EMF effects from single subsea cables, examining species responses to large-scale arrays of multiple devices and cables, where EMF strengths may be additive, should be a high priority when large scale MHK developments are deployed (Isaacman and Lee 2010).

Table 5. Some Hawaii Region Focal Species were placed into three future research path Categories (A, B, or C) based on a proposed approach (described in Figure 3) that incorporates EMF sensitivity information with the Potential Interaction Index (PII), an index that scores each species based on their likelihood of interacting with EMF generated by undersea transmission cables associated with MHK devices. Some focal species were not categorized due to a low PII score. Species within Categories in this table are ordered taxonomically following Appendix Table C, and their order is not meant to imply further prioritization.

Category A	
Alopias superciliosus - Bigeye Thresher	*Scorpaena pele*
Apristurus spongiceps - Spongehead Catshark	*Scorpaenodes corallinus*
Pseudotriakis microdon - False Catshark	*Scorpaenodes hirsutus* - Hairy Scorpionfish
Carcharhinus albimarginatus - Silvertip Shark	*Scorpaenodes kelloggi* - Dwarf Scorpionfish
Carcharhinus altimus - Bignose Shark	*Scorpaenodes evides* - Cheekspot Scorpionfish
Carcharhinus amblyrhynchos - Gray Reef Shark	*Scorpaenodes parvipinnis* - Lowfin Scorpionfish
Carcharhinus limbatus - Blacktip Shark	*Scorpaenopsis altirostris*
Sphyrna zygaena - Smooth Hammerhead	*Scorpaenopsis brevifrons* - Bigmouth Scorpionfish
Chlamydoselachus anguineus - Frilled Shark	*Scorpaenopsis cacopsis* - Nohu or Titan Scorpionfish
Hexanchus griseus - Sixgill Shark	*Scorpaenopsis diabolus* - Devil Scorpionfish, False Stonefish
Echinorhinus cookei - Prickly Shark	*Scorpaenopsis pluralis*
Somniosus pacificus - Pacific Sleeper Shark	*Sebastapistes ballieui* - Poopa'A or Spotfin Scorpionfish
Dalatias licha - Kitefin Shark	*Sebastapistes coniorta* - Speckled Scorpionfish
Etmopterus pusillus - Smooth Lanternshark	*Sebastapistes fowleri* - Fowler's Scorpionfish
Trigonognathus kabeyai - Viper Shark	*Sebastapistes galactacma* - Galactacma Scorpionfish
Hexatrygon sp. - Sixgill Stingray	*Setarches guentheri* - Deepwater Scorpionfish
Plesiobatis daviesi - Deepwater Stingray	*Taenianotus triacanthus* - Leaf Scorpionfish
Dasyatis dipterura (synonym: Dasyatis hawaiensis) - Diamond Stingray	*Poecilopsetta hawaiiensis*
Dasyatis lata - Brown Stingray, Broad Stingray, Hawaiian Stingray	**Category B**
Aetobatus narinari - Spotted Eagle Ray	*Carcharhinus galapagensis* - Galapagos Shark
Hozukius guyotensis	*Carcharhinus melanopterus* - Blackfin Reef Shark
Iracundus signifer - Decoy Scorpionfish	*Carcharhinus plumbeus* - Sandbar Shark
Neomerinthe rufescens	*Triaenodon obesus* - Whitetip Reef Shark
Plectrogenium nanum - Dwarf Thornyhead	*Sphyrna lewini* - Scalloped Hammerhead
Pontinus macrocephalus - O'Opu-Kai-Nohu	**Category C**
Pterois sphex - Hawaiian Turkeyfish	
Rhinopias xenops - High-Eye Scorpionfish or Hawaiian Rhinopias	*Carcharhinus falciformis* - Silky Shark
Scorpaena colorata	*Galeocerdo cuvier* - Tiger Shark

5.3.2. (Category B) Level 5 & 6 (EMF Impact) Focused Research

The next research path involves demonstrating whether observed species-specific effects of EMF on individuals may result in Level 5 impacts (Figure 1) by causing positive or negative outcomes on populations, communities or ecosystems (Boehlert and Gill 2010; Gill et al. 2014). These impacts could occur directly on a single species, possibly stemming from a physiological impairment that lowers growth or survival rates, or from a subsea cable disrupting a migration route to a mating site, ultimately lowering the reproductive success. Impacts also may occur indirectly by altering ecological processes, for example impacts on non-focal species resulting in a trophic cascade (Boehlert and Gill 2010; Gill et al. 2014). This is ultimately the critical step for determining whether observed effects are biologically significant (Bailey et al. 2014).

A first step in impact research is documenting whether effects cause positive or negative outcomes on individuals and the magnitude of those changes. Possible studies could involve expanding approaches described previously to document effects, to include looking for evidence of key demographic rates (e.g., growth, survival, reproduction). In some cases assessing changes in these demographic rates directly may not be feasible, therefore proxies such as changes in fish abundance, behavior or species composition before and after MHK projects are deployed may initially have to be used to begin to assess impacts (Boehlert and Gill 2010; Shumchenia et al. 2012). The overall scale of an MHK development (e.g., footprint, number and characteristics of MHK devices and cables) is likely to be an important consideration (Boehlert and Gill 2010; Shumchenia et al. 2012; Gill et al. 2014). It is possible that while the environmental effects of a single MHK device may not be measurable, larger commercial scale arrays could have significant cumulative impacts (Previsic 2010; Polagye et al. 2011; Shumchenia et al. 2012). Well-designed baseline (pre-development) and long-term studies are important features of approaches to assess impacts of EMFs (Level 5 and Level 6) of both pilot and commercial scale projects (Gay 2012; Bailey et al. 2014; Krägefsky 2014; Leeney et al. 2014).

Given the more challenging nature of studies at this scale, the proposed approach prioritizes Hawaii Region Focal Species that have both direct evidence of EMF sensitivity and a relatively higher likelihood of interacting with MHK generated EMF (High PII score). Only five species (Category B, Table 5; Appendix Table D), all sharks, would currently be candidates for this research path using the proposed approach based on currently available information (Appendix Table C, D). *Sphyrna lewini*, Scalloped Hammerhead, is likely the best candidate given the relatively high number of studies documenting EMF sensitivity for this species (Appendix Table C) and that its juveniles are relatively abundant benthic predators in Hawaii nearshore ecosystems, with some evidence of site fidelity and use of shallow bays as nursery habitat (Appendix Table D).

Understanding whether EMF effects on fishes translate into impacts may be further complicated by the environmental context and lack of knowledge on compensatory sensory capabilities of some fishes. For example, recent research suggests that elasmobranchs reliance on electrosensory abilities may be dependent on environmental conditions, being relied on more when water conditions were turbid and visual range is reduced (O'Connell et al. 2014a). A hypothesis that remains to be examined, is whether under conditions where electrosensory or magnetosensory capabilities are effected by EMF, other sensory capabilities (e.g., smell, sight) would compensate to mitigate this impairment. This may be particularly applicable in the case of large scale movements/migrations where more “local scale” electrosensory capabilities may be less involved. This could potentially reduce the likelihood that an EMF effect would translate into a fitness reduction or eventually a population level impact under certain conditions for some species.

Level 6 cumulative impacts involve incorporating additional dimensions to Level 5 impacts by considering stressors from other human impacts (Boehlert and Gill 2010; Gill et al. 2014). For elasmobranch populations, many have already experienced severe impacts from overfishing (e.g., Baum et al. 2003). At this stage these additional types of impacts could be considered as an additional manner in which to prioritize species. Boehlert and Gill (2010) and Gill et al. (2014) suggest that research needs to move from Level 4 to Levels 5 & 6 in order to permit better ability by researchers, managers and industry to improve environmental impact assessment and reduce the current uncertainty in assessing potential EMF impacts on fishes from subsea transmission cables associated with MHK devices. However, for species in the Hawaii Region, there is still considerable more Level 4 research that needs to be performed to better define EMF sensitivity thresholds for a broader range of species.

5.3.3. (Category C) Additional Life History, Movement and Habitat Use Focused Research

There is a general need for additional specific life history, movement and habitat use focused research for the Hawaii Region Focal Species. For the majority of these species there was little detailed information available other than course Behavioral Habitat Type classifications (pelagic, benthopelagic, demersal, benthic) (Appendix Table D), course general habitat descriptions (e.g., oceanic, coastal, reef associated) and documented depth ranges (Appendix Table E). High site fidelity, relatively small home range, and repeated migration routes could increase the frequency of interactions with EMF associated with subsea transmission cables associated with MHK devices. Further, some habitat use patterns, particularly those associated with a more vulnerable life stages (e.g., juvenile nursery habitat use) or behaviors (e.g., adult spawning, mating or birthing habitats) could increase the likelihood that EMF effects (behavioral or physiological responses) translate into population impacts (Normandeau et al. 2011; Gill et al. 2014). These types of movement and habitat use patterns were identified for only 19 out of the 99 Hawaii Region Focal Species (Appendix Table D).

The proposed approach initially prioritizes species as candidate for this path with direct evidence of EMF sensitivity and a Medium PII score. Based on currently available information this only includes two Hawaii Region Focal Species, both being sharks (Category C, Table 5; Appendix Table D). This is primarily due to only a small fraction of the Hawaii Region Focal Species currently having direct evidence of EMF sensitivity (11 out of 99) resulting in most species with Medium PII scores being candidates for Category A research. As more species are evaluated and found to be sensitive to EMF, they would move from Category A to Category C. Alternatively, if the likelihood of sensitivity is thought to be high enough, for example due to close taxonomic relationship with a sensitive species, and/or additional factors such as fishery, cultural or ecological importance were relevant, a Category A species could be considered a candidate for additional fish movement and habitat use focused research. Fishes in the Medium PII score group included sharks and pelagic or benthopelagic rays, and all of the benthic teleost fish. In most cases these species had a Behavioral Habitat Type of demersal or benthic (score 3), but had no other Movement Pattern or Vulnerable Habitat Use information identified (Appendix Table D). Additional life history, movement and habitat use focused research may reveal such characteristics, resulting in species receiving additional points and moving them up to a High PII score.

The geographic location of where these types of studies are performed may be particularly relevant for evaluating movement patterns for some species in Hawaii. For example, Sandbar Sharks, *Carcharhinus plumbeus,* have been observed to exhibit seasonal migrations in temperate regions while exhibiting non-migratory behavior in the tropics (Compagno 1984; Joung et al. 2004). As much as possible, future research in this path should emphasize studies performed in Hawaii at or near locations where MHK developments or cables will be or have been placed because site-specific environmental factors may influence the ecology of these fishes and their likelihood of interacting with EMFs from subsea transmission cables associated with MHK devices (Normandeau et al. 2011).

Another important element to consider is the physical habitat structure that MHK devices and unburied portions of cables will create and how this may influence the distribution and movement patterns of fishes. Reef associated fishes have been shown to be attracted to, settle on and ultimately reside on the hard substrate of MHK and offshore wind structures (Andersson and Öhman 2010; Reubens et al. 2011; Langhamer 2012; Bat et al. 2013; Bergström et al. 2013; Larsen et al. 2013; Ashley et al. 2014; Reubens et al. 2014; Wilhelmsson and Langhamer 2014; Kramer et al. 2015) increasing the potential for fishes originally located beyond an MHK project footprint to interact with MHK associated EMF on a frequent basis. An interesting related observation occurred in 2008 when Longnose Skate, *Raja rhina,* were recorded in high abundance on the seafloor at ~300 m depth along a short section of the Monterey Accelerated Research System (MARS) subsea cable. It was where the cable was suspended slightly (2-10 cm) above the seabed between rocks. While this cable does provide power to scientific monitoring equipment, during this time period it was not energized. The report was inconclusive as to whether this apparent attraction to the cable was due to the physical habitat structure the cable created, rays being attracted to a mild electric field generated by the unelectrified cable, or if it was unrelated to presence of the cable all together (Kuhnz et al. 2011). Studies examining species-specific changes in abundance and changes movement patterns of marked or tagged fish pre- and post-deployment of the physical habitat structures associated with MHK developments would be another valuable research path in the Hawaii Region.

Potential interaction with EMF from cables placed in very deep water is another area where further research is needed, particularly for the Hawaii Region where transmission cables may span between islands. In most cases it is unknown how often Hawaii Region Focal Species at various life stages would interact with cables deep cables. Elsewhere it has been observed that some elasmobranchs (e.g., rays, catsharks) deposit their egg cases on the seafloor, sometimes at hundreds of meters deep (Quattrini et al. 2009; Treude et al. 2011). First, it would be important to know the rate at which this occurs in the Hawaii Region. If it is frequent, then studies could examine if EMF exposure would result in any developmental effects (e.g., Lee and Yang 2014) for embryos developing in egg cases deposited near a transmission cable.

Since the primary focus of the present study was on interactions with EMF generated by subsea transmission cables, our approach to ranking species as candidates for research prioritized demersal and benthic species that would be more likely to interact with cables along, or buried under, the seafloor. Therefore, all of the pelagic teleost fish (e.g., mackerel, tuna) in the Hawaii Region Focal Species list were included in the Low PII score group (Appendix Table D). However, hundreds of marine fish species globally have been described in literature as aggregating around floating structures and therefore MHK devices could serve these same functions. If MHK devices or transmission cables connecting those devices near the surface down to the seafloor produce EMF that effect fishes, then pelagic fishes' tendency to aggregate around cables or structures up in the water column (i.e., FAD effects) could also be considered as they would likely attract tropical pelagic fishes, sharks, and other top predators in the Hawaii Region (Kramer et al. 2015). Previous reviews have considered both direct and indirect effects on attracted fishes. If EMF affect those fishes that are attracted, then direct impacts may be possible. Additionally if EMF increases the attraction of pelagic predators (e.g., tuna, pelagic sharks), then other reef-associated fishes could experience higher mortality rates (Boehlert and Gill 2010; Kramer et al. 2010; Krägefsky 2014; Wilhelmsson and Langhamer 2014).

6. Conclusions

- Over the past five years there have been multiple comprehensive reviews and studies evaluating the potential vulnerability of marine fishes to EMF produced by MHK and offshore wind devices and the associated transmission cables. Most documented effects involve sub-lethal behavioral responses of individual fish when in close proximity to EMF (e.g., fish being repelled by or attracted to EMF). They reach conclusions that the current state of research on this topic is still in its infancy and evaluations of potential impacts are associated with great uncertainty.

- We identified 99 Hawaii Region Focal Species which included fishes that are more likely to be sensitive to EMF. Focal species included all Elasmobranchs in the region because their ability to detect electric fields is thought to be virtually universal. Inclusion of all but one teleost fish species on the list was based on the species being in the same family as a sensitive species that occurs elsewhere in the world. The exception was Yellowfin Tuna, *Thunnus albacares*, which does occur in Hawaii and for which there exists direct evidence it can detect magnetic fields.

- Studies have only documented direct evidence of EMF sensitivity in 11 of the Hawaii Region Focal Species.

