ASSOCIAÇÃO
PORTUGUESA DOS
RECURSOS HÍDRICOS

Journal of Integrated Coastal Zone Management (2022) 22(2): 127-143
© 2022 APRH
ISSN 1646-8872
DOI 10.5894/rgci-n496
url: https://www.aprh.pt/rgci/rgci-n496.html

ENVIRONMENTAL IMPACTS ON MARINE ENERGY: COLLISION RISKS FOR MARINE ANIMALS AND PRIORITY SPECIES FOR MONITORING IN BRAZIL

Catarina Luiza Damasceno Lima da Silva[@ 1], Pedro Henrique Castello Branco Dágola[1, 2],
Marcos Antônio Cruz Moreira[1, 3], Luís Felipe Umbelino dos Santos[1, 4]

ABSTRACT: Brazil has great potential for the development of technologies for the conversion of marine energy from waves and tides, which raises the discussion about the possible environmental impacts of these projects. This article seeks to synthesize knowledge about the risks of collision of marine animals, such as mammals, fish and birds, with marine renewable energy (MRE) devices, as well as to identify priority species for environmental monitoring along the Brazilian coast. The risk of marine mammals colliding with MRE devices is influenced by regional and behavioral factors. The risk of collision in a fish community is influenced by the avoidance behavior, the distribution of fish in the MRE sites and the stages of the enterprise (installation, operation and maintenance). Seabird collision risk is influenced by species behavior (geographical distribution, seasonal habitat use, diving time and depth) and the location of MRE structures (surface and/or water column). The survey of priority species for monitoring the risk of collision with MRE devices in Brazil consisted of 5 species of marine mammals, 13 taxa of seabirds, 5 species of endangered sea turtles and 18 species or groups of species of fish of economic importance to the country. The research review did not record the occurrence of collisions with marine animals. However, this does not mean that they did not occur, but that they may not have been observed due to monitoring challenges. The study concluded that research on the interaction of marine animals with MRE devices should be encouraged, even in prototypes and non-commercial projects, in order to reduce knowledge gaps and support the development of MRE in an environmentally sound manner.

Keywords: Marine renewable energy, Collision risk, Species, Marine animals.

RESUMO: *O Brasil possui grande potencial para o desenvolvimento de tecnologias de conversão de energia marinha das ondas e marés, o que aflora a discussão sobre os possíveis impactos ambientais desses empreendimentos. Este artigo busca sintetizar os conhecimentos sobre os riscos de colisão de animais marinhos, como mamíferos, peixes e pássaros, com dispositivos de energia marinha renovável (EMR), bem como identificar as espécies prioritárias para o monitoramento ambiental ao longo da costa brasileira. O risco de colisão de mamíferos marinhos com dispositivos de EMR é influenciado por fatores regionais e comportamentais. O risco de colisão em comunidade de peixes é influenciado pelo comportamento de evasão, a distribuição dos peixes nos locais de EMR e as etapas do empreendimento (instalação, operação e manutenção). O risco de colisão de aves marinhas é influenciado pelo comportamento das espécies (distribuição geográfica, uso sazonal do habitat, tempo e profundidade de mergulho) e pela localização das estruturas de EMR (superfície e/ou coluna de água). O levantamento de espécies prioritárias para o monitoramento do risco de colisão com dispositivos de EMR no Brasil foi constituído por 5 espécies de mamíferos marinhos, 13 táxons de aves marinhas, 5 espécies de tartarugas marinhas ameaçados de extinção e por 18 espécies ou grupos de espécies de peixes de importância econômica para o país. A revisão das pesquisas não registrou ocorrência de colisões com animais marinhos. No entanto, não significa que não ocorreram, mas que podem não ter sido observadas devido aos desafios do monitoramento. O estudo concluiu que as pesquisas de interação de animais marinhos com dispositivos de EMR devem ser fomentadas, mesmo que em protótipos e projetos não comerciais, a fim de reduzir as lacunas do conhecimento e auxiliar o desenvolvimento da EMR de forma ambientalmente adequada.*

Palavras-chave: *Energia renovável marinha, Risco de colisão, Espécies, Animais marinhos.*

@ Corresponding author: catarinabio97@gmail.com

1 Fluminense Federal Institute of Education, Science and Technology. Rio de Janeiro, Brazil.
2 Email: pedrodagola@gmail.com
3 Email: mcruzcn@gmail.com
4 Email: lfumbelino@gmail.com

Submission: 25 FEB 2022; Peer review: 26 FEB 2022; Revised: 2 SEP 2022; Accepted: 2 SEP 2022; Available on-line: 12 OCT 2022

1. INTRODUCTION

The Intergovernmental Panel on Climate Change (IPCC) preliminary report reveals that the world temperature rise will reach or exceed 1.5°C between 2021 and 2040 (IPCC, 2021). Its content is a warning to the end of the fossil fuel era, and the need for massive investments in renewable energy is irrefutable. For the scenario of temperature increase below 1.5°C, the share of renewable energy in the world is expected to grow from 14% in 2018 to 74% in 2050, which requires an eight-fold increase in the annual growth rate (IRENA, 2021).

Since 2019, the IPCC has recognized Marine Renewable Energies (MRE) as a mean of mitigating climate change. The ocean can be considered an enormous reservoir of thermal energy, heat from the sun, and mechanic energy from tides and waves. Technologies can generate electrical energy from various ocean energy resources such as tides, waves, ocean thermal energy conversion (OTEC), ocean currents, wind and salinity gradients (Spellman, 2014). Ocean energy resources can potentially generate between 45 000 TWh and 130 000 TWh of electricity per year, covering more than twice the global demand for electricity (IRENA, 2020). However, the contribution of marine energy to world electricity generation and needs is nowadays very small, representing 0.1%, coming mostly from tidal power plants (EPE, 2020a).

The Brazilian energy matrix is composed of approximately 50% of renewable energies (EPE, 2021) and these sources dominate the electricity sector, accounting for more than 80% of the country's electricity generation, Figure 1.

According to the 2020 National Energy Balance, Brazil does not use RME for electricity generation, despite the extensive coastal zone of 8 698 km (MMA, 2008; EPE, 2020b) and research indicating a potential of 114 GW of the renewable energies from the sea. A survey carried out by the Federal University of Rio de Janeiro (UFRJ), through local measurements and theoretical research, estimated an energy potential of 27 GW from the tides in the north and northeast regions of Brazil. On the coast of the states of Amapá, Pará and Maranhão, tides vary between 5 to 11 m (Florêncio and Trigoso, 2020; Tolmasquim, 2016). The energy potential of the waves was estimated from the extent of each state of the federation, based on the average significant wave height in the year and the average period in the year (Tolmasquim, 2016). Thus, the energy potential of the waves was 22 GW in the Northeast, 30 GW in the Southeast and 35 GW in the South (Tolmasquim, 2016; Florêncio and Trigoso, 2020, Figure 2).

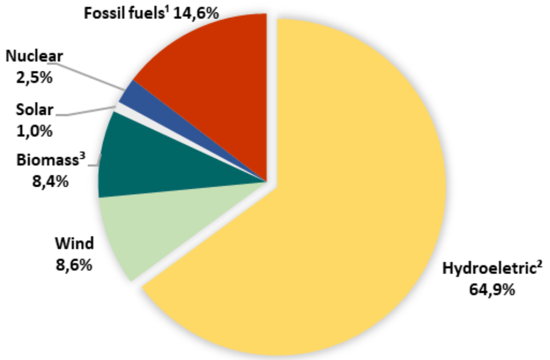

Figure 1. Domestic electricity supply of 651.3 TWh in Brazil, in 2019, by source. (Source: Adapted from the Energy Research Company (EPE, 2020b)). Notes: ¹Includes coke oven gas. ²Includes electricity imports. ³Includes firewood, sugarcane bagasse, bleach and other recoveries.

Despite the benefits of renewable sources, several studies reveal environmental impacts on renewable energy projects, which vary in type and intensity according to the technology used, geographic location, ecological resources, among other factors (Spellman, 2014). According to data from the International Energy Agency - IEA (2020), the share of renewable energies in electricity generation increased from 20% to almost 28% between 2010 and 2020. In view of the increasing trend in renewable sources, it is necessary to gather information about the impacts generated to mitigate or eliminate them.

Knowing them helps regulatory agencies in the authorization and licensing processes; and also helps government spheres responsible for the management of coastal and oceanic areas and project developers to understand what will be required from them, investing in technologies that improve maritime energy devices (Copping *et al*., 2020). Furthermore, it is vitally important to make the population of the coastal zone more aware of the environmental impacts of developments in this area (Barros *et al*., 2010). For example, when the population understands the advantages and disadvantages for the region, they may or may not oppose the implementation or permanence of renewable marine energy projects.

The exploration of ocean energy has few ventures and projects; however, like all energy exploration for human use, it also generates environmental costs (Copping *et al*., 2014). Installation and operation of RME have environmental impacts on marine animals (Keenan *et al*., 2011; Halvorsen *et al*., 2012) and physical systems (Ahmadian *et al*., 2012; Jones *et al*., 2014). This review presents research works that assess the interaction

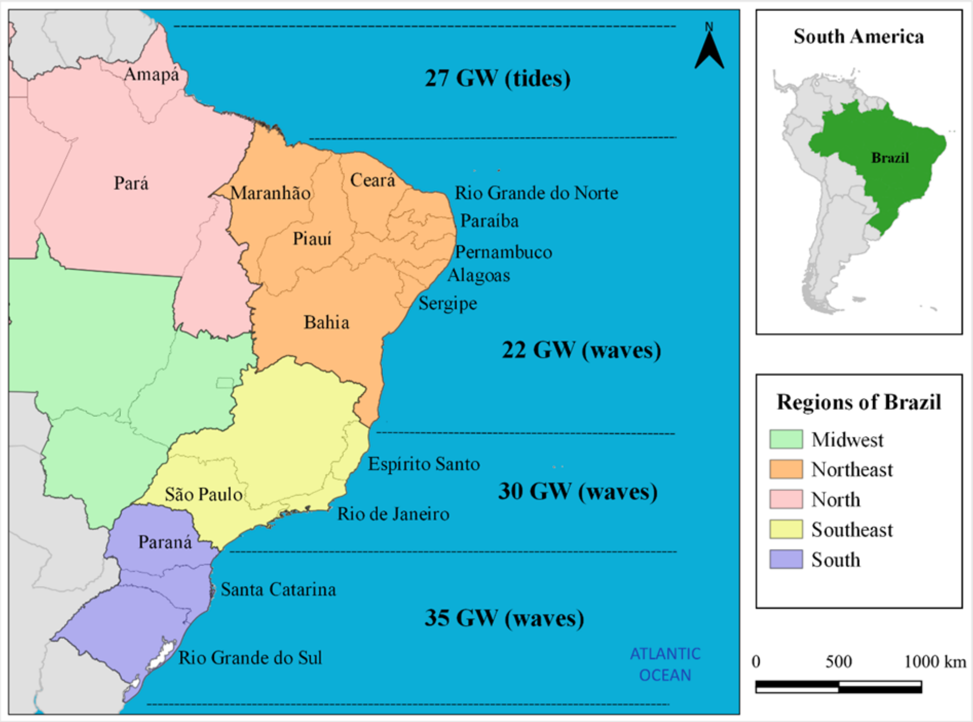

Figure 2. Estimated Brazilian theoretical potential of wave and tidal energy.

and collision risks of marine animals (mammals, fish and birds) with marine energy system of waves, tidal and currents; and since there is an estimated energy potential for the entire coast, it aims to indicate priority species for environmental monitoring of the risk of collision in Brazil.

2. METHODOLOGY

The survey on the potential environmental impacts of Marine Renewable Energy took place through the works of Spellman (2014), Tolmasquim (2016) and Copping *et al*. (2020). The summary of the state of the art on marine animal collision risk was based on Copping *et al*. (2020), report prepared by the Technological Collaboration Program in Ocean Energy Systems (OES) - Environmental. This intergovernmental program was developed to examine the environmental effects of marine energy and was established by the International Energy Agency in 2001.

The report features various laboratory, field and modeling researches, as well as international environmental monitoring programs, both to assess the interaction of marine animals and the risk of collision with RME devices. The great concern of these researches are endangered species and those of commercial and recreational importance, as additional disturbances in these populations can cause environmental and economic impacts. Therefore, to prepare a list of priority species for monitoring interaction with RME devices in Brazil, commercially important fish species were selected; and endangered species of marine mammals, birds and reptiles. The species of mammals, birds and reptiles were selected from ICMBio (2018) which used the IUCN (2001) method to categorize the risk of extinction.

According to MMA Ordinance No. 43/2014, of the Brazilian Ministry of the Environment, species threatened with extinction are those categorized as: vulnerable (VU), high risk of extinction in nature; Endangered (EN), very high risk of extinction; critically endangered (CR), extremely high risk of extinction; and extinct in the wild (EW), individuals only in cultivation, captivity or with a population (or populations) naturalized outside their natural range (ICMBio, 2018). Also for mammals, birds and reptiles, the category of extinction risk, the geographic distribution in the country, the habitat, and only for marine mammals, the presence in conservation units were informed. The fish species selected were those that make up 60% of marine fisheries production in Brazil, according to data collected by Dias-Neto and Dias (2015). From this work, the information selected was about the fishing area, habitat, average production between 1995 and 2010 in tons and the status of use or source (condition of fish stocks according to exploitation, which demonstrates the tendency to decline or population recovery) by species or group of fish species.

In the report by Copping *et al*. (2020), no research has been carried out about the risk of collision of marine animals with EMR devices in Brazil. Thus, it was not possible to identify the interaction of species of mammals, birds and fish in Brazilian territory with EMR devices. However, the species monitored in the research by Copping *et al*. (2020) were verified in publications in order to verify the occurrence in Brazil. Mammal species were consulted in ICMBio (2018) and Monteiro-Filho *et al*. (2013). Bird species were verified in ICMBio (2018) and Piacentini *et al*. (2015). And fish species were researched in ICMBio (2018) and Froese and Pauly (2021). In the research gathered by Copping *et al*. (2020) monitoring of reptile species was not observed.

3. ENVIRONMENTAL IMPACTS ON THE DEVELOPMENT OF MARINE RENEWABLE ENERGIES DEVICES

Several projects in Brazil and abroad developed ocean energy conversion technologies; however, most projects implemented in water were for testing or limited demonstration, with few commercial scale projects (Florencio and Trigoso, 2020; IRENA, 2020). Most of the environmental impact studies of these technologies were carried out as a requirement of regulatory agencies for the consent of commercial projects. In general, extensive monitoring is required to understand possible interactions of EMR devices with marine animals and habitats. However, not all instrumentation and/or data collection efforts to carry out this type of monitoring have achieved their objectives (Copping *et al*., 2020). This occurs because EMR devices are usually deployed in high energy and/or turbid places, which makes the operation of oceanographic equipment, sensor platforms and even human observation on vessels necessary to characterize these interactions difficult.

In this context, the article reviews studies on the potential risk of collision in RME devices, by examining the interactions between marine energy systems harvesting and the marine environment, called stressors and receptors, respectively, as designated by Boehlert and Gill (2010). Stressors are any part of RME systems that can cause damage or stress to a marine animal, a habitat, ecosystem processes or oceanographic processes. These stressors include moving turbine blades, anchors or foundations, mooring ropes, energy export cables, and emissions from any part of the RME system. Receptors include marine animals that live in the vicinity of an RME project, habitats where devices are deployed, and oceanographic processes such as natural water movement, wave height, sediment transport, and concentrations of dissolved gases and nutrients that sustain marine life (Copping *et al*., 2020). The interactions between stressors and receptors are analyzed through observations, laboratory and field experiments, and modeling studies (Copping *et al*., 2014; 2020). Figure 3 demonstrates some stressor-receptor

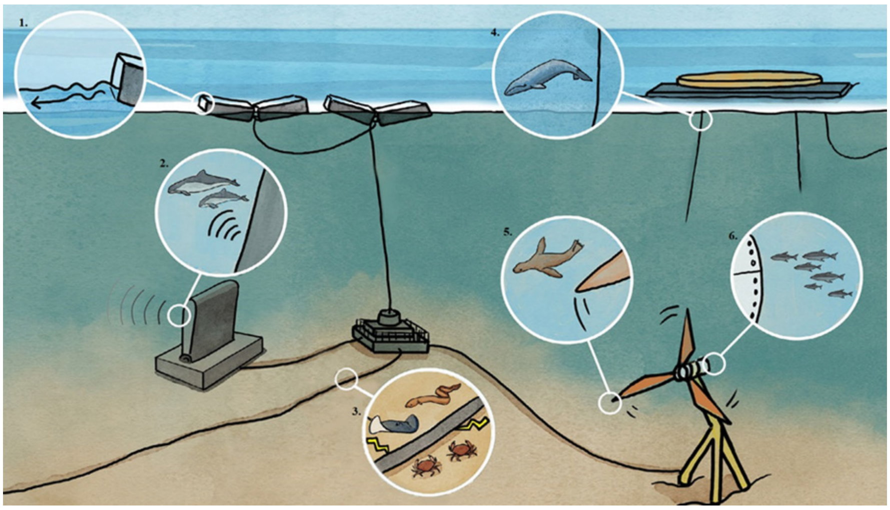

Figure 3. Potential interactions between stressor and receptor. 1. Changes in oceanographic systems; 2. Underwater noise; 3. Electromagnetic fields; 4. Mooring entanglement; 5. Collision risk and 6. Habitat changes after introduction of an RME device (Adapted from Copping *et al*., 2020).

interactions.

It is noteworthy that the risks that RME devices can pose to marine animals, habitats and the environment vary according to the attributes of the RME device (static or dynamic), energy conversion technology (waves or tides) and scale installation space (single device or matrix) (Copping *et al*., 2020). In addition, to assess the actual environmental impacts of the EMR, local investigation actions must be carried out, generally foreseen for the consent of projects: carrying out baseline surveys before project implementation, aiming to understand, quantify and assess potential environmental impacts; analysis of cumulative effects of both human activities and natural processes; determination of the project's near and far field; and preparation of environmental monitoring to assess the impacts of the project's post-installation devices.

Research related to local investigation actions should seek efforts to gather inventory information of natural species in the region and their respective patterns of distribution and normal movement in time and space (cf. Viehman *et al*., 2018; Holdman *et al*., 2019); the characteristics of RME stressors (cf. Nedwell and Brooker, 2008); and the hydrodynamic and sedimentation pattern and its variation in time and space (cf. Fairley *et al*., 2017; Khaled *et al*., 2019).

Environmental impacts of the development of RME on marine animals

Marine energy harvesting systems can harm marine animals and their habitats. Scientific research carried out focuses on the following interactions of risk to marine animals: collision with mobile and stationary devices; underwater noise generated by devices; electromagnetic fields emitted by electrical cables and devices; and entrapment in underwater cable and mooring systems. The devices can also cause changes in benthic and pelagic habitats (Copping *et al*., 2020).

Risk of collision of marine animals with mobile and stationary devices

There is great concern about marine animals colliding with moving parts of a device, such as turbine blades, moving devices such as tidal kites and blade oscillators, or stationary parts of devices such as the foundation, which can cause irreversible injury or death. For species that are already being disturbed by other human activities, losing individuals can harm the survival of the entire population. Therefore, existing environmental monitoring programs in marine energy harvesting projects are aimed at declining marine mammal populations or those in protected areas; commercially important fish species and recreational fishing; and endangered seabirds (Copping *et al*., 2020). There are no reports in the literature of collisions of marine mammals, diving seabirds and other animals with RME devices, only interaction of fish with turbines without harmful effects (Matzner *et al*., 2017; Sparling *et al*., 2020).