- There is a limited amount of information available to predict potential "effects", let alone "impacts" (as defined by Boehlert and Gill 2010; see section 4.1 in this report for further detail), of EMF from undersea power cables on marine fishes. Given the even greater paucity of this type of information available for the Hawaii Region Focal Species, we proposed an approach to prioritize fish species in Hawaii as candidates for multiple paths of future research. The prioritization approach incorporates EMF sensitivity information with a Potential Interaction Index (PII), an index that scores each species based on their likelihood of interacting with EMF generated by undersea transmission cables associated with MHK devices based on the life history, movement and habitat use information currently available in the literature. Some Hawaii Region Focal Species were prioritized as candidates for three future research path Categories (A, B or C). Given limited resources, those focal species with a low PII Score were not included in any category.

- Category A (Level 4, EMF Effect focused research as defined by Boehlert and Gill 2010; see section 5.3.1 in this report for further detail): Forty-six Hawaii Region Focal Species were prioritized as candidates for Category A. These included species with no direct evidence of EMF sensitivity, and a Medium to High PII score. The focus of this research path is to understand the species-specific effects of EMF on individuals. This involves documenting behavioral (e.g., repulsion, attraction or confusion) or physiological responses to EMF.

- Category B (Level 5 & 6, EMF Impact focused research Boehlert and Gill 2010; see section 5.3.2 in this report for further detail): Five Hawaii Region Focal Species were prioritized as candidates for Category B. This research path involves demonstrating whether observed species-specific effects of EMF on individuals may result in impacts by causing positive or negative outcomes on populations, communities or ecosystems. Given the more challenging nature of studies at this scale, the proposed approach prioritizes Hawaii Region Focal Species that have both direct evidence of EMF sensitivity and a relatively higher likelihood of interacting with MHK generated EMF (High PII score).

- Category C (life history, movement and habitat use focused research; see section 5.3.3 in this report for further detail): For the majority of the Hawaii Region Focal Species there was relatively little detailed information available on fish movement and habitat use patterns, and therefore, there is a general need for applicable information of this kind. We would initially prioritize species as candidate for this path that have direct evidence of EMF sensitivity and a Medium PII score. Based on currently available information this only includes two Hawaii Region Focal Species, both being sharks. This is primarily due to only a small fraction of the Hawaii Region Focal Species currently having direct evidence of EMF sensitivity (11 out of 99) resulting in most species with Medium PII scores being candidates for Category A research. As more species are evaluated and found to be sensitive to EMF, they would move from Category A to Category C. Alternatively, if the likelihood of sensitivity is thought to be high enough, for example due to a close taxonomic relationship with a sensitive species, and/or additional factors such as fishery, cultural or ecological importance were relevant, a Category A species could be considered a candidate for additional fish movement and habitat use focused research.

- Much of this recommended research can and should occur opportunistically as MHK pilot and commercial scale projects are deployed in the Hawaii region. The intensity and characteristics of EMF generated by transmission cables will vary depending on the cable design, current level, burial depth and local environmental conditions. Therefore, conducting *in situ* experiments from each of the research path categories, in addition to direct *in situ* quantification of the EMF generated by MHK devices and cables, will be crucial for advancing the science in this field.

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Appendix Table A. Listing of fish species for which information on sensitivity information to electric or magnetic fields was reported during the time period covered in the recent literature search (2010-March 2015).

Scientific Name	Sensitivity (E/M)[a]	Sensory Range	Evidence Basis
Chondrichthyes			
Elasmobranchii			
Orectolobiformes			
Ginglymostomatidae - nurse sharks			
Ginglymostoma cirratum	E/M? [1]		Behavioral [1]
Carcharhiniformes			
Triakidae - hound sharks			
Mustelus canis	E [2]	Minimum: 0.6 nV/cm [2]	Behavioral [2]
Scyliorhinidae - cat sharks			
Scyliorhinus canicula	E [3] [4]; E/M? [5]	9-90 µA D.C., 90 µA A.C [3]	Behavioral [3] [4] [5]
Carcharhinidae - requiem sharks			
Carcharhinus galapagensis	E/M? [6]		Behavioral [6]
Carcharhinus perezi	E/M? [7]		Behavioral [7]
Negaprion brevirostris	E/M? [7]		Behavioral [7]
Negaprion brevirostris	E/M? [8]		Behavioral [8]
Squaliformes			
Squalidae - dogfish sharks			
Squalus acanthias	E [2]; E/M? [1]	Minimum: 0.6 nV/cm [2]	Behavioral [2] [1]
Pristiformes			
Pristidae - sawfishes			
Pristis microdon	E [9]	Median: 13 nV/cm [9]	Behavioral [9]
Rajiformes			
Rajidae - skates			
Raja clavata	E/M? [5]		Behavioral [5]
Rhinobatidae - guitarfishes			
Aptychotrema rostrata	E [9]	Median: 5 nV/cm [9]	Behavioral [9]
Glaucostegus typus	E [9]	Median: 25 nV/cm [9]	Behavioral [9]
Myliobatiformes			
Myliobatidae - eagle rays			
Rhinoptera bonasus	E [10]	Minimum: 0.2 nV/cm; Median:107	Behavioral [10]

		nV/cm [10]	
Urotrygonidae - sting rays			
Urobatis jamaicensis	E [10]; E/M? [11]	Minimum: 0.2 nV/cm; Median: 22 nV/cm [10]	Behavioral [10,11]
Actinopterygii			
Chrondrosetei			
Acipenseriformes			
Acipenseridae - sturgeons			
Acipenser baerii	E/M [12]		Behavioral, Physiological [12]
Acipenser transmontanus	E/M [12]		Behavioral, Physiological [12]
Teleostei			
Anguilliformes			
Anguillidae - eels			
Anguilla anguilla	M [13]	51 μT [13]	Behavioral [13]
Cypriniformes			
Cyprinidae - minnows or carps			
Danio rerio	M [14]	35 μT [14]	Behavioral [14]
Pimephales promelas	E/M [15] [16]	36000 μT (magnets surface) to 190 μT other side tank [15]	Behavioral [15] [16]
Siluriformes			
Ictaluridae - North American catfishes			
Ictalurus punctatus	E/M [15] [16]	36000μT (magnets surface) to 190μT other side tank [15]	Behavioral [15] [16]
Gymnotiformes			
Apteronotidae - ghost knifefishes			
Apteronotus leptorhynchus	E/M [17]; E [18]		Behavioral [17] [18]
Apteronotus albifrons	E [18]		Behavioral [18]
Sternarchorhynchus curvirostris	E [18]		Behavioral [18]
Sternopygidae - glass knifefishes			
Eigenmannia lineata	E [18]		Behavioral [18]
Salmoniformes			
Salmonidae - salmon			
Oncorrhynchus spp.	M [19]		Behavioral [19]
Oncorrhynchus tshawytscha	M [20]	444-555.5 μT [20]	Behavioral [20]
Beloniformes			
Adrianichthyidae - adrianichthyids			

Oryzias latipes	E/M [21]	15-60 μT [21]	Developmental [21]
Perciformes			
Centrarchidae - sunfishes			
Lepomis microlophus	E/M [15]	36000 μT (magnets surface) to 190 μT other side tank [15]	Behavioral [15]
Lepomis spp.	E/M [16]		Behavioral [16]
Haemulidae - grunts			
Haemulon aurolineatum	M? [22]		Anatomical [22]

[a] M = magnetosensitivity; E = electrosensitivity

Appendix Table A. References:

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Appendix Table B. Categorization of general references selected during the recent literature search which covered a time period from 2010-March 2015.

References	Species-Specific EMF Sensitivity and Effects	Offshore Energy Structure and Undersea Cable Characteristics	Ecological Impacts Related to Offshore Energy Structures	Fisheries Impacts Related to Offshore Energy Structures	'Other' Category
(Ammari et al. 2014)					x
(Andersson 2011)			x		
(Andersson and Öhman 2010)			x		
(Appiott et al. 2014)			x		x
(Ashley et al. 2014)			x	x	
(Bailey et al. 2014)			x		
(Bat et al. 2013)			x	x	
(Bedore and Kajiura 2013)	x				
(Bedore et al. 2014)	x				
(Bell and Side 2011)			x		
(Bergström et al. 2013)			x		
(Bevelhimer et al. 2013)	x				
(Boehlert and Gill 2010)		x	x	x	
(Boehlert et al. 2013)	x	x	x		
(Brabant and Jacques 2010)		x	x		
(Brabant et al. 2011)		x	x		
(Cada et al. 2012)	x	x			x
(Dahlgren et al. 2014)			x		
(de Groot et al. 2014)				x	
(Dunlap et al. 2010)	x				x

(Durif et al. 2013)	x				x
(Feinberg et al. 2013)		x	x		x
(Fugère and Krahe 2010)	x				x
(Garel et al. 2014)			x		x
(Gay 2012)			x	x	
(Gill and Bartlett 2010)	x		x	x	
(Gill et al. 2012)	x		x		
(Gill et al. 2014)	x		x		
(Gonçalves et al. 2014)	x				x
(Halvorsen et al. 2011)			x		
(Hammar and Gullström 2011)			x		x
(Hammar et al. 2014)			x	x	
(Hastie et al. 2014)			x		
(Hellinger and Hoffmann 2012)	x				x
(Henkel et al. 2013)			x		x
(Henkel et al. 2014)			x		
(Holeman 2013)			x		
(Isaacman and Daborn 2011)			x		x
(Isaacman and Lee 2010)		x	x		
(Jongbloed et al. 2014)				x	x
(Jordan et al. 2011)	x				x
(Kikuchi 2010)			x		
(Kimber et al. 2011)	x				
(Kimber et al. 2014)	x				x
(Krägefsky 2014)			x	x	
(Kramer et al. 2010)			x		
(Kropp 2013)			x		

(Langhamer 2012)			x	x	
(Larsen et al. 2013)			x	x	
(Lee and Yang 2014)	x				x
(Leeney et al. 2014)			x		x
(Leung and Yang 2012)			x		
(Lin and Yu 2012)			x		
(Lindeboom et al. 2011)			x	x	
(Lozano-Minguez et al. 2011)					x
(Noatch and Suski 2012)			x	x	
(O'Connell and He 2014)	x				x
(O'Connell et al. 2011)	x				x
(O'Connell et al. 2014a)	x			x	x
(O'Connell et al. 2014b)	x				x
(O’Keeffe and Haggett 2012)					x
(Paasch et al. 2012)					x
(Polagye et al. 2011)			x		
(Putman et al. 2013)	x				x
(Putman et al. 2014)	x				x
(Ramanan et al. 2012)			x		
(Reubens et al. 2011)			x	x	
(Reubens et al. 2014)			x	x	
(Robbins et al. 2011)	x				x
(Schultz et al. 2010)	x		x		
(Scott et al. 2014)			x		
(Seitz et al. 2011)			x		
(Sheehan et al. 2013)			x		
(Sherman et al. 2013)					x

(Shumchenia et al. 2012)			x	x	x
(Siciliano et al. 2013)	x				
(Smith and O'Connell 2014)	x				x
(Spiropoulou et al. 2014)			x	x	x
(Stamper et al. 2010)	x				x
(Takebe et al. 2012)	x				x
(Valberg 2011)	x		x		
(van Deurs et al. 2012)			x		
(Want et al. 2014)			x		
(Ward et al. 2010)			x		
(Wilhelmsson and Langhamer 2014)			x	x	
(Wilson et al. 2010)			x		
(Woodruff et al. 2012)	x		x		
(Wueringer et al. 2012)	x				
(York 2010)		x			
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Appendix Table C. Hawaii Region Focal Species List with sources for inclusion and reported information on sensitivity to electric or magnetic fields. Sensory Range and Evidence Basis are only reported for species with direct evidence of EMF sensitivity, otherwise the Evidence Taxon (the related EMF sensitive taxon) is reported with its associated citations. n/a = not available.

Scientific Name	In Mundy[a]	In Ebert[b]	Evidence Taxon	Sensitivity (E/M)[c]	Sensory Range	Evidence Basis
Chondrichthyes						
Elasmobranchii						
Orectolobiformes						
Rhincodontidae - whale sharks						
Rhincodon typus - Whale Shark	X	X	Subclass (Elasmobranchii)	E	n/a	n/a
Lamniformes						
Odontaspididae - sand tigers						
Odontaspis ferox - Ragged-Tooth Shark	X	X	Subclass (Elasmobranchii)	E	n/a	n/a
Odontaspis noronhai - Bigeye Sand Tiger	X	X	Subclass (Elasmobranchii)	E	n/a	n/a
Pseudocarchariidae - crocodile sharks						
Pseudocarcharias kamoharai - Crocodile Shark	X	X	Subclass (Elasmobranchii)	E	n/a	n/a
Megachasmidae - megamouth sharks						
Megachasma pelagios - Megamouth Shark	X	X	Subclass (Elasmobranchii)	E	n/a	n/a
Alopiidae - thresher sharks						
Alopias pelagicus - Pelagic Thresher	X	X	Subclass (Elasmobranchii)	E	n/a	n/a
Alopias superciliosus - Bigeye Thresher	X	X	Subclass (Elasmobranchii)	E	n/a	n/a
Alopias vulpinus - Thresher Shark	X	X	Subclass (Elasmobranchii)	E	n/a	n/a
Cetorhinidae - basking sharks						

Cetorhinus maximus - Basking Shark	X	X	Subclass (Elasmobranchii)	E	n/a	n/a
Lamnidae - mackerel sharks						
Carcharodon carcharias - Great White Shark	X	X	Direct	E/M? (Klimley et al. 2002)	geomagnetic field [1]/electric field sensitivity [2]	Behavioral/ observational/ anatomical [3]/ theoretical
Isurus oxyrinchus - Shortfin Mako	X	X	Direct	M? [1]	geomagnetic field [1]	Behavioral/ observational
Isurus paucus - Longfin Mako	X	X	Family (*Carcharodon carcharias, Isurus oxyrinchus*)	E/M? [1-3]	n/a	n/a
Lamna ditropis - Salmon Shark	X	X	Family (*Carcharodon carcharias, Isurus oxyrinchus*)	E/M? [1-3]	n/a	n/a
Carcharhiniformes						
Scyliorhinidae - cat sharks						
Apristurus spongiceps - Spongehead Catshark	X	X	Family (*Scyliorhinus canicula*)	E, E/M?[4-6]	n/a	n/a
Pseudotriakidae - false cat sharks						
Pseudotriakis microdon - False Catshark	X	X	Subclass (Elasmobranchii)	E	n/a	n/a
Carcharhinidae - requiem sharks						
Carcharhinus albimarginatus - Silvertip Shark	X	X	Genus (*C. galapagensis, C. falciformis, C. melanopterus, C. plumbeus, C. perezi*)	E/M?[7-14]	n/a	n/a