Several collision risk models have been developed to predict the probability of collision and consequences in marine mammals (Wilson *et al*., 2007; Band, 2014). Collision potential will likely vary with local parameters such as location, water depth and tidal velocity, and with behavioral parameters of these animals such as vertical distribution in the water column, swimming in tidal currents and foraging sites. However, changes of behavior according to locations does not allow for generalization (Copping *et al*., 2020). Behavioral studies were carried out with harbor porpoises *Phocoena phocoena* (Macaulay *et al*., 2015, 2017; Benjamins *et al*., 2017), harbor seals, *Phoca vitulina* (Hastie *et al*., 2016) and gray seals *Halichoerus grypus* (Lieber *et al*., 2018). Studies such as Copping and Grear (2018) apply several input parameters and investigate the sensitivity in collision models.

Field and laboratory studies identified evasion behavior of marine mammals from locations where turbines were in operation. Overall, these animals kept an intermediary distance (hundreds of meters) from these devices, as indicated by environmental monitoring by the companies MayGen and Nova Innovation in Scotland, SeaGen in Northern Ireland, FORCE and Sustainable Marine Energy in Canada (Sparling *et al.*, 2020). Most mammal encounters occurred when the devices did not operate. More details on these studies can be found in Sparling *et al.* (2020). The preventive behavior (evasion) of these animals in the vicinity of tidal energy structures reduces the chances of collision. Collision risk modeling research should consider the avoidance rate for proper prediction. However, studies on the consequences of evasion of these animals for the region's ecosystem must be carried out.

In studies carried out to understand the interaction of fish with RME devices, unlike marine mammals, show evasion behavior on a fine scale (from centimeter till meter scale) while turbines are operating (Bevelhimer *et al.*, 2017); however, a third of the juvenile fish analyzed by Matzner *et al.* (2017) pass through turbines. To understand the avoidance behavior, laboratory research carried out in gutters showed that ray-finned tamoroks (*Gnathopogon elongatus*) are less able to avoid turbines in current locations (Yoshida *et al.*, 2020) and that the frequency of rotation of turbines significantly affected the avoidance behavior of Japanese rice fish (*Oryzias latipes*) (Zhang *et al.*, 2017). Avoidance behavior reduces the risk of collision, but these studies may indicate that local, device and fish factors, such as age, hinder this preventive action, and may increase the risk of collision in fish.

The distribution of fish in the region of marine energy harvesting systems is an important parameter for the risk of collision, as it indicates environmental factors that approach or distance fish from RME devices. Baseline surveys by Viehman and Zydlewski (2017) and Viehman *et al.* (2018) reveal that fish abundance and vertical distribution varied with season, daily cycle and tidal stages. These surveys used hydroacoustic data, which did not allow identifying the species at the survey sites. However, the authors used previous sampling to discuss the results. Viehman and Zydlewski (2017) indicated species likely to be present in the Bay of Fundy, Cobscook Bay, Maine, such as Atlantic herring (*Clupea harengus*), winter flounder (*Pseudopleuronectes americanus*), alewife (*Alosa pseudoharengus*), rainbow smelt (*Osmerus mordax*), blueback herring (*Alosa aestivalis*), American eel (*Anguilla rostrata*) and Atlantic mackerel (*Scomber scombrus*). Viehman *et al.* (2018) used samples from the Minas Passage Basin, Nova Scotia study site, and other parts of the Bay of Fundy in Canadá to determine species potentially present in the area, such as alewife (*Alosa pseudoharengus*), blueback herring (*Alosa aestivalis*), American shad (*Alosa sapidissima*), Atlantic salmon (*Salmo salar*), striped bass (*Morone saxatilis*), rainbow smelt (*Osmerus mordax*), sea lamprey (*Petromyzon marinus*), Atlantic sturgeon (*Acipenser oxyrhynchus*), American eel (*Anguilla rostrata*), Atlantic mackerel (*Scomber scombrus*), pollock (*Pollachius virens*), spotted stickleback (*Gasterosteus wheatlandi*), Atlantic herring (*Clupea harengus*), three-spine stickleback (*Gasterosteus aculeatus*) and sharks, in summer, as porbeagle (*Lamna nasus*) and spiny dogfish (*Squalus acanthias*).

Whitton *et al.* (2020) verified that vertical migrations were stimulated by the penetration of light into the water column and by particulate matter suspended in a sectional area. In this study, carried out with schools of sprat (*Sprattus sprattus*) and some of *Merlangius merlangus*, the fish remained in the device locations for only 6% of the operating time, revealing a very low collision risk. In addition to environmental factors, the stages of the marine energy project also influence the distribution of these animals. Staines *et al.* (2019) observed lower fish density during installation and maintenance periods than during normal operation of the RME device in Cobscook Bay, Maine, USA. This may indicate less potential for fish collisions in the installation and maintenance stages of marine energy systems, but greater migration. As the research used hydroacoustic data, it was not possible to identify the species that could be migrating from the area.

The availability of prey close to marine energy system structures is a parameter related to collision risk. The results obtained by Fraser *et al.* (2018) when comparing an area of RME devices with a nearby control site indicated an attraction of fish to RME devices (general increase in the observation of schools, mainly at night, and in wakeful flow). Although aggregation and vertical distribution depends on tidal phases and avoidance of device depth at high flow speed, increased fish in RME sites can lead to foraging behavior of larger predators such as marine mammals and birds, increasing the risk of collision of these species (Fraser *et al.*, 2018). The study was carried out in the Orkney Islands, Scotland, and according to the authors, the fish species likely to be present during data collection were mackerel (*Scomber scombrus*), pollack (*Pollachius pollachius*), saithe (*Pollachius virens*), sprat (*Sprattus sprattus*), herring (*Clupea harengus*) and sandeels (*Ammodytes spp.*).

Likewise, Williamson *et al.* (2019) pointed out the aggregation and concentration of fish close to turbine structures, which could attract the foraging of predators and, consequently, increase the risk of their collision. In addition, it was observed that predatory fish began to occupy deeper areas at night, which can result in greater energy expenditure and increase the risk of collision with operating turbines, due to poor visual detection in low light, with insufficient detection of changes in the flow field or noise for an avoidance action. The authors reported using observational data on fish behavior change in models that estimate the cumulative effects on the predator population and in ecosystem models. Due to the high tidal energy conditions, it was not possible to use trawls to distinguish the species. However, other studies have suggested possible species present at the site, such as Atlantic mackerel (*Scomber scombrus*), Atlantic herring (*Clupea harengus*), sprat (*Sprattus sprattus*), sandeel (*Ammodytes spp.*), haddock (*Melanogrammus aeglefinus*), ling (*Molva molva*), saithe (*Pollachius virens*), Atlantic cod (*Gadus morhua*), butterfish (*Pholis gunnellus*), scorpion fish (*Taurulus bubalis*) and pollack (*Pollachius pollachius*) (Williamson *et al.*, 2019).

Collision risk or encounter risk models (also used to estimate the probability of the animal occupying the same space as the device) typically use a physical description of the turbine and fish characteristics to estimate the potential collision rate. Studies even in worst-case scenarios have revealed small collision/encounter risk rates for fish, such as Shen *et al.* (2016) and Grippo *et al.* (2017), in Maine, in the United States; and Xodus Group (2016), in the Orkney Islands, Scotland.

Seabirds dive at operational turbine depths, presenting a collision risk that involves various behavioral movements, such as geographic distribution, seasonal habitat use, diving time and depth, among others (Sparling *et al.*, 2020). Thus, the behavior of seabirds can increase or reduce the risk of collision. In the following studies, behavior determined an increased risk of collision due to: diving depth in European shags (*Phalacrocorax aristotelis*) and black guillemot (*Cepphus grylle*) (Langton *et al.*, 2011; Furness *et al.*, 2012); the association with sites of rapid horizontal flow, such as Atlantic puffins (*Fratercula arctica*) (Waggitt *et al.*, 2016); and foraging terns (*Sterna sandvicensis, Sterna hirundo, Sterna paradisaea*) on device mats (ecological trap) (Lieber *et al.*, 2019). In addition to that, the location of RME structures, such as floating wave energy devices on the surface, can increase the risk of collision due to their use for resting seabirds, especially Arctic terns (*Sterna paradisaea*), Jackson *et al.* (2014). Collision risks were considered lower when the probability of diving close to turbines was greater in high tides than in ebb tides, and when this probability was lower in faster tidal flow (Cooper *et al.*, 2020), according to a study made with black guillemots (*Cepphus grylle*), European shags (*Phalacrocorax aristotelis*), Atlantic puffins (*Fratercula arctica*), Northern gannets (*Morus bassanus*), common guillemots (*Uria aalge*) and red-throated divers (*Gavia stellata*).

Despite these studies, foraging sites and diving behavior are highly variable among bird species, habitat use is site-specific and may vary within a site (Sparling *et al.*, 2020), making it difficult to calculate a specific risk even for the studied region. Therefore, the Scottish Natural Heritage (2016) guidance for collision risk models (using turbine and animal pattern data for estimation) can be used to choose a model suitable for the specific circumstance of the enterprise and the available data, thus avoiding generalizations.

4. PRIORITY SPECIES FOR MONITORING THE RISK OF COLLISION WITH MARINE RENEWABLE ENERGY HARVESTING SYSTEMS IN BRAZIL

Brazil was the first country in Latin America to install a wave plant, located in the port of Pecém, in the state of Ceará. In the Bacunga estuary, in the state of Maranhão, studies point to the technical feasibility of installing a tidal power plant (Ferreira and Estefen, 2009). Although the projects are not in force, the existence of dozens of bays with tidal heights between 3.7 and 8 m along the north coast of the country, and the announcement of the partnership between the Pecém Complex and the Swedish-Israeli company Eco Wave Power, for the implementation of a clean wave energy generation plant by the Ceará government, accelerate the concern with the Brazilian marine fauna (Piacentini, 2016; Ceará, 2021). In this section, a brief review of marine species found off the Brazilian coast susceptible to the risk of collision with marine renewable energy devices was carried out.

4.1 Marine mammals

In Brazil, 56 species of marine mammals have been found by 2020, of which 47 belong to the Cetacea order (whales, dolphins, porpoises), one species belongs to Sirenia and eight belong to Carnivores (seals, fur seals, elephant seal) (Santos, 2021a). Many of these marine species are called “vagant”, as they are occasional visitors to the Brazilian coast and are not part of the national survey on the risk of extinction published in 2018. According to this survey, eight species were considered threatened, with the main threats being pollution, including noise, collision with vessels and accidental fishing (ICMBio, 2018). Table 1 groups the species of marine mammals that are threatened and found in conservation areas. These species deserve special attention in monitoring the risk of collision with RME devices and vessels, when the installation, operation and maintenance of the enterprise are carried out.

RME projects are developed to operate in the coastal zone up to the maritime limit of the Exclusive Economic Zone – EEZ. These zones are located within the continental shelf according to the boundaries shown in Figure 4. Thus, the threatened species of the order Cetacea, *Balaenoptera borealis* (sei whale), *Balaenoptera physalus* (fin whale) and *Balaenoptera musculus* (blue whale) were not included in the Table 1, as records on the continental shelf are rare.

This survey does not aim to exclude the monitoring of other species of marine mammals (whales, dolphins, seals, fur seals, etc.) occurring in Brazil in areas where marine energy systems are deployed, because species that are not threatened must maintain or improve its state of conservation.

The species *Phocoena phocoena* (harbor porpoises), *Phoca vitulina* (harbor seal) and *Halichoerus grypus* (grey seals)

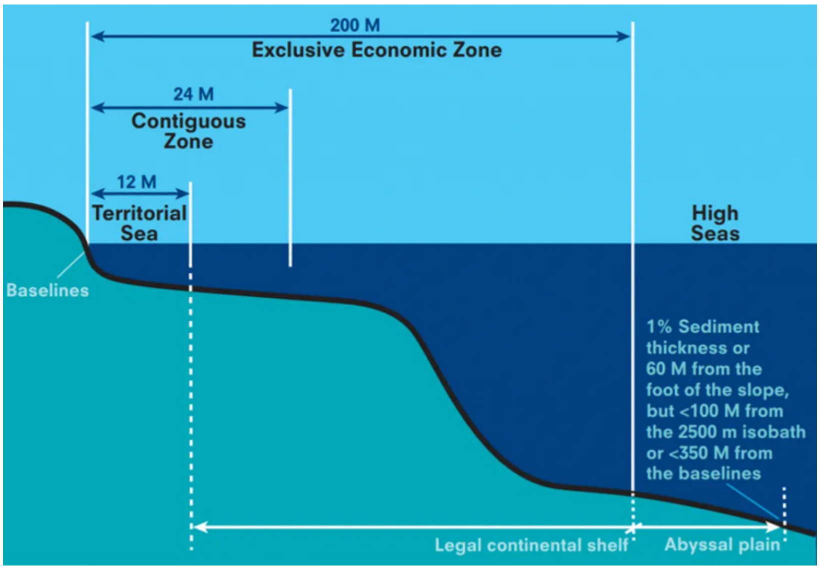

Figure 4. Maritime zones under the United Nations Convention of the Law of the Sea – UNCLOS (UNCLOS, 2012).

Table 1. Endangered species of marine mammals found in Brazilian protected areas (ICMBio, 2018; Monteiro-Filho *et al.*, 2013).

Order	Species	Common name	Category of extinction risk / Geographical distribution in Brazil / Presence in protected areas
Cetacea	*Physeter macrocephalus*	Sperm whale	Vulnerable species. Occurrence throughout the Brazilian coast, mainly in oceanic habitat. Rio Grande do Norte: REBIO Atol das Rocas. Santa Catarina: - APA Baleia Franca and REBIO Marinha do Arvoredo.
Cetacea	*Sotalia guianensis*	Guiana dolphin	Vulnerable species. Occurrence from the state of Amapá to Santa Catarina, mainly in coastal ecosystems such as bays, inlets and estuaries. The Guiana dolphin is found in 162 Brazilian conservation units, however, only the APA of Anhatomirim (SC) and REFAU Tibau do Sul (RN) have among their objectives the protection of the species.
Cetacea	*Eubalaena australis*	Southern right whale	Endangered species. Occurrence from the state of Bahia to Rio Grande do Sul, being recorded, in most cases, in places less than 10 m deep. Bahia: PARNA Marinho de Abrolhos, APA Ponta da Baleia; Santa Catarina: APA Baleia Franca; Rio Grande do Sul: REVIS Ilha dos Lobos, potentially, PARNA Lagoa do Peixe.
	Pontoporia blainvillei	Franciscana whale	Critically endangered species. It occurs from the state of Espírito Santo to Rio Grande do Sul; its preferred habitat includes coastal regions up to 50 m deep and some estuarine complexes. The species occurs in more than 70 conservation units.
Sirenia	*Trichechus manatus*	West Indian manatee	Endangered species. It occurs in the state of Alagoas, Pernambuco to the east of Ceará, appearing again on the west coast of Ceará to the Parnaíba delta, in Piauí. It reappears on Ilha do Gato, on the east coast of Maranhão, as far as the municipality of Oiapoque, in Amapá state. Alagoas: APA Piaçabuçu; Pernambuco/Alagoas: APA Costa dos Corais; Paraíba: ARIE Manguezais da Foz do Rio Mamanguape, RESEX Acaú-Goiana, APA Barra do Rio Mamanguape; Ceará: RESEX Prainha do Canto Verde; Maranhão/Piauí/Ceará: APA Delta do Parnaíba; Maranhão: RESEX Cururupu and Quilombo do Frexal; Pará: RESEX Chocoaré-Mato Grosso, São João da Ponta, Mãe Grande de Curuçá, Maracanã, Gurupi-Piriá, Marinha de Caeté-Taperaçu, Marinha de Tracuateua, Marinha de Soure; Amapá: ESEC Maracá-Jipioca, PARNA Cabo Orange.

Note: The following are Portuguese acronyms whose meanings have been translated into English: APA - Environmental Preservation Area; ARIE – Area of Relevant Ecological Interest; ESEC – Ecological Station; PARNA – National Park; REBIO - Biological Reserve; REFAU – Fauna Reserve; RESEX – Extractive Reserve and REVIS – Wildlife Refuge.

are not found on the Brazilian coast but were surveyed in Europe, and studies assessed their behavior with underwater devices and the risk of collision. This fact attests the need for conducting similar research on the installation and operation of these systems in Brazil. In addition, the behavioral differences of animals in nearby locations reaffirm the need for research on the interaction of Brazilian marine mammals (receptors) with RME devices and turbines (stressors).

4.2 Marine fish community

In Brazil, more than 1 300 species of marine fish are known, of which 98 have been classified as threatened with extinction. Of the species threatened with extinction, 72 were registered in conservation units, which keep the integrity of portions of the habitat, contributing to its preservation. It is advisable, in areas where RME systems are installed, to observe the occurrence of species threatened with extinction on the list of the Ministry of the Environment, according to Ordinance No. 445/2014.

According to Copping *et al*. (2020), commercially important fish species are included in the environmental monitoring carried out in international marine energy undertakings. The extinct Ministry of Fisheries and Aquaculture, in 2012, listed 121 species or groups of fish, 12 crustaceans and 10 molluscs (total: 143) as part of the marine biodiversity of commercial fisheries. From this biodiversity, 25 species or group of species are responsible for about 60% of the marine fishery production in Brazil. These species had an average production of more than 4 000 tons or relevant social and economic importance for national marine fisheries from 1995 to 2010 (Dias-Neto and Dias, 2015).

Table 2 presents the 18 main species or group of fish species of economic importance for Brazil. Crustacean species, such as shrimp, lobsters and crabs, were removed as they are not the target of this article. Table 2 also informs the use status of this set of species or group of fish species. Marine fish produced by aquaculture were not considered, as this activity usually takes place in a confined and controlled space. Thus, they would hardly be part of a collision risk analysis with RME devices.

In addition to the related species, the following are important for Brazilian commercial fisheries: swordfish (*Xhipias gladius)*, common dolphinfish (*Coryphaena hippurus*), king mackerel (*Scomberomorus cavalla*), blackfin tuna (*Thunnus atlanticus*), frigate tuna (*Auxis thazard), wahoo (Acanthocybium solandri), opah or moonfish (Lampris guttatus*), bluefish (*Pomatomus saltatrix*), stripped bass (*Centropomus spp.*), dusky grouper (*Epinephelus marginatus* and others), Atlantic goliath grouper (*Epinephelus itajara* and others), flounder (several species), Atlantic promfret (*Brama spp.*), red porgy (*Pagrus pagrus*), crucifix sea catfish (*Sciades proops*), among others (Dias-Neto and Dias, 2015).

Other species such as white marlin (*Tetrapterus albidus*), Atlantic sailfish (*Istiophorus albicans) and Atlantic blue marlin (Makaira nigricans*) are important for sport fishing. Due to the critical situation of stocks, they face restrictions on commercial fishing, as recommended by the International Commission for the Conservation of Atlantic Tunas – ICCAT (Dias-Neto and Dias, 2015). Therefore, they should also be part of environmental monitoring programs when they occur in areas of RME systems.

Research related to the interaction of fish with RME devices has mostly taken place in the United States, Canada and the United Kingdom, in the temperate zone of the Northern Hemisphere. It was expected that few species would occur in Brazil, as much of its territory is in the tropical zone. Only two species of shark/dogfish were found in Brazilian waters: porbeagle (*Lamna nasus*) and picked dogfish (*Squalus acanthias). Porbeagles occur off the southern coast of Brazil and are often found in groups in both coastal and oceanic waters up to 1 800m deep (Silveira, 2020). In Brazil, the porbeagle (Lamna nasus*) was not considered endangered (EN), being classified as insufficient data (DD). The picked dogfish (*Squalus acanthias*) is restricted to the coast of the southern region of the country and occurs sporadically in the states of Santa Catarina and Rio Grande do Sul. It is a demersal specie of cold and temperate waters, occurring on the continental shelf and higher slope. Picked dogfish was considered critically endangered (CR) in the country, with a declining population trend, and is included in the National Action Plan for the Conservation of Endangered Sharks and Marine Rays (ICMBio, 2018). Although studies carried out near the Bay of Fundy, Maine (USA) and Nova Scotia (Canada) do not assess the specific interaction of these animals with RME devices, these works are reference for future studies and environmental monitoring of marine energy projects that may be installed in the south of the country, where porbeagles and picked dogfish occur.