Carcharhinus altimus - Bignose Shark	X	X	Genus (*C. galapagensis, C. falciformis, C. melanopterus, C. plumbeus, C. perezi*)	E/M? [7-14]	n/a	n/a
Carcharhinus amblyrhynchos - Gray Reef Shark	X	X	Genus (*C. galapagensis, C. falciformis, C. melanopterus, C. plumbeus, C. perezi*)	E/M? [7-14]	n/a	n/a
Carcharhinus falciformis - Silky Shark	X	X	Direct	E [8]{	0.2-10V and 0.1- 5A, DC	Behavioral
Carcharhinus galapagensis - Galapagos Shark	X	X	Direct	E/M? [13]{	n/a	n/a
Carcharhinus limbatus - Blacktip Shark	X	X	Genus (*C. galapagensis, C. falciformis, C. melanopterus, C. plumbeus, C. perezi*)	E/M? [7-14]	n/a	n/a
Carcharhinus longimanus - Oceanic Whitetip Shark	X	X	Genus (*C. galapagensis, C. falciformis, C. melanopterus, C. plumbeus, C. perezi*)	E/M? [7-14]	n/a	n/a
Carcharhinus melanopterus - Blackfin Reef Shark	X	X	Direct	E	0.2-10V and 0.1- 5A, DC[8] ; minimum: 4 nV/cm[7]	Behavioral [8]
Carcharhinus plumbeus - Sandbar Shark	X	X	Direct	E/M	minimum: 0.5 nV/cm[11]; 25-100 μT[12];	Behavioral, observational, anatomical [10], theoretical

Galeocerdo cuvier - Tiger Shark	X	X	(no response)	none [8]	n/a	None: no behavioral response to 0.2-10V and 0.1-5A, DC [8]
Prionace glauca - Blue Shark	X	X	Direct	E/M? [1]	5 nV/cm [15]; geomagnetic field[1]	Behavioral/ observational
Triaenodon obesus - Whitetip Reef Shark	X	X	Direct	E [8]	0.2-10V and 0.1- 5A, DC [8]	Behavioral [8]
Sphyrnidae - hammerhead sharks						
Sphyrna lewini - Scalloped Hammerhead	X	X	Direct	E/M [1]	minimum: 0.4 nV/cm [11]; 11-35 μV/cm [16]; 4.16 ± 0.59 V/m (head twitch), 18.50 ± 13.27 V/m (retreat) [17]; 25- 100 μT [12]	Behavioral/ observational/ anatomical[10]/ theoretical
Sphyrna mokarran - Great Hammerhead	X	X	Genus (*S. lewini*)	E/M [1,10-12,16-18]	n/a	n/a
Sphyrna zygaena - Smooth Hammerhead	X	X	Genus (*S. lewini*)	E/M [1,10-12,16-18]	n/a	n/a
Hexanchiformes						
Chlamydoselachidae - frilled sharks						
Chlamydoselachus anguineus - Frilled Shark	X	X	Subclass (Elasmobranchii)	E	n/a	n/a
Hexanchidae - cow sharks						
Hexanchus griseus - Sixgill Shark	X	X	Subclass (Elasmobranchii)	E	n/a	n/a
Echinorhiniformes						
Echinorhinidae - bramble sharks						

Echinorhinus cookei - Prickly Shark	X	X	Subclass (Elasmobranchii)	E	n/a	n/a
Squaliformes						
Centrophoridae - gulper sharks						
Centrophorus granulosus - Gulper Shark	X		Subclass (Elasmobranchii)	E	n/a	n/a
Centrophorus tessellatus - Mosaic Gulper Shark	X	X	Subclass (Elasmobranchii)	E	n/a	n/a
Somniosidae - sleeper sharks						
Somniosus pacificus - Pacific Sleeper Shark		X	Subclass (Elasmobranchii)	E	n/a	n/a
Dalatiidae - deep-sea dogfish sharks						
Dalatias licha - Kitefin Shark	X	X	Subclass (Elasmobranchii)	E	n/a	n/a
Euprotomicrus bispinatus - Pygmy Shark	X	X	Subclass (Elasmobranchii)	E	n/a	n/a
Isistius brasiliensis - Collared Dogfish or Cookie-Cutter Shark	X	X	Subclass (Elasmobranchii)	E	n/a	n/a
Etmopteridae - deep-sea dogfish sharks or lantern sharks						
Centroscyllium nigrum - Combtooth Dogfish	X	X	Subclass (Elasmobranchii)	E	n/a	n/a
Etmopterus bigelowi - Blurred Smooth Lantern Shark	X	X	Subclass (Elasmobranchii)	E	n/a	n/a
Etmopterus lucifer - Blackbelly Lantern Shark	X	X	Subclass (Elasmobranchii)	E	n/a	n/a
Etmopterus pusillus - Smooth Lanternshark	X	X	Subclass (Elasmobranchii)	E	n/a	n/a
Etmopterus villosus - Hawaiian Lanternshark	X	X	Subclass (Elasmobranchii)	E	n/a	n/a
Trigonognathus kabeyai - Viper Shark	X	X	Subclass (Elasmobranchii)	E	n/a	n/a
Somniosidae - deep-sea dogfish sharks or sleeper sharks						

Zameus squamulosus - Velvet Dogfish	X	X	Subclass (Elasmobranchii)	E	n/a	n/a
Torpediniformes						
Torpedinidae - electric rays						
Torpedo sp. - Electric Ray	X ** listed as sp. only	X	Genus (*T. californica*)	E [19]	n/a	n/a
Myliobatiformes						
Hexatrygonidae - sixgill rays						
Hexatrygon sp. - Sixgill Stingray	X ** listed as sp. Only	X	Subclass (Elasmobranchii)	E	n/a	n/a
Plesiobatidae - deepwater stingrays						
Plesiobatis daviesi - Deepwater Stingray	X	X	Subclass (Elasmobranchii)	E	n/a	n/a
Dasyatidae - stingrays						
*Dasyatis dipterura (*synonym: *Dasyatis hawaiensis)* - Diamond Stingray	X		Genus (*D. sabina*)	E [20-25]	n/a	n/a
Dasyatis lata - Brown Stingray, Broad Stingray, Hawaiian Stingray	X	X	Genus (*D. sabina*)	E [20-25]	n/a	n/a
Pteroplatytrygon violacea - Pelagic Stingray	X	X	Direct	E [26]	min 0.3 nV/cm; median 40 nV/cm [26]	Behavioral [26]
Myliobatidae - manta rays						

Aetobatus narinari - Spotted Eagle Ray	X		Family (*Rhinoptera bonasus*)	E [27]	n/a	n/a
Manta birostris - Giant Manta or Manta	X	X **listed with ?	Subclass (Elasmobranchii)	E	n/a	n/a
Manta alfredi - Reef Manta Ray	X	X	Subclass (Elasmobranchii)	E	n/a	n/a
Mobula japanica - Spinetail Mobula	X	X	Subclass (Elasmobranchii)	E	n/a	n/a
Mobula tarapacana - Chilean Devil Ray	X		Subclass (Elasmobranchii)	E	n/a	n/a
Actinopterygii						
Teleostei						
Scorpaeniformes						
Scorpaenidae - scorpionfishes						
Dendrochirus barberi - Hawaiian Lionfish	X		Family (*Sebastes inermis*)	M [28]	n/a	n/a
Ectreposebastes imus - Black Scorpionfish	X		Family (*Sebastes inermis*)	M [28]	n/a	n/a
Hozukius guyotensis	X		Family (*Sebastes inermis*)	M [28]	n/a	n/a
Iracundus signifer - Decoy Scorpionfish	X		Family (*Sebastes inermis*)	M [28]	n/a	n/a
Neomerinthe rufescens	X		Family (*Sebastes inermis*)	M [28]	n/a	n/a
Phenacoscorpius megalops - Noline Scorpionfish	X		Family (*Sebastes inermis*)	M [28]	n/a	n/a
Plectrogenium nanum - Dwarf Thornyhead	X		Family (*Sebastes inermis*)	M [28]	n/a	n/a
Pontinus macrocephalus - O'Opu-Kai-Nohu	X		Family (*Sebastes inermis*)	M [28]	n/a	n/a
Pterois sphex - Hawaiian Turkeyfish	X		Family (*Sebastes inermis*)	M [28]	n/a	n/a

Rhinopias xenops - High-Eye Scorpionfish or Hawaiian Rhinopias	X	Family (*Sebastes inermis*)	M [28]	n/a	n/a
Scorpaena colorata	X	Family (*Sebastes inermis*)	M [28]	n/a	n/a
Scorpaena pele	X	Family (*Sebastes inermis*)	M [28]	n/a	n/a
Scorpaenodes corallinus	X	Family (*Sebastes inermis*)	M [28]	n/a	n/a
Scorpaenodes hirsutus - Hairy Scorpionfish	X	Family (*Sebastes inermis*)	M [28]	n/a	n/a
Scorpaenodes kelloggi - Dwarf Scorpionfish	X	Family (*Sebastes inermis*)	M [28]	n/a	n/a
Scorpaenodes evides - Cheekspot Scorpionfish	X; as S. littoralis in corrections	Family (*Sebastes inermis*)	M [28]	n/a	n/a
Scorpaenodes parvipinnis - Lowfin Scorpionfish	X	Family (*Sebastes inermis*)	M [28]	n/a	n/a
Scorpaenopsis altirostris	X	Family (*Sebastes inermis*)	M [28]	n/a	n/a
Scorpaenopsis brevifrons - Bigmouth Scorpionfish	X	Family (*Sebastes inermis*)	M [28]	n/a	n/a
Scorpaenopsis cacopsis - Nohu Or Titan Scorpionfish	X	Family (*Sebastes inermis*)	M [28]	n/a	n/a
Scorpaenopsis diabolus - Devil Scorpionfish or False Stonefish	X	Family (*Sebastes inermis*)	M [28]	n/a	n/a
Scorpaenopsis pluralis	X	Family (*Sebastes inermis*)	M [28]	n/a	n/a
Sebastapistes ballieui - Poopa'A or Spotfin Scorpionfish	X	Family (*Sebastes inermis*)	M [28]	n/a	n/a
Sebastapistes coniorta - Speckled Scorpionfish	X	Family (*Sebastes inermis*)	M [28]	n/a	n/a

Sebastapistes fowleri - Fowler's Scorpionfish	X	Family (*Sebastes inermis*)	M [28]	n/a	n/a
Sebastapistes galactacma - Galactacma Scorpionfish	X	Family (*Sebastes inermis*)	M [28]	n/a	n/a
Setarches guentheri - Deepwater Scorpionfish	X	Family (*Sebastes inermis*)	M [28]	n/a	n/a
Taenianotus triacanthus - Leaf Scorpionfish	X	Family (*Sebastes inermis*)	M [28]	n/a	n/a
Perciformes					
Scombridae - mackerels					
Acanthocybium solandri - Wahoo	X	Family (*Thunnus albacares*)	M [29,30]	n/a	n/a
Auxis rochei - Bullet Mackerel	X	Family (*Thunnus albacares*)	M [29,30]	n/a	n/a
Auxis thazard - Frigate Mackerel	X	Family (*Thunnus albacares*)	M [29,30]	n/a	n/a
Euthynnus affinis - Kawakawa	X	Family (*Thunnus albacares*)	M [29,30]	n/a	n/a
Euthynnus lineatus - Black Skipjack	X	Family (*Thunnus albacares*)	M [29,30]	n/a	n/a
Katsuwonus pelamis - Skipjack Tuna	X	Family (*Thunnus albacares*)	M [29,30]	n/a	n/a
Scomber japonicus - Pacific Chub Mackerel	X	Family (*Thunnus albacares*)	M [29,30]	n/a	n/a
Thunnus alalunga - Albacore	X	Genus (*T. albacares*)	M [29,30]	n/a	n/a
Thunnus albacares - Yellowfin Tuna	X	Direct	M	10 to 50 µT changes to field [29]	behavioral/ anatomical [30]
Thunnus obesus - Bigeye Tuna	X	Genus (*T. albacares*)	M [29,30]	n/a	n/a
Thunnus orientalis - Pacific Bluefin Tuna	X	Genus (*T. albacares*)	M [29,30]	n/a	n/a

Sarda orientalis - Striped Bonito	X	Family (*Thunnus albacares*)	M [29,30]	n/a	n/a
Scomber australasicus - Spotted Mackerel	X	Family (*Thunnus albacares*)	M [29,30]	n/a	n/a
Pleuronectiformes					
Pleuronectidae - righteye flounders					
Poecilopsetta hawaiiensis	X	Family (*Pleuronectes platessa*)	M?[31]	n/a	n/a

[a] Mundy BC (2005) Checklist of the fishes of the Hawaiian Archipelago. Bishop Museum Press.

[b] Hawaii Checklist from Dave Ebert used for IUCN Shark Specialist group workshop.

[c] M=magnetosensitivity, E=electrosensitivity

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Appendix Table D. Life history, movement and habitat use information used to score columns in the Potential Interaction Index (PII) for the Hawaii Region Focal Species. The PII is an index that scores each species based on their likelihood of interacting with EMF generated by undersea transmission cables associated with MHK devices. Column scores are summed across rows to yield a PII Score. Hawaii Region Focal Species were then prioritized as candidates within three future research path Categories (A, B or C) based on EMF sensitivity information and the PII Score, although some were not categorized due to a low (1-2) PII score. Species are ordered taxonomically according to Appendix Table C.