4.3 Seabirds

Seabirds are those that depend on the resources existing in marine environments for their survival, being highly adapted to live in the sea (Branco, 2004). They spend most of their lives moving across the oceans, remaining on land only for breeding. They can also be called oceanic or pelagic birds.

Table 2. Marine fish economically important for Brazil (Source: Dias-Neto and Dias, 2015).

Species or species groups	**Common name**	**Fishing area / Habitat**	**Average production for the period 1995 to 2010 (tons)**	**Use status / source**
Sardinella brasiliensis	Brazilian sardine	Southeast and South. It inhabits coastal waters, entering bays and estuaries. It is found between 30 and 100 meters deep.	56 334	Overexploited
Micropogonias furnieri	Whitemouth croaker	Southeast and South, but it is also found along the entire Brazilian coast. It is a coastal demersal species, associated with freshwater mouths.	28 319	Overexploited
Opistonema oglinum (Atlantic thread-herring), Harengula jaguana (scaled sardine) and others.	Other sardines (Atlantic thread-herring, scaled sardine and others)	Brazil. They inhabit coastal areas and usually form schools.	21 842	Fully exploited
Katsuwonus pelamis	Skipjack tuna	Southeast and South. They occur in oceanic areas, therefore, are exploited by industrial fishing.	23 449	Fully exploited
Thunnus obesus (bigeye tuna), *Thunnus alalunga* (albacore), *Thunnus albacares* (yellowfin tuna)	Other tuna (albacore, bigeye tuna and yellowfin tuna)	Brazil. They occur in oceanic areas, therefore, it is exploited by industrial fishing.	19 520	Full / in recovery
Cynoscion acoupa	Acoupa weakfish	North and Northeast, but occurs along the entire Brazilian coast. It has demersal and coastal habits, in shallow and brackish waters of estuaries and river mouths.	16 981	Fully exploited
Mugil spp.	Mugil	Brazil. Species with wide distribution, occurring in coastal, marine and estuarine waters.	13 623	Fully exploited
Species of the Ariidae family.	Catfish	Brazil. Most of the species occur in coastal areas, shallow, with muddy or sandy bottoms.	10 669	Fully exploited
Umbrina canosai	Argentine croaker	Southeast and South. Demersal species, occuring in coastal and marine areas.	9 969	Overexploited
Several species	Dogfish / sharks	Brazil. The vast majority of species are considered predators and occupy pelagic, demersal, abyssal, coastal, estuarine or freshwater environments.	9 946	Fully exploited
Scomberomorus brasiliensis	Serra Spanish mackerel	Brazil. They have pelagic behavior and a more coastal geographic distribution, being caught in small-scale fisheries.	9 883	Fully exploited
Sciades parkeri (VU).	Gillbacker sea catfish	North. It is a demersal species, found in estuaries and coastal waters up to 20 meters deep in northern Brazil, and can also be found in fresh water.	7 749	Fully exploited
Cynoscion guatucupa	Stripped weakfish	Southeast and South. In southern Brazil, they occur in coastal waters, generally at depths below 50 m, but specimens have already been captured at 150 m.	7 180	Overexploited
Lutjanus purpureus (VU)	Southern red snapper	North and Northeast. It is a marine demersal species, from tropical reef environments, occurring at depths from 26 to 340 m.	6 281	Overexploited
Macrodon ancylodon	King weakfish	North and Northeast. Demersal fish found in shallow coastal waters, in sand and mud bottoms, occurring at depths of 30 to 70 m.	5 753	Fully exploited
Urophycis brasiliensis	Brazilian codling	Southeast and South. Inhabits shallow coastal waters up to 190 m deep. Adults are close to the bottom, while young people are pelagic.	4 427	Fully exploited
Macrodon ancylodon	King weakfish	Southeast and South. Demersal fish found in shallow coastal waters, inhabits sand and mud bottoms, occurring at depths of 30 to 70 m.	4 064	Overexploited
Lophius gastrophysus	Blackfin goosefish	Southeast and South. It is a fish that inhabits the continental shelf and the upper slope, with reduced mobility, and is found between 40 m and 620 m in depth.	2 221	Overexploited

In Brazil, there are 13 taxa (species and subspecies) threatened with extinction according to the National Action Plan for the Conservation of Seabirds - PAN Aves Marinhas (Table 3), approved by Ordinance MMA/ICMBio No. 286, of 4 April of 2018.

In addition to these taxa, *Procellaria aequinoctialis* (white-chinned petrel), *Procellaria conspicillata* (spectacled petrel), *Thalassarche chlororhynchos* (Atlantic yellow-nosed albatross), *Diomedea epomophora* (Southern royal albatross), *Diomedea sanfordi* (Northern royal albatross), *Diomedea exulans* (wandering albatross), and *Diomedea dabbenena* (Tristan's albatross), of the Procellariiformes order, deserve attention in the assessment of the risk of collision, as they are seabirds and appear in the red book of endangered Brazilian fauna, despite not being included in the priority conservation strategies of the PAN Aves Marinhas. These birds occur mainly in the south and southeast of Brazil.

Of the species studied to assess the risk of seabirds colliding with RME devices, only the common tern (*Sterna hirundo*) and the Arctic tern (*Sterna paradisaea*) occur in Brazil. Lieber *et al*. (2019) observed in Northern Ireland that these species preferred to forage in device wake locations, which may increase the risk of collision with turbulent structures (shallow pinnacle at 5 m depth) as they forage close to the surface. Jackson *et al*. (2014) found that Arctic terns used floating wave energy devices to rest and potentially forage, which could increase the risk of collision. Thus, studies aimed at evaluating the stressor-receptor interaction of these species in the country already have data to be compared.

The neotropic cormorant (*Nannopterum brasilianus*), traditionally found in Brazil, is considered to be of the *Phalacrocorax* genus. Kennedy and Spencer (2014), however, showed that neotropical species, including the Galapagos Islands, belong to distinct clades and should be recognized in another genus (Piacentini *et al*., 2015), which makes the European shag (*Phalacrocorax aristotelis*), studied in Scotland, United Kingdom, a different specie of cormorant.

Table 3. Endangered bird taxa according to the PAN Aves Marinhas (Source: ICMBio, 2018).

Order	Species	Common name	Category of extinction risk / Geographical distribution in Brazil
Suliformes	*Sula sula*	Red-footed booby	Endangered (EN). In Brazil, it occurs in Fernando de Noronha, Atol das Rocas and the São Pedro and São Paulo archipelago. Strictly pelagic.
Suliformes	*Fregata ariel*	Lesser frigatebird	Critically endangered (CR). Occurrence of the subspecies *Fregata ariel trinitatis*, restricted to the islands of Trindade and Martin Vaz, in Espírito Santo, inhabits tropical and subtropical seas.
Suliformes	*Fregata minor*	Great frigatebird	Critically Endangered (CR). Occurrence of the subspecies *Fregata minor nicolli* on the islands of Trindade and Martin Vaz, Espírito Santo, inhabits tropical and subtropical seas.
Phaethontiformes	*Phaethon aethereus*	Red-billed tropicbird	Endangered (EN). Occurrence only of the subspecies *Phaethon a. aethereus*, with reproduction in Abrolhos and Fernando de Noronha. There are occasional records on the coast of Maranhão, Atol das Rocas, north and south of Bahia. They are mainly pelagic, inhabiting tropical and subtropical seas.
Phaethontiformes	*Phaethon lepturus*	White-tailed tropicbird	Endangered (EN). Occurrence in Abrolhos and Fernando de Noronha, also breeding sites. They are mainly pelagic, inhabiting tropical and subtropical seas.
Procellariiformes	*Pterodroma madeira*	Zino's petrel	Endangered (EN). There are records, by geolocators, on the coast of northeastern Brazil, a probable wintering area. Pelagic species.
Procellariiformes	*Pterodroma deserta*	Desertas petrel	Critically Endangered (CR). Overwintering areas between the coast of Ceará and Pernambuco, Espírito Santo and north of São Paulo. Pelagic species.
Procellariiformes	*Pterodroma incerta*	Atlantic petrel	Endangered (EN). Regular occurrence in waters adjacent to the south and southeast coast of Brazil, but there are records in the North and Northeast regions. Pelagic species.
Procellariiformes	*Pterodroma arminjoniana*	Trindade petrel	Critically endangered (CR). It takes place on Trindade Island, in Espírito Santo. Highly pelagic species, rarely approaching land.
Procellariiformes	*Puffinus lherminieri*	Dusky-backed shearwater	Critically endangered (CR). In Brazil, it only reproduces on two islands of Fernando de Noronha. Pelagic species.
Charadriiformes	*Sterna dougallii*	Roseate tern	Vulnerable (VU). There are records of passage in the Southeast, Northeast and North, but the wintering area occurs only in Bahia.
Charadriiformes	*Sterna hirundinacea*	South American tern	Vulnerable (VU). Largest records occur from Espírito Santo to Rio Grande do Sul. It nests in Brazil and is almost exclusively coastal.
Charadriiformes	*Thalasseus maximus*	Royal tern	Endangered (EN). Largest records occur from Espírito Santo to Rio Grande do Sul, but there are occurrences in the North and Bahia. It nests in islands of São Paulo. Inhabits coastal areas.

It is advisable that international studies be carried out in Brazil, even with common species and similar devices, when installation, operation and decommissioning of RME systems occur, as species tend to have behavioral variations (foraging and diving) in different locations. The search for local research in the region of the project should also be considered, so to obtain behavioral data on the species to be applied in the collision risk models.