Scientific Name	Behavioral Habitat Type[a]	BHT Score	Movement Pattern[b]	MP Score	Vulnerable Habitat Use[c]	VH Score	Pii Score	Category
Rhincodon typus - Whale Shark	**pelagic:** epipelagic [1-4] as cited by [5]	**1**	**none identified:** seasonal pelagic migrations onshore-offshore coinciding with coral spawn [6], aggregate to feed on fish spawn [7]; dependent on prey availability [8]	**0**	**none identified**	**0**	**1**	
Odontaspis ferox - Ragged-Tooth Shark	**benthopelagic:** benthopelagic [1,3,9-11] as cited by [5]	**2**	**none identified:** possible vertical diel migration [10]	**0**	**none identified:** large individuals (>200 cm TL) tend to inhabit depths less than 100 m while almost all small individuals (<150 cm TL) were collected at depths greater than 300 m [12]	**0**	**2**	
Odontaspis noronhai - Bigeye Sand Tiger	**pelagic:** pelagic [2,13] as cited by [5]	**1**	**none identified**	**0**	**none identified**	**0**	**1**	
Pseudocarcharias kamoharai - Crocodile Shark	**pelagic*:** Epi- and mesopelagic with occasional near-bottom occurrences [1,2,9] as cited by [5]	**1**	**none identified:** possible diel migration **[**2]	**0**	**none identified**	**0**	**1**	

Megachasma pelagios - Megamouth Shark	**pelagic:** epi- and mesopelagic [2,9,14-19] as cited by [5]	**1**	**none identified:** diel migration [2,9,14-19] as cited by [5], crepuscular vertical migrator**[**18]	**0**	**none identified**	**0**	**1**	
Alopias pelagicus - Pelagic Thresher	**pelagic:** epipelagic [1,2,9,11] as cited by [5]	**1**	**none identified:** move north into warmer pelagic waters during El Niño years [1] as cited in [20]	**0**	**none identified**	**0**	**1**	
Alopias superciliosus - Bigeye Thresher	**benthopelagic*:** pelagic and near bottom [1,2,9] as cited by [5]	**2**	**none identified:** diel vertical migration [21], crepuscular [22], migratory [23], seasonal latitudinal pelagic migration associated with warm water, mainly inhabits tropical waters [24]	**0**	**vulnerable habitat (?):** Juveniles remain in pupping location for several years. Hypothesized that females giving birth are primarily distributed in coastal areas or at shallow depths since they were rarely caught during the study [25]. Occasionally will enter coastal or shallow waters [26].	**1**	**3**	**A**
Alopias vulpinus - Thresher Shark	**pelagic:** pelagic [1,2,9,11] as cited by [5]	**1**	**none identified:** highly active, inshore and northernly migrations during warm seasons, diel vertical migration [20]	**0**	**none identified:** sex-segregated, pupping/nursery grounds in shallow coastal waters [2,27,28] as cited by [20], primarily occurs within 72-135 km of land [24,29-32] as cited by [20]	**0**	**1**	

Cetorhinus maximus - Basking Shark	**pelagic:** coastal- and epi-pelagic [1,2,9] as cited by [5]	**1**	**none identified:** known to make transatlantic migrations (one tagging study), most studies determine that they tend to stay in one place and have distinct populations [33]	**0**	**none identified:** over winter in deeper water [1,2,9] as cited by [5]; have a strong tendency to aggregate in coastal areas of continental shelves or shelf-edge habitiats (tidal fronts) [34,35]; forage just below surface **[**33]	**0**	**1**	
Carcharodon carcharias - Great White Shark	**pelagic:** pelagic [1,2] as cited by [5]	**1**	**site fidelity:** Site Fidelity was indicated by multiple sitings over 2 year period; 78% of sharks returned to Guadalupe Island annually [36]; Capable of migration across oceanic regions [1,2] as cited by [5];Capable of migrations from Guadalupe Island to the Hawaiian Islands during spring [37].	**1**	**none identified:** Capable of migrations from Guadalupe Island to the Hawaiian Islands during spring, Females stay offshore through autumn while males only through mid-summer. At surface during night, frequent deep dives during the day. At Hawaiian Islands, spent 62.8% of time between 0-5m depth while traveling [37]. 78% of sharks returned to Guadalupe Island annually. Site Fidelity was indicated by multiple sitings over 2 year period [36]; tagging studies have shown that juveniles have a strong affinity for coastal regions [38]. Adults have been shown to aggregate seasonally	**0**	**2**	

					at pinniped haulout sites [36,39,40]			
Isurus oxyrinchus - Shortfin Mako	**pelagic:** epipelagic [1,3] as cited by [5]	**1**	**none identified:** migratory [23,41]	**0**	**none identified:** Partruition occurs in fall [42]; tagging tracks reported that they spent 80% of the time at 0–12 m, 15% at 12–24 m, and 5% at depths >24 m [43]. Hypothesized to prefer 18°C water temps [44], Nursery areas appear to be close to the coast [45]	**0**	**1**	
Isurus paucus - Longfin Mako	**pelagic:** epipelagic [1] as cited by [5]	**1**	**none identified**	**0**	**none identified**	**0**	**1**	
Lamna ditropis - Salmon Shark	**pelagic:** epi- and mesopelagic [46] as cited by [5]	**1**	**none identified:** migratory; seasonal migration south in winter and spring [46] as cited by [5], [47]	**0**	**none identified:** partruition occurs in late spring/early summer [48] Spend most of their time above 40m depth [49], sex-segregation	**0**	**1**	

					[50-53] as cited by [49]			
Apristurus spongiceps - Spongehead Catshark	**demersal/engybenthic*:** 'slope associated' [54] as cited by [5]	**3**	**none identified**	**0**	**none identified**	**0**	**3**	**A**
Pseudotriakis microdon - False Catshark	**demersal/engybenthic*:** 'slope associated' [54,55] as cited by [5]	**3**	**none identified**	**0**	**none identified**	**0**	**3**	**A**
Carcharhinus albimarginatus - Silvertip Shark	**demersal/engybenthic*:** benthic and midwater feeder [1,2,9,11] as cited by [5], [54]	**3**	**site fidelity:** exhibits site fidelity on reefs, although scale of home range not well defined [56]	**1**	**none identified:**	**0**	**4**	**A**
Carcharhinus altimus - Bignose Shark	**demersal/engybenthic*:** demersal [1,3,9,57] as cited by [5]	**3**	**none identified:** diurnal vertical migrator [58]	**0**	**none identified:** juveniles may occur in warm surface waters (~25m) [1,59], Adults rare in shallow waters[54], bottom-associated [1,3,9,57] as cited by [5], found near the edge of continental and insular shelves and uppermost slopes[1]	**0**	**3**	**A**

Carcharhinus amblyrhynchos - Gray Reef Shark	**benthopelagic*:** Coastal-pelagic near the bottom [1,11,60,61] as cited by [5]	**2**	**site fidelity:** exhibits site fidelity, but considered wide-ranging [62,63], diel pattern vertical movement during dawn and dusk, inhabit deeper waters (60m) during spring than winter (35m) on average, females show strongest patterns of site fidelity site fidelity in the case of islands and atolls but not GBR, Australia [64]; Daily agrregations of female sharks observed in shallow water near atolls in the Central Pacific Ocean, between March and May [65]	**1**	**none identified:** adapted to wide range of environmental conditions, mating believed to occur in fall [66]	**0**	**3**	**A**
Carcharhinus falciformis - Silky Shark	**benthopelagic*:** epipelagic, near the bottom or in the open sea [1,3] as cited by [5]	**2**	**none identified:** seem to move from the equator toward higher latitudes in summer [24]	**0**	**vulnerable habitat:** give birth late spring to summer, more abundant along the edge of continental and insular shelves [67], newborns and juveniles demersal and occupy nursery grounds on shelf waters, exhibit sex-segregation [67], distribution limited to waters above 23°C [9],	**1**	**3**	**C**

Carcharhinus galapagensis - Galapagos Shark	**demersal/engybenthic*:** often bottom associated but sometimes pelagic [1,9] as cited by [5]	**3**	**site fidelity:** seasonal migrations (for reproduction?) suggested but believed to have some site fidelity to offshore islands [68]	**1**	**none identified:** found nearshore in Hawai'i, mating occurs early in the year, pregnant females potentially move north to give birth [69], commonly associated with clear water and hard-bottom substrate with rugged relief [70]; abundance is inversely related to sandbar shark abundance, year-round sitings at French Frigate Shoals (NHI) [68], juveniles thought to inhabit deeper water [69]	**0**	**4**	**B**
Carcharhinus limbatus - Blacktip Shark	**demersal/engybenthic*:** Bottom associated or pelagic [1,3,9,57] as cited by [5]	**3**	**none identified:** seasonal migrations (southeastern United States) **[**71]	**0**	**vulnerable habitat**: Often off river mouths and estuaries, muddy bays, mangrove swamps, lagoons, and coral reef drop-offs [1]; in southeastern United States mating can occur seasonally in specific bays, young remain in shallow areas (nursery habitats?) [71]	**1**	**4**	**A**
Carcharhinus longimanus - Oceanic Whitetip Shark	**pelagic:** epipelagic [1,3,9,72] as cited by [5]	**1**	**none identified:** migratory	**0**	**none identified:** clear preference for open ocean; aggregates around food sources [73]	**0**	**1**	

Carcharhinus melanopterus - Blackfin Reef Shark	**demersal/engybenthic***: reef associated [1,9] as cited by [5]	**3**	**site fidelity:** exhibits site fidelity, but considered wide-ranging, diel pattern vertical movement during dawn and dusk, site fidelity in the case of islands and atolls but not GBR, Australia [74], high site fidelity at Palmyra Atoll, but make occasional long range excursions[75], inbred offspring suggest that they are residents in Moorea **[**76]	**1**	**vulnerable habitat**: females migrate to same nursury for each birthing event (philopatry) most of the time close by, but sometimes crossing 50km in deep oceans in Moorea, males tend to migrate more than females [76]; prefer shallow coastal habitats for birthing and pupping and potential nursery grounds in shallow bay at Magnetic Island in Queensland, Australia [77]	**1**	**5**	**B**
Carcharhinus plumbeus - Sandbar Shark	**demersal/engybenthic*:** pelagic, but usually bottom associated; benthic feeders [1,9,11] as cited by [5]	**3**	**site fidelity:** migratory in temperate regions, non-migratory in tropical regions [1,78]	**1**	**none identified:** males move into shallow water in summer to mate [70], Common at bays, river mouths and in harbors; avoids sandy beaches and the surf zone, coral reefs and rough bottom, and surface waters [1], coastal-pelagic but bottom-associated [5], juveniles in coastal waters in pacific side of Mexico [79]	**0**	**4**	**B**
Galeocerdo cuvier - Tiger Shark	**demersal/engybenthic*:** often bottom associated but sometimes pelagic [1,19,80,81] as cited by [5]	**3**	**none identified:** offshore movements away from Hawaiian Islands, large home ranges [82], diel vertical migrations in populations in Hawaii [83],	**0**	**none identified:** in the NWHI congregate predictably around small sandy islets each summer to prey on abundant fledging	**0**	**3**	**C**

			arrhythmic wide-ranging movements, long absences [84]		albatross [83]			
Prionace glauca - Blue Shark	**pelagic:** epipelagic [1,9] as cited by [5]	**1**	**none identified:** migratory, known to return to general area which they are tagged, seasonal latitudinal migrations, [44] highly migratory [85]	**0**	**none identified:** sex segregation seasonally, young often born in spring and summer [86], pupping and pelagic nursery areas seem to be located in transition zones where there is a large prey biomass for the juveniles [85]	**0**	**1**	
Triaenodon obesus - Whitetip Reef Shark	**demersal/engybenthic*:** reef associated [1,3,9,11] as cited by [5]	**3**	**site fidelity:** highly associated with coral reefs and often seen resting in caves, will return to home cave after foraging [87], some individauls in Hawaii show high philopatry (resighted at same location multiple times during 7 year period), but movements up to 26 km observed [88]	**1**	**none identified:** observed mating in shallow waters of the Hawaiian Islands, mating occurs in april and may in Hawaii, pupping season is May into early June [88]	**0**	**4**	**B**
Sphyrna lewini - Scalloped Hammerhead	**benthopelagic* (adults):** pelagic, often bottom associated [1,5,89] as cited by [5]; **demersal/engybenthic (juveniles):** demersal [90]	**3**	**site fidelity:** juveniles show site fitelity, adults migratory, females migrate to bay and estuary sites in Hawaii to give birth [91]; juveniles resident in nursery habitat for up to 1 year [90]; show some resident behavior at Malpelo Island and other islands in the Eastern	**1**	**vulnerable habitat:** females migrate to bay and estuary sites in Hawaii to give birth; Kaneohe bay and other bays and estuaries in Hawaii used as nursery grounds by juveniles for ~4 months[91]; juveniles use Kaneohe	**1**	**5**	**B**

			Tropical Pacific [92]		bay nursery habitat for up to 1 year [90]; juveniles found inshore, females move offshore at a smaller size than males to form schools [93].			
Sphyrna mokarran - Great Hammerhead	**benthopelagic*:** pelagic, often bottom associated [1,9] as cited by [5]	**2**	**none identified:** migratory	**0**	**none identified**	**0**	**2**	
Sphyrna zygaena - Smooth Hammerhead	**benthopelagic*:** pelagic, often bottom associated [1,19] as cited by [5]: **demersal/engybenthic (juveniles):** demersal [94]	**3**	**site fidelity (?):** adults migratory [95]; juveniles remain in coastal nursery habitats (South Africa) [94]	**1**	**vulnerable habitat:** known to prey on stingrays on shallow sand flats [96], juveniles remain in coastal nursery habitats with adults found on deep reefs at the edge of the continental shelf, move inshore for mating [94]	**1**	**4**	**A**
Chlamydoselachus anguineus - Frilled Shark	**benthic*:** benthic, one pelagic record [1,9] as cited by [5]	**3**	**none identified**	**0**	**none identified**	**0**	**3**	**A**
Hexanchus griseus - Sixgill Shark	**demersal/engybenthic*:** near bottom, occasionally pelagic [1,9,57] as cited by [5]	**3**	**site fidelity:** exhibit site fidelity (Puget Sound, Washington, USA) [97], diel vertical migrations [98]	**1**	**none identified:** adults usually below 91m [1,9,57] as cited by [5], observations suggest that shallow-water activity is not related to either reproduction or feeding and its purpose remains unclear [99]	**0**	**4**	**A**

Echinorhinus cookei - Prickly Shark	**demersal/engybenthic:** engybenthic [1,9,11,57] as cited by [5]	**3**	**site fidelity:** diel onshore/offshore migrations between static locations (Monterey Canyon, California, USA) [100].	**1**	**none identified:** sedentary during the day and active in water column at night [101]	**0**	**4**	**A**
Centrophorus granulosus - Gulper Shark	**benthopelagic:** benthopelagic [1,9] as cited by [5]	**2**	**none identified**	**0**	**none identified**	**0**	**2**	
Centrophorus tessellatus - Mosaic Gulper Shark	**benthopelagic:** benthopelagic [1,102] as cited by [5]	**2**	**none identified**	**0**	**none identified**	**0**	**2**	
Somniosus pacificus - Pacific Sleeper Shark	**demersal/engybenthic*:** epibenthic [1,9,103] as cited by [5]	**3**	**none identified**	**0**	**none identified:** rarely come to surface at low latitudes, stay below photic zones [104]	**0**	**3**	**A**
Dalatias licha - Kitefin Shark	**demersal/engybenthic*:** usually near bottom but often pelagic [1] as cited by [5]	**3**	**none identified**	**0**	**none identified**	**0**	**3**	**A**
Euprotomicrus bispinatus - Pygmy Shark	**pelagic*:** Epi-, meso- and perhaps bathypelagic [1,9] as cited by	**1**	**none identified**	**0**	**none identified**	**0**	**1**	
Isistius brasiliensis - Collared Dogfish, Cookie-Cutter Shark	**pelagic*:** epi- to bathypelagic [1,9] as cited by [5]	**1**	**none identified:** diurnal migration from >1000m to the surface [1,9] as cited by [5]	**0**	**none identified:** pelagic existence, neutral buoyancy [105]	**0**	**1**	
Centroscyllium nigrum - Combtooth Dogfish	**benthopelagic:** benthopelagic [1,106] as cited by [5]	**2**	**none identified**	**0**	**none identified**	**0**	**2**	
Etmopterus bigelowi - Blurred Smooth Lantern Shark	**benthopelagic:** benthopelagic [107] as cited by [5]	**2**	**none identified**	**0**	**none identified**	**0**	**2**	
Etmopterus lucifer - Blackbelly Lantern Shark	**benthopelagic:** benthopelagic [1] as cited by [5]	**2**	**none identified**	**0**	**none identified**	**0**	**2**	