4.4 Marine reptiles

The Reptilia class has some marine species of the orders Squamata, Crocodylia and Testudines. In Brazil, marine reptiles are represented by 5 of the 7 species of marine turtles (Table 4) existing in the world (Sforza *et al*., 2017). Belonging to the Testudines order, sea turtles use estuaries and/or oceans in their life cycle (Santos, 2021b). Sea turtles have great ecological importance, due to the cycling of energy and nutrients between different environments, in the control of the species they feed on and as a food source for crustaceans, birds, fish and mammals, although their predators are more restricted in the adult phase (Bjorndal, 1997).

Most of the world's sea turtles (*Caretta caretta, Chelonia mydas, Dermochelys coriacea, Eretmochelys imbricata, Lepidochelys olivacea, Natator depressus and Lepidochelys kempi*) are threatened with extinction, except for *Natator depressus* (Salvarani *et al*., 2013). The decline of populations is associated with human activities on their habitat, such as incidental capture through the use of different fishing gears and pollution by solid waste, which can hinder female access to the spawning site (compromising reproductive success) and become food (Mascarenhas *et al*., 2008), and climate change, due to the role of temperature in determining the sex of embryos. A 2°C increase in sand temperature can lead to the feminization of the entire population (Salvarani *et al*., 2013).

The life cycle of sea turtles is long and has a wide geographic distribution between feeding and reproduction areas, in a marine environment, and spawning sites, in a terrestrial environment. The sexual maturation of sea turtles varies between 10 and 50 years, depending on the species. For example, the maturation of *Chelonya midas* can range between 25 and 50 years (Sforza *et al*., 2017). These characteristics (late maturation, long life cycle and migratory behavior) imply a slow population replacement capacity which, added to anthropic actions, make sea turtles vulnerable species and, therefore, the target of various protection programs and projects. In Brazil, several federal, state and municipal marine and coastal protection areas were created to protect these species, such as the National Marine Park of Fernando de Noronha-PE and the Biological Reserves of Atol das Rocas-RN, of Santa Isabel-SE, and Train-ES (Sforza *et al*., 2017).

Based on the above, sea turtles are vulnerable to marine developments and, therefore, were included in this list of priority species for monitoring RME systems. Even though there are no studies that monitor the interaction of these animals with EMR devices in Copping *et al*. (2020). This fact agrees with Sforza *et al*. (2017), who developed a guide with information on areas of relevance for the conservation of turtles, in order to guide entrepreneurs, environmental agencies, consultants and researchers involved in the environmental licensing process in these areas. The publication attests the potential impacts of the implementation and operation of the main types of enterprise, with an indication of mitigation and monitoring measures. However, marine energy projects were not analyzed by Sforza *et al*. (2017), but due to damage caused by other

Table 4. Species of sea turtles from Brazil (Source: ICMBio, 2018).

Family	Species	Common name	Category of extinction risk / Geographical distribution in Brazil
Cheloniidae	*Caretta caretta*	Loggerhead turtle	Endangered (EN). Occurrence of individuals between Pará and Rio Grande do Sul, in coastal or oceanic areas. Priority spawning areas: north coast of Rio de Janeiro, Espírito Santo, north of Bahia and Sergipe.
Cheloniidae	*Chelonia mydas*	Green sea turtle	Vulnerable (VU). They are registered throughout the Brazilian coast and show more coastal habits. Priority spawning areas: Ilha da Trindade (ES), Atol das Rocas (RN) and Fernando de Noronha (PE).
Cheloniidae	*Eretmochelys imbricata*	Hawksbill turtle	Critically endangered (CR). Occurrence throughout the Brazilian coast. Priority spawning areas: northern Bahia and the state of Sergipe; and south of Rio Grande do Norte.
Cheloniidae	*Lepidochelys olivacea*	Olive ridley turte	Endangered (EN). Occurrence records throughout the Brazilian coast. Priority spawning areas: north of Bahia to the south coast of Alagoas.
Dermochelydae	*Dermochelys coriacea*	Leatherback turtle	Critically Endangered (CR). Occurrence records throughout the Brazilian coast. Priority spawning area: north coast of Espírito Santo.

types of projects (collision with tourist or industrial vessels, with rocky blocks in the construction of breakwaters and rockfall in coastal works, and entanglement by garbage, which make them more susceptible to collision with vessels), sea turtles must be included in research on the risk of collision with RME systems in what concerns the following behavior patterns: (1) evasion or attraction, (2) migration from preferred locations, and (3) vertical distribution in the water column due to the flow generated by turbines.

5. CONCLUSIONS

The pressing need to reduce greenhouse gas emissions to slow global warming is the driving force behind the development of the renewable energy sector. Brazil's potential to develop marine renewable energy systems touches upon the discussion about the environmental impacts of these technologies on ecosystems. The risk of collision of marine animals such as mammals, fish and birds is a factor of concern for the environmental monitoring of international RME projects.

The surveys evaluated did not record the occurrence of collisions with marine animals, which does not mean that they did not occur, but that they may not have been registered, due to the limitation of implemented projects and the significant challenges of monitoring. Furthermore, some studies have great data uncertainty. These factors allow gaps in knowledge of RME collision risk.

The integration of research from the fields of engineering, technology and biology is a solution, both for improving the understanding of the risks of collision of marine animals and for reducing this risk. Improving the knowledge of the risk of collision of marine animals can reduce barriers in the consent of RME projects, by adopting conservative levels of risk of collision, without considering the parameter of evasion of animals, preventing the development of the marine renewable energy sector in the world. In the review, no studies were identified with sea turtles, an animal that is the target of several environmental conservation projects in Brazil and with a strong influence on environmental conditions. Only four species, two of fish (*Lamna nasus* and *Squalus acanthias*) and two of birds (*Sterna hirundo* and *Sterna paradisaea*) occurring in the country were found in the analyzed studies, revealing the little knowledge of the interaction of Brazilian marine fauna with RME devices.

The need for future studies, even on prototypes or individual equipment, is essential to assess the potential risks of collision and other impacts of marine animal portrayed in this article (underwater noise, electromagnetic fields, mooring entanglement and changes in habitat). Therefore, fostering the development of these RME systems in the country is essential. Towards a future with zero GHG emissions, this article provides information for entrepreneurs, researchers and environmental agencies involved in environmental licensing, by indicating priority species for monitoring the interaction and risk of collision with RME devices in Brazil, with information on geographic distribution, habitats and extinction risk category or exploitation status necessary for environmental impact studies.

CONTRIBUTIONS

Catarina Luiza Damasceno Lima da Silva: Study design, methodology development, data collection and analysis, and manuscript writing.

Luís Felipe Umbelino dos Santos: Conception of the study, review of data analysis, suggestions and study advisorship, writing of the manuscript.

Marcos Antônio Cruz Moreira: Conception of the study, review of data analysis, suggestions and study advisorship, writing of the manuscript.

Pedro Henrique Castello Branco Dágola: Data analysis, work suggestions, writing and translation of the manuscript.

All authors contributed to the writing (reviewing and editing) of the manuscript.

REFERENCES

Ahmadian, R.; Falconer, R.; Bockelmann-Evans, B. (2012) - Far-field modelling of the hydro-environmental impact of tidal stream turbines. *Renewable Energy, 38* (1): 107-116. DOI: 10.1016/j.renene.2011.07.005.

Band, B. (2014) - Detailed Collision Risk Assessment: Marine Mammals, Basking Shark, and Diving Birds (Report No. REP 443-04-01 20141120). 233p. European Marine Energy Centre, Annex 3, Stromness, Orkney. https://tethys.pnnl.gov/publications/emec-fall-warness-test-site-environmental-appraisal.

Barros, S. R.; Wasserman, J. C.; Lima, G. B. (2010) - Risco Ambiental na zona costeira: uma proposta interdisciplinar de gestão participativa para os Planos de Controle a Emergências dos portos brasileiros. *Revista de Gestão Costeira Integrada-Journal of Integrated Coastal Zone Management, 10* (2): 217-227. DOI: 10.5894 / rgci173.

Bevelhimer, M.; Scherelis, C.; Colby, J.; Adonizio, M. A. (2017) - Hydroacoustic Assessment of Behavioral Responses by Fish Passing

Near an Operating Tidal Turbine in the East River, New York. *Transactions of the American Fisheries Society, 146* (5): 1028-1042. DOI: 10.1080/00028487.2017.1339637.

Benjamins, S.; van Geel, N.; Hastie, G.; Elliott, J.; Wilson, B. (2017) - Harbour porpoise distribution can vary at small spatiotemporal scales in energetic habitats. *Deep Sea Research Part II: Topical Studies in Oceanography, 141*: 191-202. DOI: 10.1016/j.dsr2.2016.07.002.

Bjorndal, K. A. (1997) - Foraging ecology and nutrition of sea turtles. In: Lutz, P. L.; Musick, J. A. (eds.), The biology of sea turtles, pp.199-231, CRC Press, Boca Raton, FL, EUA. ISBN: 0849384222. Disponível on-line em: http://www.seaturtle.org/library/BjorndalKA_1997_InThebiologyofseaturtles_p199-231.pdf.

Boehlert, G.; Gill, A. (2010) - Environmental and ecological effects of ocean renewable energy development: A current synthesis. Oceanography 23 (2): 68–81. DOI: 10.5670/oceanog.2010.46.

Branco, J. O. (2004) - Aves marinhas das Ilhas de Santa Catarina. In: Branco, J. O. (org.), Aves marinhas e insulares brasileiras: bioecologia e conservação, pp.15-36, UNIVALI, Itajaí, SC, Brasil. ISBN: 8586447919. Disponível on-line em: http://www.avesmarinhas.com.br/Cap%C3%ADtulo%201.pdf.

Ceará (2021) – Complexo do Pecém e Eco Wave Power assinam Memorando de Entendimento para implantação de Usina de Ondas. Governo do Estado do Ceará, Brasil. Disponível online em: https://www.ceara.gov.br/2021/06/01/complexo-do-pecem-e-eco-wave-power-assinam-memorando-de-entendimento-para-implantacao-de-usina-de-ondas/. Acesso em: 10 set. 2021.

Cooper, E.; Brocklehurst, J.; Smith, K. (2020) – ENFAIT - Enabling Future Arrays in Tidal Year 3 Environmental Monitoring Report. 23p., Nova Innovation Ltd., Edinburgh, Scotland. https://www.enfait.eu/wp-content/uploads/2020/10/EnFAIT-EU-0057-Y3-Environmental-Monitoring-Report-v1.0.pdf.

Copping, A. E., Battey, H.; Brown-Saracino, J.; Massaua, M.; Smith, C. (2014) - An international assessment of the environmental effects of marine energy development. *Ocean and coastal management, 99*: 3-13. DOI: 10.1016/j.ocecoaman.2014.04.002.

Copping, A. E.; Grear, M. E. (2018) - Applying a simple model for estimating the likelihood of collision of marine mammals with tidal turbines. *International Marine Energy Journal, 1 (1)*: 27-33. DOI: 10.36688/imej.1.27-33.

Copping, A. E.; Hemery, L.G. (2020) - OES-Environmental 2020 State of the Science Report: Environmental Effects of Marine Renewable Energy Development Around the World. Ocean Energy Systems (OES), Richland, WA, U.S. https://doi.org/10.2172/1632878.

Dias-Neto, J.; Dias, J. de F. O. (2015) - O uso da biodiversidade aquática no Brasil: uma avaliação com foco na pesca, 288p., Ibama, Brasília, DF, Brasil.

EPE - Empresa de Pesquisa Energética (s/d) (2020a) - Anuário Estatístico de Energia Elétrica 2020. 256p., Empresa de Pesquisa Energética, Rio de Janeiro, RJ, Brasil. https://www.epe.gov.br/pt/publicacoes-dados-abertos/publicacoes/anuario-estatistico-de-energia-eletrica.

EPE - Empresa de Pesquisa Energética (s/d) (2020b) - Balanço Energético Nacional 2020: Ano base 2019. 292p., Empresa de Pesquisa Energética, Rio de Janeiro, RJ, Brasil. https://www.epe.gov.br/sites-pt/publicacoes-dados-abertos/publicacoes/PublicacoesArquivos/publicacao-479/topico-528/BEN2020_sp.pdf.

EPE - Empresa de Pesquisa Energética (s/d) (2021) - Relatório Síntese do Balanço Energético Nacional 2021- Ano base 2020. 73p., Empresa de Pesquisa Energética, Rio de Janeiro, RJ, Brasil. https://www.epe.gov.br/pt/publicacoes-dados-abertos/publicacoes/balanco-energetico-nacional-2021.

Fairley, I.; Karunarathna, H.; Chatzirodou, A. (2017) - Modelling the Effects of Marine Energy Extraction on Non-Cohesive Sediment Transport and Morphological Change in the Pentland Firth and Orkney Waters. Report by Swansea University for Marine Scotland Science, Swansea, UK. https://data.marine.gov.scot/sites/default/files/SMFS%200807.pdf.

Ferreira, R. M.; Estefen, S. F. (2009) - Alternative concept for tidal power plant with reservoir restrictions, *Renewable Energy, 34*: 1151-1157. DOI: 10.1016/j.renene.2008.08.014.

Florêncio, M.; Trigoso, F. B. M. (2020) - Pesquisas e projetos desenvolvidos no Brasil para o aproveitamento do potencial de geração de energia elétrica com ondas e marés. VIII Congresso Brasileiro de Energia Solar – Anais CBENS 2020 (ISBN: 978-65-993338-0-4), Fortaleza, CE, Brasil. https://anaiscbens.emnuvens.com.br/cbens/article/view/972.

Fraser, S.; Williamson, B. J.; Nikora, V.; Scott, B. E. (2018) - Fish distributions in a tidal channel indicate the behavioural impact of a marine renewable energy installation. *Energy Reports, 4*: 65-69. DOI:10.1016/j.egyr.2018.01 .008.

Froese, R.; D. Pauly. (Eds) (2021) – FishBase (06/2021) [banco de dados]. Disponível em: www.fishbase.org.

Furness, R. W.; Wade, H. M.; Robbins, A. M. C.; Masden, E. A. (2012) - Assessing the sensitivity of seabird populations to adverse effects from tidal stream turbines and wave energy devices. *ICES Journal of Marine Science, 69* (8): 1466-1479. DOI: 10.1093/icesjms/fss131.

Grippo, M.; Shen, H.; Zydlewski, G.; Rao, S.; Goodwin, A. (2017) - Behavioral Responses of Fish to a Current-Based Hydrokinetic Turbine Under Multiple Operational Conditions: Final Report (ANL/EVS-17/6). 42p., Report by Argonne National Laboratory for U.S. Department of Energy, Illinois, U.S. In: https://publications.anl.gov/anlpubs/2017/02/129701.pdf.

Halvorsen, M. B.; Casper, B. M.; Woodley, C. M.; Carlson, T. J.; Popper, A. N. (2012) - Threshold for onset of injury in Chinook salmon from exposure to impulsive pile driving sounds. *Plos One, 7* (6): e38968. DOI: 10.1371/journal.pone.0038968.

Hastie, G. D.; Russell, D. J. F.; Benjamins, S.; Moss, S.; Wilson, B.; Thompson, D. (2016) - Dynamic habitat corridors for marine predators; intensive use of a coastal channel by harbour seals is modulated by tidal currents. B*ehavioral Ecology and Sociobiology, 70* (12): 2161-2174. DOI:10.1007/s00265-016-2219-7.

Holdman, A. K.; Haxel, J. H.; Klinck, H.; Torres, L. G. (2019) - Acoustic monitoring reveals the times and tides of harbor porpoise (*Phocoena phocoena*) distribution off central Oregon, U.S.A. *Marine Mammal Science, 35* (1): 164-186. DOI:10.1111/mms.12537.

ICMBio - Instituto Chico Mendes de Conservação da Biodiversidade (2018) - *Livro Vermelho da Fauna Brasileira Ameaçada de Extinção*. 4162p., Ministério do Meio Ambiente, Instituto Chico Mendes de Conservação da Biodiversidade, Brasília, DF, Brasil.

IEA- International Energy Agency (s/d) (2020) - Mix de geração de eletricidade global, 2010-2020. International Energy Agency, Paris, France. In: https://www.iea.org/data-and-statistics/charts/global-electricity-generation-mix-2010-2020.

IPCC - Intergovernmental Panel on Climate Change (2021) - Summary for Policymakers. In: Masson-Delmotte, V.; Zhai, P.; Pirani, A.; Connors, S. L.; Péan, C.; Berger, S.; Caud, N.; Chen, Y.; Goldfarb, L.; Gomis, M. I.; Huang, M.; Leitzell, K.; Lonnoy, E.; Matthews, J. B. R.; Maycock, T. K.; Waterfield, T.; Yelekçi, O.; Yu, R. and Zhou, B. (eds.) Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, pp. 3−32. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. DOI:10.1017/9781009157896.001.

IRENA - International Renewable Energy Agency (s/d) (2020) - Innovation outlook: Ocean energy technologies. 112p., International Renewable Energy Agency, Abu Dhabi, United Arab Emirates. https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2020/Dec/IRENA_Innovation_Outlook_Ocean_Energy_2020.pdf.

IRENA - International Renewable Energy Agency (s/d) (2021) - World Energy Transitions Outlook: 1.5°C Pathway. 312p., International Renewable Energy Agency, Abu Dhabi, United Arab Emirates. https://www.irena.org/publications/2021/Jun/World-Energy-Transitions-Outlook.

IUCN - International Union for Conservation of Nature (2001). Red List Categories and Criteria: Version 3.1. 30p., IUCN Species Survival Commission, Gland, Switzerland and Cambridge, UK. https://portals.iucn.org/library/sites/library/files/documents/RL-2001-001.pdf.

Jackson, A. C. (2014) - Riding the waves: use of the Pelamis device by seabirds. Proceedings of the 2nd International Conference on Environmental Interactions of Marine Renewable Energy Technologies (EIMR) 2014, Stornoway, Isle of Lewis, Outer Hebrides, Scotland. Disponível on-line em https://tethys.pnnl.gov/sites/default/files/publications/jacksonetal2014.pdf.

Jones, C.; Magalen, J.; Roberts, J. (2014) - Wave Energy Converter (WEC) Array Effects on Wave, Current, and Sediment Circulation: Monterey Bay, CA (Report No. SAND2014-17401). 39p., Report by Sandia National Laboratories for U.S. Department of Energy, Califórnia, U.S. https://tethys.pnnl.gov/sites/default/files/publications/Jones-et-al-2014.pdf.

Khaled, F.; Guillou, S.; Hadri, F.; Méar, Y. (2019) - Numerical modelling of the effect of the hydro-kinetic turbines on the transport of sediments - Application to the Rhone site. *MATEC Web Conference, 261*: 05003. DOI: 10.1051/matecconf /201926105003.

Keenan, G.; Sparling, C.; Williams, H.; Fortune, F. (2011) - Sea Gen Environmental Monitoring Programme Final Report. 81p., Report by Royal Haskoning for Marine Current Turbines (MCT), Edinburgh, U.K. https://tethys.pnnl.gov/sites/default/files/publications/Final_EMP_report_SeaGen.pdf.

Kennedy M.; Spencer H. G. (2014) - Classification of the cormorants of the world. Molecular *Phylogenetics and Evolution, 79*: 249-257. DOI: 10.1016/j.ympev.2014.06.020.

Langton, R.; Davies, I. M.; Scott, B. E. (2011) - Seabird conservation and tidal stream and wave power generation: Information needs for predicting and managing potential impacts. *Marine Policy, 35* (5): 623-630. DOI: 10.1016/j.marpol.2011.02.002.

Lieber, L.; Nimmo-Smith, W. A. M.; Waggitt, J. J.; Kregting, L. (2018) - Fine-scale hydrodynamic metrics underlying predator occupancy patterns in tidal stream environments. *Ecological Indicators, 94*: 397-408. DOI: 10.1016/j.ecolind.2018.06.071.