Etmopterus pusillus - Smooth Lanternshark	adults **benthopelagic:**benthopelagic [1,9,107] as cited by [5]; juveniles **demersal/engybenthic:** juveniles caught at bottom, adults caught in midwater [108]	**3**	**none identified**	**0**	**none identified**	**0**	**3**	**A**
Etmopterus villosus - Hawaiian Lanternshark	**benthopelagic:** benthopelagic [1,109,110] as cited by [5]	**2**	**none identified**	**0**	**none identified**	**0**	**2**	
Trigonognathus kabeyai - Viper Shark	**demersal/engybenthic:** engybenthic [111,112] as cited by [5]	**3**	**none identified**	**0**	**none identified**	**0**	**3**	**A**
Zameus squamulosus - Velvet Dogfish	**benthopelagic*:** pelagic and benthopelagic [1,9,113,114] as cited by [5]	**2**	**none identified**	**0**	**none identified**	**0**	**2**	
Torpedo sp. - Electric Ray	**n/a:** Unknown pending species identification [19] as cited by [5]	**3**	**none identified**	**0**	**none identified**	**0**	**n/a**	
Hexatrygon sp. - Sixgill Stingray	**benthic:** benthic [9,60,115-117] as cited by [5]	**3**	**none identified**	**0**	**none identified**	**0**	**3**	**A**
Plesiobatis daviesi - Deepwater Stingray	**benthic:** benthic [9,115,118,119] as cited by [5]	**3**	**none identified**	**0**	**none identified:** bottom associated, over sand [60]	**0**	**3**	**A**
Dasyatis dipterura (synonym: Dasyatis hawaiensis) - Diamond Stingray	**benthic:** benthic [120,121] as cited by [5], [122]	**3**	**none identified**	**0**	**none identified:** inhabit shallow inshore waters [122]	**0**	**3**	**A**

Dasyatis lata - Brown Stingray, Broad Stingray, Hawaiian Stingray	**benthic:** benthic [60,109,123]	**3**	**site fidelity:** juveniles (Kanoehe Bay, Oahu Hawaii) displayed site fidelity over relatively short periods (active tracking, days) [124]	**1**	**vulnerable habitat:** juveniles abundant in shallow bays and estuaries, nursery habitat, adults found in deep water, parturition occurs in summer [125]	**1**	**5**	**A**
Pteroplatytrygon violacea - Pelagic Stingray	**pelagic:** pelagic [126] as cited by [5]	**1**	**none identified**	**0**	**none identified:** usually encountered in upper ocean over deep water [127]	**0**	**1**	
Aetobatus narinari - Spotted Eagle Ray	**benthopelagic:** benthopelagic [3,9,128] as cited by [5]	**2**	**site fidelity (?):** high gene flow in Florida and Mexico populations, long range seasonal migration, but some site fidelity shown **[129]**	**1**	**none identified**	**0**	**3**	**A**
Manta birostris - Giant Manta or Manta	**pelagic:** pelagic [3,9,128,130,131] as cited by [5]	**1**	**site fidelity:** individuals sighted over long time periods in Hawaii [132], though to be more widely distributed than *M. alfredi* [131], site fidelity shown in feeding areas, cleaning stations and mating areas **[132]**	**1**	**none identified:** feed near surface, primarily in near-shore environments [133]	**0**	**2**	
Manta alfredi - Reef Manta Ray	**pelagic:** epipelagic [131] as cited by [5]	**1**	**site fidelity:** Home range analysis identified a diel cycle between offshore waters, a nearshore cleaning station (Makolea Point), a diurnal foraging area(offshore of reef at Ho'ona Bay), and a nocturnal foraging area (Mahaiula Bay) in Hawaii [134], known to show site	**1**	**none identified**	**0**	**2**	

			fidelity elsewhere in Hawaii near coastal areas **[133,135,136] as cited in** [134]					
Mobula japanica - Spinetail Mobula	**pelagic:** pelagic [9,137] as cited by [5]	**1**	**none identified**	**0**	**none identified:** feed at depth at night, spend time at surface during day in warm waters [138]		**1**	
Mobula tarapacana - Chilean Devil Ray	**pelagic:** epipelagic [139] as cited by [5]	**1**	**none identified**	**0**	**none identified**	**0**	**1**	
Dendrochirus barberi - Hawaiian Lionfish	**benthic*:** benthic, occasionally benthopelagic [130,140,141] as cited by [5]	**3**	**none identified:** possible diel migration [130,140,141] as cited by [5]	**0**	**none identified:** found under ledges in turbid lagoons and clear seaward drifts [142], benthic in crevices and caves during day, or sometimes benthopelagic at night at 1-134m [130,140,141] as cited by [5]	**0**	**3**	
Ectreposebastes imus - Black Scorpionfish	**benthopelagic:** benthopelagic [60,141,143-145] as cited by [5]	**2**	**none identified**	**0**	**none identified**	**0**	**2**	
Hozukius guyotensis	**benthic:** benthic [118,146,147] as cited by [5]	**3**	**none identified**	**0**	**none identified**	**0**	**3**	**A**

Iracundus signifer - Decoy Scorpionfish	**benthic:** benthic [130,141] as cited by [5]	**3**	**none identified**	**0**	**none identified**	**0**	**3**	**A**
Neomerinthe rufescens	**benthic:** benthic [60,141,148] as cited by [5]	**3**	**none identified**	**0**	**none identified**	**0**	**3**	**A**
Phenacoscorpius megalops - Noline Scorpionfish	**benthic:** benthic [141,149] as cited by [5]	**3**	**none identified**	**0**	**none identified**	**0**	**3**	**A**
Plectrogenium nanum - Dwarf Thornyhead	**benthic:** benthic [118,150] as cited by [5]	**3**	**none identified**	**0**	**none identified**	**0**	**3**	**A**
Pontinus macrocephalus - O'Opu-Kai-Nohu	**benthic:** benthic [4,60,118,119,141,151,152] as cited by [5]	**3**	**none identified**	**0**	**none identified**	**0**	**3**	**A**
Pterois sphex - Hawaiian Turkeyfish	**benthic:** benthic [60,130,141] as cited by [5]	**3**	**none identified:** diel migration? [60,130,141] as cited by [5]	**0**	**none identified**	**0**	**3**	**A**
Rhinopias xenops - High-Eye Scorpionfish or Hawaiian Rhinopias	**benthic:** benthic [109,118,141,153] as cited by [5]	**3**	**none identified**	**0**	**none identified**	**0**	**3**	**A**
Scorpaena colorata	**benthic:** benthic [141] as cited by [5]	**3**	**none identified**	**0**	**none identified**	**0**	**3**	**A**
Scorpaena pele	**benthic:** benthic [141] as cited by [5]	**3**	**none identified**	**0**	**none identified**	**0**	**3**	**A**

Scorpaenodes corallinus	**benthic:** benthic [141] as cited by [5]	**3**	**none identified**	**0**	**none identified**	**0**	**3**	**A**
Scorpaenodes hirsutus - Hairy Scorpionfish	**benthic:** benthic [4,141,143,154-156]as cited by [5]	**3**	**none identified**	**0**	**none identified**	**0**	**3**	**A**
Scorpaenodes kelloggi - Dwarf Scorpionfish	**benthic:** benthic [4,118,141,154]as cited by [5]	**3**	**none identified**	**0**	**none identified**	**0**	**3**	**A**
Scorpaenodes evides - Cheekspot Scorpionfish	**benthic:** benthic [109,118,141,143,151,157]as cited by [5]	**3**	**none identified**	**0**	**none identified**	**0**	**3**	**A**
Scorpaenodes parvipinnis - Lowfin Scorpionfish	**benthic:** benthic [130,141,158-160] as cited by [5]	**3**	**none identified**	**0**	**none identified**	**0**	**3**	**A**
Scorpaenopsis altirostris	**benthic:** benthic [60,141,161] as cited by [5]	**3**	**none identified**	**0**	**none identified**	**0**	**3**	**A**
Scorpaenopsis brevifrons - Bigmouth Scorpionfish	**benthic:** benthic [141,151,161,162] as cited by [5]	**3**	**none identified**	**0**	**none identified**	**0**	**3**	**A**
Scorpaenopsis cacopsis - Nohu or Titan Scorpionfish	**benthic:** benthic [130,141,161] as cited by [5]	**3**	**none identified**	**0**	**none identified**	**0**	**3**	**A**

Scorpaenopsis diabolus - Devil Scorpionfish or False Stonefish	**benthic:** benthic [4,109,118,141,143,151,154,156,161] as cited by [5]	**3**	**none identified**	**0**	**none identified**	**0**	**3**	**A**
Scorpaenopsis pluralis	**benthic:** benthic [161] as cited by [5]	**3**	**none identified**	**0**	**none identified**	**0**	**3**	**A**
Sebastapistes ballieui - Poopa'A or Spotfin Scorpionfish	**benthic:** benthic [4,130,141] as cited by [5]	**3**	**none identified**	**0**	**none identified**	**0**	**3**	**A**
Sebastapistes coniorta - Speckled Scorpionfish	**benthic:** benthic [130,141,160]as cited by [5]	**3**	**none identified:** diel migration?	**0**	**none identified**	**0**	**3**	**A**
Sebastapistes fowleri - Fowler's Scorpionfish	**benthic:** benthic [4,141,151,154,155,163] as cited by [5]	**3**	**none identified**	**0**	**none identified**	**0**	**3**	**A**
Sebastapistes galactacma - Galactacma Scorpionfish	**benthic:** benthic [4,119,141,151]	**3**	**none identified**	**0**	**none identified**	**0**	**3**	**A**
Setarches guentheri - Deepwater Scorpionfish	**benthic*:** Benthic and perhaps bethopelagic [60,143,144,164] as cited by [5]	**3**	**none identified**	**0**	**none identified**	**0**	**3**	**A**
Taenianotus triacanthus - Leaf Scorpionfish	**benthic:** benthic [4,11,118,130,140,141,143,154,156,165,166] as cited by [5]	**3**	**none identified**	**0**	**none identified**	**0**	**3**	**A**

Acanthocybium solandri - Wahoo	**pelagic:** epipelagic [107] as cited by [5]	**1**	**site fidelity:** possible seasonal site fidelity (Baja California Mexico) [167], seasonal migration north during summer [168], extensive dispersal at all life stages [169]	**1**	**none identified**	**0**	**2**	
Auxis rochei - Bullet Mackerel	**pelagic:** epipelagic [168,170] as cited by [5]	**1**	**none identified:** migratory [168]	**0**	**none identified:** schooling and spawning aggregations present in August 1 mile offshore Oahu[171], juveniles found offshore in midwater[172]	**0**	**1**	
Auxis thazard - Frigate Mackerel	**pelagic:** epipelagic [168,170] as cited by [5]	**1**	**none identified:** migratory [168]	**0**	**none identified:** schooling and spawning aggregations present in August 1 mile offshore Oahu[171], juveniles found offshore in midwater [172]	**0**	**1**	
Euthynnus affinis - Kawakawa	**pelagic:** epipelagic [5,151,168] as cited by [5]	**1**	**none identified:** migratory [168] [173]	**0**	**none identified:** juveniles may enter bays and harbors[168], size-segregated migrations[173]	**0**	**1**	
Euthynnus lineatus - Black Skipjack	**pelagic:** epipelagic [3,168]as cited by [5]	**1**	**none identified:** migratory [168]	**0**	**none identified**	**0**	**1**	

Katsuwonus pelamis - Skipjack Tuna	**pelagic:** epi- and mesopelagic [168] as cited by [5]	**1**	**none identified:** migratory [168]	**0**	**none identified**: juveniles found offshore in midwater [172], no behavioral association with fish aggregation devices, no difference in swimming depths during day and night [174], clear preference for waters above 17°C [175], spend most of their time above thermocline [176], smaller skipjack tuna live primarily in the upper isothermal layer, whereas the larger individuals tend to occur in deeper water[177]	**0**	**1**	
Scomber japonicus - Pacific Chub Mackerel	**pelagic:** epi- and mesopelagic [3,164,168,178,179] as cited by [5]	**1**	**none identified:** diel migration [168], high genetic variation suggests it is migratory[180],considered migratory in Japan but form somewhat disinct sub-populations [181]	**0**	**none identified:** spawning occurs in neritic waters, temp preference between 10-27°C [182], juveniles found at inshore nursury grounds in Japan [183]	**0**	**1**	
Thunnus alalunga - Albacore	**pelagic:** epi- and mesopelagic [168] as cited by [5]	**1**	**none identified:** migratory [168]	**0**	**none identified:** juveniles typically found in warm surface waters, adults in cooler deeper waters [168], spawning may extend from March to September in Hawaiian waters, juveniles tend to stay around Hawaiian Islands for some time [184]		**1**	

Thunnus albacares - Yellowfin Tuna	**pelagic:** epipelagic [5,168]	**1**	**none identified:** migratory [168]	**0**	**none identified:** juveniles restricted to warm surface waters, adults found at various depths [168], behavior of association with fish aggregating devices, adults spend small percentage of time at surface [174], in Hawaii, adults found above 100 m depth, both juveniles and adults associate with FADs [185], juveniles more abundant offshore than inshore in Hawaii[177], known nursery habitat offshore of Hawaii [186]	**0**	**1**	
Thunnus obesus - Bigeye Tuna	**pelagic:** epi- and mesopelagic [3,168] as cited by [5]	**1**	**none identified:** migratory [168]	**0**	**none identified:** larvae are found in tropical waters and as they grow fish move into temperate waters [168], associate with buoys and FADs in Hawaii [187], also island reef ledges and seamounts [188],	**0**	**1**	
Thunnus orientalis - Pacific Bluefin Tuna	**pelagic:** epipelagic [168] as cited by [5]	**1**	**none identified:** migratory [168]	**0**	**none identified:** migrate closer to shore and northward along coast of North America and Japan during summer [168], horizontal and vertical movement patterns in juveniles (avg. swimming depths	**0**	**1**	

					shallower during summer), feed along fronts [189], juveniles known to make long migrations from eastern to western Pacific [190]			
Sarda orientalis - Striped Bonito	**pelagic:** epipelagic [3,151,168,178,191] as cited by [5]	**1**	**none identified:** migratory [168]	**0**	**none identified:** An epipelagic, neritic species occurring in waters of 13.5º to 23°C, schooling with small tunas [168]	**0**	**1**	
Scomber australasicus - Spotted Mackerel	**pelagic:** epipelagic [151,168,178,192,193] as cited by [5]	**1**	**none identified:** migratory [168]	**0**	**none identified:** An epipelagic, neritic species, schooling by size [168]	**0**	**1**	
Poecilopsetta hawaiiensis	**benthic:** benthic [60,115,144,194,195] as cited by [5]	**3**	**none identified**	**0**	**none identified**	**0**	**3**	**A**

[a] Species were categorized into one of four behavioral habitat types (BHT) based on the definitions provided in Mundy (2005): pelagic (living entirely in open water) (score: 1), benthopelagic (living primarily in the water column but at times in sensory proximity to substrates) (score: 2), demersal/engybenthic (living primarily at, but not resting upon, substrates) (score: 3), benthic (living primarily in contact with substrates) (score: 3). *Categorization based on best professional judgment when the exact categorization terminology was not present in a reference.

[b] Species that exhibit site fidelity are more likely to have repeated and/or prolonged EMF exposures to MHK structures or cables. Categories: none identified (no evidence of site fidelity present in the literature) (score: 0), site fidelity (some evidence of site fidelity present in the literature) (score: 1).

[c] Some habitat use patterns, particularly those associated with a more vulnerable life stages (e.g., juvenile nursery habitat use) or behaviors (e.g., adult spawning, mating, egg depositing, birthing) could increase the likelihood of EMF effects (behavioral responses) translating into population impacts. Categories: none identified (no evidence of vulnerable habitat use pattern present in the literature) (score: 0), vulnerable habitat use (evidence of vulnerable habitat use pattern present in the literature) (score: 1).

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Appendix Table E. Additional habitat use and range information for the Hawaii Region Focal Species.

Scientific Name	Global Geographic Range	Hawaii Region Geographic Range	Depth Range (m)	General Habitat
Rhincodon typus - Whale Shark	**Widespread:** circumglobal in tropical, sub-tropical, and warm-temperate waters [1-4] as cited by [5]	Hawai'i Island to Kaua'i (northern limit unknown), undoubtedly occurs at Johnston Atoll although no published records have been found; surface to unknown depths [6-9] as cited by [5], [10]	0 to >1286 m [11]	oceanic, coastal, lagoons, coral atolls [1-4] as cited by [5]
Odontaspis ferox - Ragged-Tooth Shark	**Widespread:** Discontinuously distributed in the Gulf of Mexico, eastern North Atlantic, Mediterranean, South Africa, Madagascar, central Indian Ocean, Japan, western and southeastern Australia, New Zealand, the Hawaiian Islands, Malpelo Island, and southern California to the tip of Baja California [1,3,12-14] as cited by [5]	O‘ahu and Lisianski at 185–310 m; perhaps at the Hancock Seamounts at 260 m [9,15,16] as cited by [5]	13 to 420 m [1,3,12-14] as cited by [5]	
Odontaspis noronhai - Bigeye Sand Tiger	**Widespread:** off Madeira, Brazil, the Gulf of Mexico, the Indian Ocean or South China Sea, the Marshall Islands, and the Hawaiian Islands [2,17] as cited by [5]	Southwest of Hawai‘i Island at ca. 450 m [17] as cited by [5]	60-1000 m [17] [2] as cited by [5]	perhaps slope-associated [17] [2] as cited by [5]

Pseudocarcharias kamoharai - Crocodile Shark	**Widespread:** Probably circumglobal in the tropical and subtropical Indian, Pacific, and Atlantic oceans, but distribution discontinuous [1,2,12] as cited by [5]	Probably throughout Hawaiian Ridge and at Johnston Atoll, but recorded only from the main Hawaiian Islands [1] as cited by [5]	0-590 m [1,2,12] as cited by [5]	oceanic [1,2,12] as cited by [5]
Megachasma pelagios - Megamouth Shark	**Widespread:** Tropical and warm-temperate in the Atlantic, Indian, and Pacific oceans; from each side of the Atlantic Ocean off Brazil and Senegal, western Australia, Sulawesi, the Philippines, Japan, the Hawaiian Islands, and California [2,9,12,18-22] as cited by [5]	O‘ahu at 165 m [23,24] as cited by [5]	5-600 m [2,9,12,18-22] as cited by [5]	
Alopias pelagicus - Pelagic Thresher	**Widespread:** Indo-transPacific from South Africa and the Red Sea through northern Australia, New Caledonia, Taiwan, southern Japan, Micronesia, and eastward to the Galapagos Islands, and the mouth of the Gulf of California to Ecuador but known from disjunct localities [1,2,12,14] as cited by [5]	Recorded from O‘ahu and other, unspecified localities in the Hawaiian Islands. Probably occurs at Johnston Atoll but no records exist [1,2,8,9,25] as cited by [5]	1-152 m [1,2,12,14] as cited by [5]	oceanic [1,2,12,14] as cited by [5]
Alopias superciliosus - Bigeye Thresher	**Widespread:** Circumglobal in all tropical and subtropical seas except Red Sea, straying into temperate areas [1,2,12] as cited by [5]	North and south of main archipelago, likely Johnston Atoll; below 650 ft [1,2,8,9,26] as cited by [5]	1-500 m [1,2,12] as cited by [5]	coastal and oceanic [1,2,12] as cited by [5]

Alopias vulpinus - Thresher Shark	**Widespread:** Circumglobal in all tropical to temperate seas except the Red Sea, but more common in temperate waters; disjunct populations [1,2,12,14] as cited by [5]	Johnston Atoll and O'ahu at 320 m, probably occurs throughout the region including the Hancock Seamounts but is likely rare [1,2,27,28] as cited by [5]	0-366 m [1,2,12,14] as cited by [5]	Oceanic and coastal although most abundant near land [1,2,12,14] as cited by [5]
Cetorhinus maximus - Basking Shark	**Widespread:** Antitropical at the marings of the Arctic, Atlantic, and Pacific Oceans [1,2,12] as cited by [5]	Maui (single stranding); Compagno 2001 map incorrect to include all of Hawaii [8,9,29] as cited by [5]	at/near surface; 1m-unknown [1,2,12] as cited by [5]	along continental shelves and continental islands, but occasionally open-ocean, overwintering in deeper water [1,2,12] as cited by [5]
Carcharodon carcharias - Great White Shark	**Widespread:** Antitropical in all seas, less common in warm waters than in temperate regions [1,2] as cited by [5]	Hawai'i Island to O'ahu and perhaps Laysan at 1 to 48 m [1,8,9,25] as cited by [5]	0-1280 m [1,2] as cited by [5]	Coastal [1,2] as cited by [5]
Isurus oxyrinchus - Shortfin Mako	**Widespread:** Circumglobal in all seas from temperate through tropical areas [1,3] as cited by [5]	Maui to the Hancock Seamounts, probably throughout the archipelago and Johnston Atoll at 35–219 m [1,2,9,25,30-32] as cited by [5]	1-500 m [1,3] as cited by [5]	littoral, coastal, oceanic [1,3] as cited by [5]

Isurus paucus - Longfin Mako	**Widespread:** Known from disjunct localities in the tropical through warm-temperate Indian, Pacific, and Atlantic oceans [1] as cited by [5]	South of Johnston and north of the Hawaiian Islands; the Hancock Seamounts and Johnston Atoll are within the range of this species but no records exist. [8] stated that longfin mako "are not common in Hawai'i" [1,2,8,9,29] as cited by [5]	unknown, but likely deeper that *I. oxyrhincus* [1] as cited by [5]	oceanic [1] as cited by [5]
Lamna ditropis - Salmon Shark	**Widespread:** A Subarctic Pacific endemic generally known from 30°N to and into the Bering Sea, from southern Japan to the Gulf of Alaska and eastward to central Baja California, northward to the Bering Straits[33] as cited by [5]	Could occur at the Hancock Seamounts at the southern part of its seasonal migration [33] as cited by [5], [34]	0-152 m [1]	
Apristurus spongiceps - Spongehead Catshark	**Restricted range:** patchy in Indonesia and Hawaii [35] as cited by [5]	One record from Nihoa at 572-1463 m [9,36] as cited by [5]	572 to 1482 m [35] as cited by [5]	upper to mid-slope [35] as cited by [5]
Pseudotriakis microdon - False Catshark	**Widespread:** Western North Atlantic (New York and New Jersey), eastern North Atlantic (Iceland to Senegal), western Indian Ocean (Aldabra Islands), western Pacific (Japan, Taiwan Province of China, New Zealand, Western Australia, and Hawaii) [35,37] as cited by [5]	Hawai'i Island to Lisianski at 173–1500 m [28,31,38,39] as cited by [5]	200 to 1500 m [35,37] as cited by [5]	continental and insular slopes, occasionally wandering onto continental shelves [35,37] as cited by [5]

Carcharhinus albimarginatus - Silvertip Shark	**Widespread:** Western Indian Ocean (East Africa, Madagascar and the Red Sea), western Pacific (southern Japan), from Taiwan Province of China southwards to Indonesia, northern Australia, eastern New Guinea and the Solomon Islands, eastern Central Pacific [1,2,12,14] as cited by [5], [35]	One record from O'ahu at 30 m - "probably a waif" [1,4,8,40] as cited by [5]	0 to 800 m [1,2,12,14] as cited by [5], [35]	Prefers offshore islands, coral reefs and banks [1,2,12,14] as cited by [5], [35] within 1 km seaward of reef edge [41]
Carcharhinus altimus - Bignose Shark	**Widespread:** Circumglobal in tropical and subtropical seas [1,3,12,32] as cited by [5]	O'ahu to Kaua'i at 27-360 m [31,32,38] as cited by [5]	90-810m although young may occur at 25m [1,3,12,32] as cited by [5]	near shelf breaks and drop-offs [1,3,12,32] as cited by [5]
Carcharhinus amblyrhynchos - Gray Reef Shark	**Widespread:** Indo-Pacific from Madagascar to China, Lord Howe Island, the Hawaiian Islands, and Pitcairn Island [1,14,28,42] as cited by [5]	Johnston Atoll and Hawai‘i Island to Kure at 10–275 m [38,42-46] as cited by [5]	1-275m [1,14,28,42] as cited by [5]	often near drop-offs [1,14,28,42] as cited by [5]
Carcharhinus falciformis - Silky Shark	**Widespread:** Circumglobal in all tropical and subtropical seas except the Mediterranean, straying into temperate waters; distribution discontinuous [1,3] as cited by [5]	O‘ahu to Laysan and the Hancock Seamounts at 37 m [1,6,31,38,47,48] as cited by [5]	18-500 m [1,3] as cited by [5]	littoral [1,3] as cited by [5]

Carcharhinus galapagensis - Galapagos Shark	**Widespread:** Circumglobal in the tropical and subtropical Indian, Pacific, and Atlantic oceans; distribution disjunct and generally associated with oceanic islands [1,12] as cited by [5]	Hawai‘i Island to Midway and the Hancock Seamounts, perhaps also Johnston Atoll [9,31,46,48-50] as cited by [5]	1-286 m [1,12] as cited by [5]	
Carcharhinus limbatus - Blacktip Shark	**Widespread:** Circumglobal in all tropical and subtropical seas but distribution disjunct [1,3,12,32] as cited by [5]	Hawai‘i Island to Midway at 13–64 m [9,25,31,32,51,52] as cited by [5]	1-64 m, usually <31m [1,3,12,32] as cited by [5]	close inshore, off river mouths and estuaries, offshore [1,3,12,32] as cited by [5]
Carcharhinus longimanus - Oceanic Whitetip Shark	**Widespread:** Primarily oceanic in all tropical and subtropical seas except Mediterranean, straying into temperate areas [1,3,12,53] as cited by [5]	Johnston Atoll, Cross Seamount, and Hawai‘i Island to O‘ahu at 1–230 m. Probably throughout the archipelago but seen most often at Hawai‘i Island [1,9,30,40,44,53] as cited by [5]	1-230 m, usually over water depths of > 184 m [1,3,12,53] as cited by [5]	
Carcharhinus melanopterus - Blackfin Reef Shark	**Widespread:** Indo-Pacific from Red Sea and South Africa to south-eastern Australia and southern Japan, east to the Hawaiian Islands and Tuamoto Archipelago; Mediterranean Sea, where it is a Lessepsian immigrant [1,12] as cited by [5]	Hawai‘i Island to O‘ahu at 1 m to unknown depths [8,9,25,40,43] as cited by [5]	shallow depths [1,12] as cited by [5]	reef associated [1,12] as cited by [5]

Carcharhinus plumbeus - Sandbar Shark	**Widespread:** Distribution disjunct in tropical and subtropical areas of the Atlantic, Indian, and western Pacific oceans. In the central Pacific, this species occurs only in the Hawaiian Islands and the Marquesas. Records from the eastern tropical Pacific are questionable. [1,12,14] as cited by [5]	Hawai‘i Island to Necker at 20–278 m [9,31,48,54] as cited by [5]	intertidal to 280 m [1,12,14] as cited by [5]	coastal [1,12,14] as cited by [5]
Galeocerdo cuvier - Tiger Shark	**Widespread:** Circumglobal in tropical to subtropical seas except the Mediterranean, frequently straying into temperate waters [1,9,55,56] as cited by [5]	Johnston Atoll and Hawai‘i Island to the Hancock Seamounts at 1-371 m [9,25,31,46,49,56,57] as cited by [5]	1-371 m [1,9,55,56] as cited by [5]	
Prionace glauca - Blue Shark	**Widespread:** Circumglobal in all tropical through temperate seas; the most widely distributed shark [1,12] as cited by [5]	Throughout entire region from Hawai‘i Island and the Hancock Seamounts, probably at Johnston Atoll, at 1–230 m [9,30,44,53,58] as cited by [5]	1-350 m [1,12] as cited by [5]	oceanic, fringe-littoral [1,12] as cited by [5]

Triaenodon obesus - Whitetip Reef Shark	**Widespread:** Indo-transPacific from South Africa and the Red Sea through Pakistan, India, western Australia to Central America. In the Pacific, from Queensland, Australia north to the Ryukyu Islands, to the Hawaiian Islands and the Pitcairn group, east to the offshore islands of the Americas, and El Salvador to northern Peru [1,3,12,14] as cited by [5]	Johnston Atoll and Hawai‘i Island to Kure (more abundant in Northwestern Hawaiian Islands than main islands) at 11–122 m [9,27,46,48,59] as cited by [5]	1-330 m, most often at 8-40 m [1,3,12,14] as cited by [5]	reef associated [1,3,12,14] as cited by [5]
Sphyrna lewini - Scalloped Hammerhead	**Widespread:** Circumglobal in all warm-temperate through tropical seas except perhaps Mediterranean; disjunct records in the central Pacific [1,5,60] as cited by [5]	Hawai‘i Island to French Frigate at 1–275 m [9,27,31,52,61-63] as cited by [5]	intertidal to 275m [1,5,60] as cited by [5]	Coastal, semi-oceanic [1,5,60] as cited by [5]
Sphyrna mokarran - Great Hammerhead	**Widespread:** Circumglobal in all tropical and subtropical seas, but known only from French Polynesia and occassionally from the Hawaiian Islands on the central Pacific tectonic plate [1,12] as cited by [5]	Hawai‘i Island to O‘ahu [63,64] as cited by [5]	>80 m [1,12] as cited by [5]	Coastal, semi-oceanic [1,12] as cited by [5]