Lieber, L.; Nimmo-Smith, W. A. M.; Waggitt, J. J.; Kregting, L. (2019) - Localised anthropogenic wake generates a predictable foraging hotspot for top predators. *Communications Biology, 2* (1): 123. DOI: 10.1038/s42003 -019-0364-z.

Macaulay, J.; Malinka, C.; Coram, A.; Gordon, J.; Northridge, S. (2015) - The density and behaviour of marine mammals in tidal rapids (Report No. MR 7.1.2). 53p., Sea Mammal Research Unit, University of St. Andrews, St. Andrews, Scotland. https://tethys.pnnl.gov/sites/default/files/publications/MR7-1-2_porpoise_in_tidal_rapids_VF1.pdf.

Macaulay, J.; Gordon, J.; Gillespie, D.; Malinka, C.; Northridge, S. (2017) - Passive acoustic methods for fine-scale tracking of harbour porpoises in tidal rapids. *The Journal of the Acoustical Society of America, 141 (2)*: 1120-1132. DOI: 10.1121/1.4976077.

Matzner, S.; Trostle, C.; Staines, G.; Hull, R.; Avila, A.; Harker-Klimes, G. (2017) - Triton: Igiugig Fish Video Analysis (PNNL-26576). 60p., Pacific Northwest National Laboratory, Richland, WA, U.S. https://tethys.pnnl.gov/sites/default/files/publications/Triton-Igiugig-Report.pdf.

Mascarenhas, R.; Batista, C. P.; Moura, I. F.; Caldas, A. R.; da Costa Neto, J. M.; Vasconcelos, M. Q.; Rosa, S. S. *et al*. (2008) - Lixo marinho em área de reprodução de tartarugas marinhas no Estado da Paraíba (Nordeste do Brasil). *Revista de Gestão Costeira Integrada-Journal of Integrated Coastal Zone Management, 8* (2): 221-231. DOI: 10.5894/rgci138.

MMA- Ministério do Meio Ambiente (2008) - Macrodiagnóstico da Zona Costeira e Marinha do Brasil. 242p., Ministério do Meio Ambiente, Brasília, DF, Brasil.

Monteiro-Filho, E. L. A.; Oliveira, L. V.; Monteiro, K. D. K. A.; Filla, G. F.; Quito, L.; Godoy, D. F. (2013) - Guia Ilustrado de Mamíferos Marinhos do Brasil. 106p., Instituto de Pesquisa Cananéia (IPeC), São Paulo, Brasil.

Nedwell, J.; Brooker, A. (2008) - Measurement and Assessment of Background Underwater Noise and its Comparison with Noise from Pin Pile Drilling Operations During Installation of the SeaGen Tidal Turbine Device, Strangford Lough (Report No. 724R0120). 37p., Subacoustech Ltd., County of Down, Northern Ireland. https://tethys.pnnl.gov/sites/default/files/publications/Nedwell-Brooker-2008.pdf.

Piacentini, Patricia. (2016) - Faltam estratégias no Brasil para gerar energia das marés. *Ciência e Cultura, 68* (3): 11-13. DOI: 10.21800/2317-66602016000300005.

Piacentini, V. D. Q.; Aleixo, A.; Agne, C. E.; Maurício, G. N.; Pacheco, J. F.; Bravo, G. A.; Cesari, E. (2015) - Lista comentada das aves do Brasil pelo Comitê Brasileiro de Registros Ornitológicos. *Revista Brasileira de Ornitologia* (ISSN 2178-7875), 23 (2): 91-298. Disponível on-line em http://www.revbrasilornitol.com.br/BJO/article/view/1263/pdf_905.

Salvarani, P. I.; de Menezes Fernandes, A. C.; Morgado, F. M. R. (2013) - Percepção ambiental de estudantes na conservação das tartarugas marinhas em Aveiro, Portugal. *Revista de Gestão Costeira Integrada-Journal of Integrated Coastal Zone Management, 13* (2): 137-144. DOI: 10.5894/rgci334.

Santos, M. C. O. (2021a) - Mamíferos marinhos. In: Harari, J. (org.), Noções de Oceanografia, pp.627-646. Instituto Oceanográfico, São Paulo, Brasil. https://www.inserver.com.br/usp/livros/nocoes-oceanografia.pdf.

Santos, M. C. O. (2021b) - Tartarugas marinhas. In: Harari, J. (org.), Noções de Oceanografia, pp.573-597. Instituto Oceanográfico, São Paulo, Brasil. https://www.inserver.com.br/usp/livros/nocoes-oceanografia.pdf.

Sforza, R.; Marcondes, A. C. J.; Pizetta, G. T. (2017) - Guia de Licenciamento Tartarugas Marinhas-Diretrizes para avaliação e mitigação de impactos de empreendimentos costeiros e marinhos. Instituto Chico Mendes de Conservação da Biodiversidade, Brasília, DF, Brasil. https://www.icmbio.gov.br/portal/images/stories/comunicacao/publicacoes/publicacoes-diversas/guia_licenciamento_tartarugas_marinhas_v8.pdf.

Scottish Natural Heritage (s/d) (2016) - Assessing collision risk between underwater turbines and marine wildlife. 92p., Scottish Natural Heritage, Inverness, Scotland. In: https://tethys.pnnl.gov/sites/default/files/publications/scottish-natural-heritage-report.pdf.

Shen, H.; Zydlewski, G. B.; Viehman, H. A.; Staines, G. (2016) - Estimating the probability of fish encountering a marine hydrokinetic device. Renewable Energy, 97: 746-756. DOI: 10.1016/j.renene.2016.06.026.

Silveira, F. F. (2020) - Fauna digital do Rio Grande do Sul [banco de dados]. Disponível em http://ufrgs.br/faunadigitalrs /lamna-nasus-tubarao-sardo/.

Sparling, C.E.; Seitz, A.C.; Masden, E.; Smith, K. (2020) - Collision Risk for Animals around Turbines. In A.E. Copping; L.G. Hemery (Eds.), OES-Environmental 2020 State of the Science Report: Environmental Effects of Marine Renewable Energy Development Around the World, pp.28-65, Ocean Energy Systems (OES), Richland, WA, U.S. https://doi.org/10.2172/1632881.

Spellman, F. R. (2014) - Environmental impacts of renewable energy. 470p., CRC press, Boca Raton, U.S. https://doi.org/10.1201/b17744

Staines, G.; Zydlewski, G.; Viehman, H. (2019) - Changes in Relative Fish Density Around a Deployed Tidal Turbine during on-Water Activities. *Sustainability, 11* (22): 6262. DOI: 10.3390/su11226262.

Tolmasquim, M. T. (2016) - Energia Renovável: Hidráulica, Biomassa, Eólica, Solar, Oceânica. 452p., Empresa de Pesquisa Energética, Rio de Janeiro, Brasil. ISBN 978-85-60025-06-0.

UNCLOS - United Nations Convention of the Law of the Sea (s/d) (2012) - UNCLOS at 30. 15p., United Nations, New York, USA. In: www.un.org/depts/los/convention_agreements/pamphlet_unclos_at_30.pdf.

Viehman, H. A.; Zydlewski, G. B. (2017) - Multi-scale temporal patterns in fish presence in a high-velocity tidal channel. *PLOS ONE, 12* (5): e0176405. DOI: 10.1371/journal.pone.0176405.

Viehman, H.; Boucher, T.; Redden, A. (2018) - Winter and summer differences in probability of fish encounter (spatial overlap) with MHK devices. *International Marine Energy Journal, 1*(1): 9-18. DOI: 10.36688/imej.1.9-18 .

Waggitt, J. J.; Cazenave, P. W.; Torres, R.; Williamson, B. J.; Scott, B. E. (2016) - Quantifying pursuit-diving seabirds' associations with fine-scale physical features in tidal stream environments. *Journal of Applied Ecology, 53* (6): 1653-1666. DOI: 10.1111/1365-2664.12646

Williamson, B.; Fraser, S.; Williamson, L.; Nikora, V.; Scott, B. (2019) - Predictable changes in fish school characteristics due to a tidal turbine support structure. *Renewable Energy, 141*: 1092-1102. DOI: 10.1016 /j.renene.2019.04.065.

Wilson, B.; Batty, R.; Daunt, F.; Carter, C. (2007) - Collision Risks Between Marine Renewable Energy Devices and Mammals, Fish and Diving Birds. 110p., Scottish Association for Marine Science, Oban, Scotland. https://tethys.pnnl.gov/sites/default/files/publications/Wilson-et-al-2007.pdf.

Whitton, T. A.; Jackson, S. E.; Hiddink, J. G.; Scoulding, B.; Bowers, D.; Powell, B.; D'Urban Jackson, T.; Gimenez, L.; Davies, A. G. (2020) - Vertical migrations of fish schools determine overlap with a mobile tidal stream marine renewable energy device. *Journal of Applied Ecology, 57* (4): 729-741. DOI: 10.1111/1365-2664.13582.

Xodus Group (s/d) (2016) - Brims Tidal Array Collision Risk Modelling - Atlantic Salmon (Report No. A-100242-S02-TECH-001). 11p., Xodus Group, London, UK. In: https://tethys.pnnl.gov/sites/default/files/publications/Brims-Tidal-Array-Collision-Modeling-2016.pdf.

Yoshida, T.; Zhou, J.; Park, S.; Muto, H.; Kitazawa, D. (2020) - Use of a model turbine to investigate the high striking risk of fish with tidal and oceanic current turbine blades under slow rotational speed. *Sustainable Energy Technologies and Assessments, 37*: 100634. DOI: 10.1016/j.seta.2020.100634.

Zhang, J.; Kitazawa, D.; Taya, S.; Mizukami, Y. (2017) - Impact assessment of marine current turbines on fish behavior using an experimental approach based on the similarity law. *Journal of Marine Science and Technology, 22* (2): 219-230. DOI: 10.1007/s00773-016-0405-y.