Sphyrna zygaena - Smooth Hammerhead	**Widespread:** Distribution disjunct, circumglobal in all subtropical seas, perhaps anti-tropical. Known only from the Hawaiian Islands on the Pacific tectonic plate [1,9] as cited by [5]	Maui to Niʻihau at 33–139 m [9,25,31,32,65] as cited by [5]	1-139 m [1,9] as cited by [5]	Coastal, semi-oceanic [1,9] as cited by [5]
Chlamydoselachus anguineus - Frilled Shark	**Widespread:** Circumtemperate, but known from disjunct localities in the eastern North Atlantic, off both sides of southern Africa, Japan, the Emperor Seamounts, Australia, New Zealand, Chile, and California [1,12] as cited by [5]	There are no confirmed records from within the Hawaiian 200-nmi EEZ, but it has been collected at Milwaukee and Colahan Seamounts at 240–270 m just north of the Hawaiian Ridge [9,12,66] as cited by [5]	one pelagic record at 20 m over >1500 m depth [1,12] – as cited by [5]	
Hexanchus griseus - Sixgill Shark	**Widespread:** Circumtemperate and antitropical in all seas except the Red Sea and Gulf of California [1,12,32] as cited by [5]	Hawaiʻi Island to the Hancock Seamounts and north to Kinmei Seamount at 110–1400 m, usually at >330 m [9,28,31,32,39,54,58] as cited by [5]	1-2500 m [1,12,32] as cited by [5]	
Echinorhinus cookei - Prickly Shark	**Widespread:** Trans-Pacific endemic known only from Taiwan, Japan, southern Australia, New Zealand, Belau, the Hawaiian Islands, Malpelo Island, California to Baja California, the Gulf of California, Costa Rica to Peru, and Chile.	Cross Seamount and Hawaiʻi Island to Milwaukee Seamount at 177–420 m, usually >294 m [6,9,28,31,32,39,58,67] as cited by [5]	11-650 m, usually >69 m [1,12,14,32] as cited by [5]	

	[1,12,14,32] as cited by [5]			
Centrophorus granulosus - Gulper Shark	**Widespread:** Perhaps circumsubtropical except for the eastern Pacific, with disjunct records from the Gulf of Mexico, Mediterranean Sea, Atlantic, Indian, and western Pacific oceans. Known only from southern Japan, Papua New Guinea, northeastern Australia, and perhaps the Hawaiian Islands in the Pacific [1,12] as cited by [5]	O‘ahu at 500 m (tentative ID) [9,28] as cited by [5]	100-1200 m [1,12] as cited by [5]	
Centrophorus tessellatus - Mosaic Gulper Shark	**Widespread:**Perhaps Indo-Pacific but known only from the Maldives, southern Japan and the Hawaiian Islands [1,68] as cited by [5]	O‘ahu at 260–370 m [9,15] as cited by [5]	260-728 m [1,68] as cited by [5]	
Somniosus pacificus - Pacific Sleeper Shark	**Widespread:** Antitropical in the boreal through temperate Pacific Ocean, Bering Sea, and southern Arctic Ocean above the Bering Strait; along continental margins from 70°N to 20°N off Baja	O`ahu to Lisianski at 1000-2348 m [39,69] as cited by [5]	0-2348 m [1,12,39] as cited by [5]	occuring progressively deeper at the poles [1,12,39] as cited by [5]

	California and at 40–50°S off Tasmania and southern New Zealand. Unconfirmed records from the southern Indian and Atlantic oceans. [1,12,39] as cited by [5]			
Dalatias licha - Kitefin Shark	**Widespread:** Circumtemperate; disjunct and perhaps antitropical in the temperate and subtropical Atlantic, Pacific, and Indian oceans: Georges Bank, Gulf of Mexico, Eastern North Atlantic, Medi- terranean Sea, Gulf of Guinea, western Indian Ocean, Japan, eastern and southern Australia, New Zealand, and the Hawaiian Islands [1] as cited by [5]	Maui to Milwaukee Seamount at 260–350 m [1,9,58,66,70] as cited by [5]	37-1800 m [1] as cited by [5]	
Euprotomicrus bispinatus - Pygmy Shark	**Widespread:** Circumtemperate in the south Atlantic and southern Indian oceans, antitropical in Pacific [1,12] as cited by [5]	Hawai‘i Island through Midway, perhaps Johnston Atoll and the Hancock Seamounts; probably throughout the area, in epipelagic waters [1,9,27,71] as cited by [5]	1-400 m, perhaps >1800 m [1,12]– as cited by [5]	

Isistius brasiliensis - Collared Dogfish, Cookie-Cutter Shark	**Widespread:** Circumsubtropical in the Atlantic, Indian and Pacific oceans, often near oceanic islands [1,12] as cited by [5]	Hawai‘i Island to the Hancock Seamounts at 1–302 m [6,9,27,58,72,73] as cited by [5]	1-3500 m [1,12]– as cited by [5]	
Centroscyllium nigrum - Combtooth Dogfish	**Widespread:** The Hawaiian Islands and isolated localities in the eastern Pacific including southern California, Panama, Cocos Islands, Columbia, Ecuador, Chile, and the Galapagos [1,74] as cited by [5]	O‘ahu to the Hancock Seamounts at 764–920 m [9,15,36,58] as cited by [5]	269-1143 m [1,74] as cited by [5]	
Etmopterus bigelowi - Blurred Smooth Lantern Shark	**Widespread:** Tropical and subtropical in Atlantic, Indian, and Pacific oceans. In Pacific, known only from off Okinawa, southeastern Australia, the Emperor Seamounts, northern Hawaiian Ridge, and the Nazca/Sala y Gomez Ridge [75] as cited by [5]	The Emperor Seamounts through the Hancock Seamounts to about 390 m[9,75] as cited by [5]	163-1000 m [75] as cited by [5]	
Etmopterus lucifer - Blackbelly Lantern Shark	**Widespread:** Southern Atlantic and Indian oceans to the western Pacific from Japan to New Zealand; Nazca and Sala y Gomez ridges in the eastern South Pacific. Records from the Hawaiian Islands are unconfirmed. Perhaps antitropical. [1] as cited by [5]	Unconfirmed from Hawaiian Islands, but reported from main Hawaiian Islands to Koko Seamount at 270-400 m [1,9,12,66,76] as cited by [5]	183-823 m [1] as cited by [5]	

Etmopterus pusillus - Smooth Lanternshark	**Widespread:** Circumtemperate in the Atlantic, Indian, and Pacific oceans. In western Pacific from Japan to New Zealand, known only from the Emperor Seamounts and Hawaiian Ridge on central Pacific Plate [1,12,75] as cited by [5]	Midway to the Hancock and southern Emperor Seamounts at 263–400 m [9,48,58,66,75,77] as cited by [5]	200-1000 m, possibly to 1998 m [1,12,75] as cited by [5]	
Etmopterus villosus - Hawaiian Lanternshark	**Restricted range:** Hawaiian endemic [1,48,78] as cited by [5]	Recorded from Hawai‘i Island to the Hancock Seamounts at 280–1610 m [9,36,48,78] as cited by [5]	280-1610 m [1,48,78] as cited by [5]	
Trigonognathus kabeyai - Viper Shark	**Widespread:** A western-central North Pacific endemic known only from Japan and the northern Hawaiian Ridge [77,79] as cited by [5]	Southeast Hancock Seamount, collected with a bottom trawl at 270 m [9,77] as cited by [5]	270-360 m [77,79] as cited by [5]	
Zameus squamulosus - Velvet Dogfish	**Widespread:** Gulf of Mexico, tropical and south Atlantic, South Africa, Australia, southern Japan, Kyushu-Palau Ridge, Okinawa Trough, South China Sea, New Zealand, the Hawaiian Islands, and Chile [1,12,80,81] as cited by [5]	Northeast of Kaua‘i at 27–35 m [9,81] as cited by [5]	27-1500 m (or 2000 m), most at 400-900 m [1,12,80,81] as cited by [5]	

Torpedo sp. - Electric Ray	**Widespread:** Unknown pending species identification [9] as cited by [5]	476 m off Maui and 265–274 m in the Kalohi Channel between Moloka‘i and Läna‘i [9,70] as cited by [5]	Unknown [9] as cited by [5]	unknown - perhaps undescribed, perhaps not [9] as cited by [5]
Hexatrygon sp. - Sixgill Stingray	**Widespread:** pending species identification; H. bickelli is known from South Africa, H. longirostra and three other nominal species from the South China Sea, East China Sea, and Taiwan. The genus is also known from Indonesia, western and eastern Australia [12,28,70,82,83] as cited by [5]	Hawai‘i Island to Maui at 622–950 m [9,28,70] as cited by [5]	362-1120 m [12,28,70,82,83] as cited by [5]	
Plesiobatis daviesi - Deepwater Stingray	**Widespread:** South Africa and Mozambique to the Kyushu-Palau Ridge, southern China, western and eastern Australia, the Mariana Islands and the Hawaiian Islands [12,70,84,85] as cited by [5]	Hawai‘i Island to French Frigate at 185–780 m [12,70,84,85]as cited by [5]	44-780 m [12,70,84,85] as cited by [5]	

Dasyatis dipterura (synonym: Dasyatis hawaiensis) - Diamond Stingray	**Widespread:** Eastern Pacific from California to Peru, the Galapagos Islands, and from the Hawaiian Islands. [27,86] as cited by [5]	O‘ahu [3,14,28,48,87] as cited by [5]	10–355 m [27,86] as cited by [5]	inhabit shallow inshore waters [88]
Dasyatis lata - Brown Stingray, Broad Stingray, Hawaiian Stingray	**Widespread:** The Hawaiian Islands and Taiwan [28,48,87] as cited by [5]	Moloka'i to Laysan [9,25,28,70,86,89] as cited by [5]	40-357 m [28,48,87] as cited by [5]	
Pteroplatytrygon violacea - Pelagic Stingray	**Widespread:** Circumglobal in all tropical through temperate seas but not yet documented from the western or central Indian Ocean [90] as cited by [5]	Probably throughout the region. Specimens have been taken near the Hancock Seamounts and approximately 100 nmi southwest of Hawai‘i Island. The Bishop Museum has specimens collected in and near Hawaiian waters. [9,53,90] as cited by [5]	1 to 381 m (usually 1 to 100 m) [90] as cited by [5]	
Aetobatus narinari - Spotted Eagle Ray	**Widespread:** Circumglobal in all tropical and subtropical seas, straying into temperate areas [3,12,91] as cited by [5]	Johnston Atoll and Hawai‘i Island to Kure and the Hancock Seamounts at ca. 7 m [9,25,43,45,46,49,92] as cited by [5]	1-60 m [3,12,91] as cited by [5]	usually found near land [3,12,91] as cited by [5]

Manta birostris - Giant Manta or Manta	**Widespread:** Circumglobal in tropical through warm-temperate waters [3,12,46,91,93] as cited by [5]	Johnston Atoll and Hawai‘i Island to Midway at 1–120 m [9,27,29,46,49] as cited by [5]	surface to at least 120 m [3,12,46,91,93] as cited by [5]	
Manta alfredi - Reef Manta Ray	**Widespread:** The tropical and subtropical eastern Atlantic Ocean and Indo-Pacific from East Africa through Indonesia to southern Japan, the Solitary Islands off the east coast of Australia, the Hawaiian Islands, and French Polynesia [93] as cited by [5]	Uncertain because of the long-standing synonymy of this species with *M. birostris*, but likely at Johnston Atoll and Hawai`i Island to Midway. This is probably the more common of the two species in nearshore waters of the archipelago [93] as cited by [5]		occurring more often in nearhsore waters than *M. birostris* [93] as cited by [5]
Mobula japanica - Spinetail Mobula	**Widespread:** Probably circumtropical and subtropical in Gulf of California, Pacific, Atlantic, and Indian oceans [12,94] as cited by [5]	Maui to O‘ahu [9,25,27] as cited by [5]		
Mobula tarapacana - Chilean Devil Ray	**Widespread:** Circum-warm temperate. Reported in the Pacific from off Chile, the Gulf of California, the Tuamotu Archipelago, the Hawaiian Islands, Taiwan, and Japan [64] as cited by [5]	Maui at 1-60m [64] as cited by [5]	1-60 m [64] as cited by [5]	

Dendrochirus barberi - Hawaiian Lionfish	**Restricted range:** Hawaiian Islands and Johnston Atoll endemic [36,46,95] as cited by [5]	Johnston Atoll and Hawaiʻi Island to Kure Atoll and Bank 8 at 1–134 m [25,36,43,46,48,58,95,96] as cited by [5]	1-134 m [36,46,95] as cited by [5]	in crevices and caves during day, occasionally benthopelagic at night [36,46,95] as cited by [5]
Ectreposebastes imus - Black Scorpionfish	**Widespread:** Circumglobal in the tropical and subtropical Atlantic, Indian, and Pacific oceans; in the Pacific from Japan, New Caledonia, Australia, the Line Islands, the Hawaiian Islands, the Marquesas, the Galapagos Islands, and off Peru [28,95,97-99] as cited by [5]	Maui to Oʻahu at 200–775 m [28,70,95,99,100] as cited by [5]	150-2000 m, usually at 500-850 m [28,95,97-99] as cited by [5]	
Hozukius guyotensis	**Restricted range:** Emperor Seamount endemic [66,84,101] as cited by [5]	The Hancock Seamounts; also from the Milwaukee, and Koko Seamounts at 540–1100 m [58,101] as cited by [5]	420-1200 m [66,84,101] as cited by [5]	

Iracundus signifer - Decoy Scorpionfish	**Widespread:** Indo-Pacific from east Africa and Mauritius to southern Japan, Taiwan, the Hawaiian Islands, the Cook Islands, and the Pitcairn Group [46,95] as cited by [5]	Hawai‘i Island to Maro Reef at 9–110 m [25,48,51,70,92,95] as cited by [5]	9-110 m [46,95] as cited by [5]	on reefs, rock, and sand near rock or reefs [46,95] as cited by [5]
Neomerinthe rufescens	**Restricted range:** Hawaiian Islands and Johnston Atoll endemic [28,95,102] as cited by [5]	Johnston Atoll, Cross Seamount, and Hawai‘i Island to Kaua‘i at 75–420 m [28,36,70,95,102] as cited by [5]	75-420 m [28,95,102] as cited by [5]	
Phenacoscorpius megalops - Noline Scorpionfish	**Widespread:** Eastern Indian Ocean and Pacific from Indonesia and the Philippines to the Hawaiian Islands and the southern Emperor Seamounts [95,103] as cited by [5]	O‘ahu and Koko Seamount at 350-500 m [95,103] as cited by [5]	68-622 m [95,103] as cited by [5]	perhaps associated with pink coral [95,103] as cited by [5]
Plectrogenium nanum - Dwarf Thornyhead	**Widespread:** Indo-Pacific from Madagascar, Japan, the Kyushu-Palau Ridge, and the Hawaiian Islands [84,104] as cited by [5]	Hawai‘i Island to Laysan at 262–642 m [36,70,95] as cited by [5]	250-650 m [84,104] as cited by [5]	
Pontinus macrocephalus - O'Opu-Kai-Nohu	**Widespread:** Pacific endemic known from southern Japan, the Ogasawara Islands, Micronesia, Samoa, Johnston Atoll, and the Hawaiian Islands [4,28,84,85,95,105,106] as cited by [5]	Johnston Atoll and Hawai‘i Island to Kure Atoll at 120–367 m [15,25,36,46,48,58,70,95,107] as cited by [5]	120-367 m [4,28,84,85,95,105,106] as cited by [5]	

Pterois sphex - Hawaiian Turkeyfish	**Restricted range:** Hawaiian Islands endemic [28,46,95] as cited by [5]	Hawai‘i Island to Kure Atoll at 3-124 m [25,28,45,48,49,51,70,96] as cited by [5]	3-124 m [28,46,95] as cited by [5]	on rocky and coral reefs, under ledges and in caves during day [28,46,95] as cited by [5]
Rhinopias xenops - High-Eye Scorpionfish or Hawaiian Rhinopias	**Restricted range:** Northwestern and central Pacific endemic known from Japan and the Hawaiian Islands, perhaps Indo-Pacific [48,84,95,108] as cited by [5]	Maui to Midway at 36–124 m [36,48,70,109] as cited by [5]	36-124 m [48,84,95,108] as cited by [5]	on coral or rocks [48,84,95,108] as cited by [5]
Scorpaena colorata	**Restricted range:** Hawaiian Islands and Johnston Atoll endemic [95] as cited by [5]	Johnston Atoll and Moloka‘i to Bank 11 at 79–272 m [36,46,48,66,70,95] as cited by [5]	79-272 m [95] as cited by [5]	
Scorpaena pele	**Restricted range:** Hawaiian Islands endemic [95] as cited by [5]	Maui to O‘ahu at 176–243 m [70,95] as cited by [5]	176-243 m [95] as cited by [5]	
Scorpaenodes corallinus	**Widespread:** Indo-Pacific from east Africa to Indonesia, the Hawaiian Islands, and the Society Islands [95] as cited by [5]	Hawai‘i Island to O‘ahu at 8–18 m [95] as cited by [5]	2-18 m [95] as cited by [5]	in coral reefs [95] as cited by [5]
Scorpaenodes hirsutus - Hairy Scorpionfish	**Widespread:** Indo-Pacific from east Africa and the Red Sea to the Ryukyus, Taiwan, Australia, Micronesia, the Hawaiian Islands, and Pitcairn Island [4,95,97,110-112]as cited by [5]	Johnston Atoll and O‘ahu to Midway at 8–30 m [49,95,111] as cited by [5],	1-40m [4,95,97,110,111] [112]as cited by [5]	in coral reefs [4,95,97,110-112]as cited by [5]

Scorpaenodes kelloggi - Dwarf Scorpionfish	**Widespread:** Indo-Pacific from east Africa to southern Japan, Taiwan, Micronesia, the Line Islands, the Hawaiian Islands, and the Society Islands [4,84,95,110]as cited by [5]	Johnston Atoll and Hawai‘i Island to Midway at 6–24 m [25,46,49,86,95] as cited by [5]	6-24m [95] [4,84,110]as cited by [5]	in coral reefs [95] [4,84,110]as cited by [5]
Scorpaenodes evides - Cheekspot Scorpionfish	**Widespread:** Indo-Pacific from east Africa to southern Japan, the Ogasawara Islands, Australia, Taiwan, the Hawaiian Islands, Rapa, and the Marquesas [48,84,95,97,105,113]as cited by [5]	O‘ahu to Midway at 21–104 m [6,48,49,95] as cited by [5]	21-104m [48,84,95,105], [97,113]as cited by [5]	in caves and crevices of rocky and coral reefs [48,84,95,105], [97,113]as cited by [5]
Scorpaenodes parvipinnis - Lowfin Scorpionfish	**Widespread:** Indo-Pacific from east Africa and the Red Sea to the Ryukyus, Australia, Lord Howe Island, Micronesia, the Hawaiian Islands, and the Marquesas [25,46,95,96,114] as cited by [5]	Johnston Atoll and Hawai‘i Island to O‘ahu at 1–45 m [25,46,95,96,114] as cited by [5]	1-49 m [25,46,95,96,114] as cited by [5]	in coral [25,46,95,96,114] as cited by [5]
Scorpaenopsis altirostris	**Restricted range:** Hawaiian Islands endemic [28,95,109] as cited by [5]	Hawai‘i Island to Moloka‘i at 79–190 m [28,36,95,109] as cited by [5]	79-190 m [28,95,109] as cited by [5]	
Scorpaenopsis brevifrons - Bigmouth Scorpionfish	**Restricted range:** Hawaiian Islands endemic [95,105,109,115] as cited by [5]	Hawai‘i Island to Midway at 1–38 m [49,95,109] as cited by [5]	1-35 m [95,105,109,115] as cited by [5]	on coral or rocks [95,105,109,115] as cited by [5]

Scorpaenopsis cacopsis - Nohu or Titan Scorpionfish	**Restricted range:** Hawaiian Islands endemic [46,95,109] as cited by [5]	Hawai‘i Island to Kure Atoll at 4–61 m [25,45,46,49,95,96,109,116] as cited by [5]	4-61 m [46,95,109] as cited by [5]	on reefs [46,95,109] as cited by [5]
Scorpaenopsis diabolus - Devil Scorpionfish or False Stonefish	**Widespread:** Indo-Pacific from east Africa and the Red Sea to southern Japan, the Ogasawara Islands, Australia, Micronesia, the Line Islands, the Hawaiian Islands, the Society Islands, and the Marquesas [4,48,84,95,97,105,109,110,112] as cited by [5]	Johnston Atoll and Hawai‘i Island to Midway at 1–55 m [25,46,48,49,95,117] as cited by [5]	1-70m [4,48,84,95,97,105,109,110,112] as cited by [5]	on or near coral, rock, or rubble bottoms [4,48,84,95,97,105,109,110,112] as cited by [5]
Scorpaenopsis pluralis	**Restricted range:** Hawaiian Islands endemic known only from the holotype [109] as cited by [5]	Laysan at 100 m [109] as cited by [5]	110m [109] as cited by [5]	
Sebastapistes ballieui - Poopa'a or Spotfin Scorpionfish	**Restricted range:** Hawaiian Islands and Johnston Atoll endemic [4,46,95] as cited by [5]	Johnston Atoll and Hawai‘i Island to Midway at 1–11 m [25,46,49,95,96,118] as cited by [5]	1-11m [4,46,95] as cited by [5]	in or near coral [4,46,95] as cited by [5]
Sebastapistes coniorta - Speckled Scorpionfish	**Widespread:** Central Pacific endemic from Wake Island, the Hawaiian Islands, Johnston Atoll, and the Line Islands [46,95,96]as cited by [5]	Johnston Atoll and Hawai‘i Island to Midway at 1–33 m [46,48,49,95,96,119] as cited by [5]	1-33 m [95,96]; [46]as cited by [5]	inquiline in the coral *Pocillopora meandrina* during the day [95,96]; [46]as cited by [5]

Sebastapistes fowleri - Fowler's Scorpionfish	**Widespread:** Indo-Pacific from the Comoro Islands and Mauritius to Indonesia, the Ogasawara Islands, Micronesia, the Hawaiian Islands, Samoa, French Polynesia, and Pitcairn Island [4,95,105,110,111,120] as cited by [5]	Johnston Atoll and Hawaiʻi Island to Oʻahu at 14–30 m [95,111,121,122] as cited by [5]	3-61 m [4,95,105,110,111,120] as cited by [5]	on sand, coral, or coral rubble [4,95,105,110,111,120] as cited by [5]
Sebastapistes galactacma - Galactacma Scorpionfish	**Widespread:** Pacific endemic from the Ogasawara Islands, Micronesia, the Hawaiian Islands, and Rapa [4,85,95,105]	Maui to Midway at 8–64 m [25,46,48,86] as cited by [5]	6-64 m [4,85,95] [105]	in coral and coral rubble [4,85,95] [105]
Setarches guentheri - Deepwater Scorpionfish	**Widespread:** Circumglobal in the tropical and subtropical Atlantic, Indian, and Pacific oceans [28,97,98,123] as cited by [5]	Cross Seamount and Hawaiʻi Island to Colahan Seamount at 177–780 m [28,36,48,66,70,95,124]as cited by [5]	150-780 m [28,97,98,123] as cited by [5]	
Taenianotus triacanthus - Leaf Scorpionfish	**Widespread:** Indo-Pacific from South Africa and the Chagos Archipelago to the Ryukyus, Australia, Micronesia, the Hawaiian Islands, and the Tuamotus; A single record from the Galapagos Islands is likely based on a waif [4,14,36,46,84,95,97,110,112,125,126] as cited by [5]	Hawaiʻi Island to Midway at 1–134 m, usually at 1–14 m [36,49,95,96,116] as cited by [5]	1-134 m, usually at 1-20 m [4,14,36,46,84,95,97,110,112,125,126] as cited by [5]	

Acanthocybium solandri - Wahoo	**Widespread:** Almost circumglobal between 40°N–40°S, although usually near topography, in the tropical through warm-temperate Gulf of Mexico, Mediterranean Sea, Atlantic, Indian, and Pacific oceans [107] as cited by [5],	Johnston Atoll and Hawai‘i Island to the Hancock Seamounts at 1 m [25,46,48,86,127] as cited by [5]	0-12 m [107] as cited by [5]	
Auxis rochei - Bullet Mackerel	**Widespread:** Almost circumglobal, usually near topography, between 60°N–48°S in the tropical to temperate Gulf of Mexico, Mediterranean Sea, Atlantic, Indian, and Pacific oceans [128,129] as cited by [5]	Läna‘i to O‘ahu at 1 m [6,130,131] as cited by [5]	10+ m [128,129] as cited by [5]	
Auxis thazard - Frigate Mackerel	**Widespread:** Almost circumglobal, usually near topography between 60°N–48°S in the tropical to temperate Gulf of Mexico, Mediterranean Sea, Red Sea, Atlantic, Indian, and Pacific oceans [128,129] as cited by [5]	Hawai‘i Island to O‘ahu at 1 m [25,86,130,131]as cited by [5]	1-45m [128] [129]as cited by [5]	

Euthynnus affinis - Kawakawa	**Widespread:** Indo-Pacific, usually near topography, from South Africa and the Red Sea to Indonesia, southern Japan, the Ogasawara Islands, Australia, Micronesia, the Hawaiian Islands, and French Polynesia [5,105,128] as cited by [5]	Johnston Atoll and Hawaiʻi Island to Kure Atoll at 1 m [25,46,48,86] as cited by [5]	0-200m [5,105,128] as cited by [5]	
Euthynnus lineatus - Black Skipjack	**Widespread:** Eastern tropical Pacific endemic from southern California to the Galapagos Islands and Peru; two stray specimens recorded from the Hawaiian Islands [3,128] as cited by [5]	Known from Hawaiʻi Island and Molokaʻi at 1 m as waifs [132,133] as cited by [5]	0-40 m [3,128]as cited by [5]	
Katsuwonus pelamis - Skipjack Tuna	**Widespread:** Circumglobal between 60°N–50°S in the tropical to boreal Gulf of Mexico, Mediterranean Sea, Atlantic, Indian, and Pacific oceans [128] as cited by [5]	Johnston Atoll and Hawaiʻi Island to the Hancock Seamounts at 1 m [25,46,48,86,127] as cited by [5]	0-260 m [128] as cited by [5]	
Scomber japonicus - Pacific Chub Mackerel	**Widespread:** A trans-Pacific endemic when considered distinct from S. colias, but antitropical and reported only from the Hawaiian Islands on the Pacific Plate. Otherwise known from Japan through the Philippines in the western Pacific and southern Alaska to Chile in	Johnston Atoll and Hawaiʻi Island to the Hancock Seamounts at 27–99 m and to 342 m fishing depths [25,48,58,136]as cited by [5]	0-300 m [3,123,128,134,135]as cited by [5]	

	the eastern Pacific [3,123,128,134,135] as cited by [5]			
Thunnus alalunga - Albacore	**Widespread:** Nearly circumglobal between 50°N–40°S in the tropical through temperate Mediterranean Sea, Atlantic, Indian, and Pacific oceans except the eastern tropical Pacific [128] as cited by [5]	O‘ahu to the Hancock Seamounts [6,27,137]as cited by [5]	0-600 m [128] as cited by [5]	avoiding the surface in the tropics [128] as cited by [5]
Thunnus albacares - Yellowfin Tuna	**Widespread:** Circumglobal between 40°N–40°S in the Gulf of Mexico, Atlantic, Indian, and Pacific oceans [5,128] as cited by [5]	Johnston Atoll and Hawai‘i Island to the Hancock Seamounts at 1 m [5,25,46,48] as cited by [5]	0-200 m [5,128] as cited by [5]	
Thunnus obesus - Bigeye Tuna	**Widespread:** Nearly circumglobal between 45°N–40°S in the Atlantic, Indian, and Pacific oceans except the extreme eastern equatorial Pacific [3,128] as cited by [5]	Hawai‘i Island to Midway and the Hancock Seamounts, probably at Johnston Atoll [25,44,48] as cited by [5]	0-250 m [3,128] as cited by [5]	

Thunnus orientalis - Pacific Bluefin Tuna	**Widespread:** North Pacific endemic found between 3–60°N. Populations or stray specimens are recorded from off western Australia, New Guinea, and the eastern south Pacific [128] as cited by [5]	O'ahu [27,138] as cited by [5]	0-200 m [128] as cited by [5]	
Sarda orientalis - Striped Bonito	**Widespread:** Indo-trans Pacific from South Africa and the Red Sea to Indonesia, Japan, the Ogasawara Islands, western Australia, and Baja California to Peru; known only from the Hawaiian Islands on the central Pacific Plate [3,15,105,128,134] as cited by [5]	O‘ahu to Pearl and Hermes Reef at 90–110 m [139,140] as cited by [5]	1-167m [3,15,105,128,134] as cited by [5]	usually near topography [3,15,105,128,134] as cited by [5]
Scomber australasicus - Spotted Mackerel	**Widespread:** Indo-Pacific with disjunct populations in the northwestern Indian Ocean to Red Sea and otherwise from Japan and the Ogasawara Islands southward to Australia and New Zealand, the Hawaiian Islands on the Pacific Plate, and Socorro Island near Mexico. [105,128,134,141,142] as cited by [5]	Main Hawaiian Islands to the Hancock Seamounts at fishing depths to 265 m [15,25,48,143] as cited by [5]	1-160m and fishing depths to 265m [105,128,134,141,142] as cited by [5]	usually near topography [105,128,134,141,142] as cited by [5]

Poecilopsetta hawaiiensis	**Restricted range:** Hawaiian Islands and Emperor Seamount endemic [28,70,98,144,145] as cited by [5]	Hawai'i Island to Laysan and Koko Seamount at 80–435 m [28,36,48,70,144-146] as cited by [5]	80-435 m [28,70,98,144,145] as cited by [5]	on sand [28,70,98,144,145] as cited by [5]

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