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Review of anthropogenic impacts other than fishing on cartilaginous fishes

New Zealand Aquatic Environment and Biodiversity Report No. 107.

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Many human activities in the sea other than fishing could impact cartilaginous fishes (chondrichthyans – sharks, skates, rays and chimaeras), leading to displacement, interference with migratory, spawning and feeding behaviour, and death. Potentially deleterious human impacts include noise from pile driving, dredging and sonar surveys; electromagnetic fields (EMFs) generated by power stations; loss of habitat, eutrophication and entrapment caused by aquaculture facilities; and alteration of behaviour by ecotourism. In this report, we review the available information on such impacts. There is a dearth of information worldwide on anthropogenic impacts on chondrichthyans. The few original field-based studies were conducted on only a handful of species. Different species probably respond differently to various stimuli in their environment so the validity of extrapolating the results from the available studies to other species and locations is dubious.

Sharks and rays hear underwater sound best in low frequency bands (less than 1000 Hz). Noises in this range may be produced by shipping, underwater construction, pile driving, dredging, power stations and sonic surveys. Loud sounds in their audible range may repel sharks and rays whereas low sounds may attract them. Thus the animal’s response may depend on its distance from the source and the volume of the source. Species-specific and probably location-specific studies are required to assess actual impacts. Coastal development and dredging can affect sharks and rays through reduction in habitat area and quality, removal or repulsion of prey, or increased noise and EMFs. Two studies that addressed such impacts showed a clear reduction in shark abundance and survival in nursery areas following development.

Elasmobranchs (chondrichthyans other than chimaeras) have an extremely sensitive electromagnetic sense. EMFs can either attract or repel elasmobranchs. Sharks sometimes bite undersea cables because they emit EMFs that mimic those given off by prey. Power cables in the sea, such as those in an array of power generating turbines, typically generate relatively weak EMFs. Furthermore, EMF production can be reduced by shielding and burying the cable, and using DC rather than AC voltage. Although few direct studies have been conducted on elasmobranch responses to cables, modelling and theoretical considerations suggest that undersea cables can be designed to have minimal impact on elasmobranchs. In addition to EMF production, marine power stations may have physical impacts on elasmobranchs such as creating barriers to transit routes, collision, long-term displacement, habitat removal and decrease or increase in habitat heterogeneity.

Sharks may be attracted to aquaculture cages because of the concentration of potential prey, and become trapped inside where they may be killed by farmers attempting to remove them. More benign methods are being developed to release trapped sharks, and cage construction is evolving in an attempt to reduce their entrapment. The sparse available evidence suggests that aquaculture facilities may not affect the seasonal migratory behaviour of sharks, but further research in this area is required.

Shark-based ecotourism is an increasingly popular activity. Two studies assessed the impact of shark-cage diving on great white sharks, and the results were contradictory. In a South African study there was only a minor effect due to chumming on the sharks, and the effect declined over time. In contrast, in an Australian study, significant changes in shark behaviour were observed. Further work is required to determine what other factors might be important, such as the intensity of the tourism activity and the level of chumming.

Interactions between humans and chondrichthyans will undoubtedly increase in future. Our knowledge of the extent of such interactions, their impacts on the animals, and ways to mitigate such impacts, is sadly lacking. In New Zealand, resource consent hearings and Environment Court hearings are increasingly asking how human intrusions into the sea will affect marine animals (including chondrichthyans), but currently we have few answers.

1. INTRODUCTION

Chondrichthyan fishes (sharks, skates, rays and chimaeras) are generally slow-growing and have a low reproductive rate compared with other fishes. Consequently their productivity is low and their capacity to recover from human-induced mortality is limited. The effects of over-fishing on many chondrichthyan species are well understood and documented. Many other human activities, particularly in coastal and continental shelf areas, could potentially impact chondrichthyans, leading to displacement from habitats, interference with migratory, spawning and feeding behaviour, and death. Potentially deleterious human impacts include noise from pile driving, dredging and sonar surveys; electromagnetic fields generated by power cables in wind and tidal power stations; loss of habitat, eutrophication and entrapment of animals caused by aquaculture facilities; and alteration of behaviour by ecotourism.

The New Zealand National Plan of Action for the Conservation and Management of Sharks (NPOA) came into effect in October 2008 (Ministry of Fisheries 2008). It contains a suite of planned actions in the areas of research, compliance and management that aim "to ensure the conservation and management of sharks [defined to include all chondrichthyans] and their long-term sustainable use". The NPOA's focus was on the impacts of fishing, which is likely to constitute the greatest threat to the sustainability of sharks. However, it is anticipated that non-fishing related impacts on sharks will be incorporated into later versions (Ministry of Fisheries 2008). The NPOA contains a requirement to conduct a review of its achievements, and this will be carried out by the Ministry for Primary Industries in 2013. The purpose of the present study is to review anthropogenic impacts, other than fishing, on chondrichthyans in order to inform the NPOA review.

The overall objective of the study is:
"To collate and summarise information in support of a review of the National Plan of Action for the Conservation and Management of Sharks (NPOA – Sharks)".

The Specific objectives of project ENV201101 are:

1. To collate and summarise information in support of a review of the National Plan of Action for the Conservation and Management of Sharks (NPOA – Sharks).
2. To identify research gaps from Objective 1 and suggest cost-effective ways these could be addressed.
3. Information gathering on the full range of factors influencing shark populations, including emerging issues like the impacts on shark populations of noise, finfish aquaculture, tidal power generation and coastal development.

Objectives 1 and 2 were addressed by an earlier study (Francis & Lyon 2012). Objective 3 is addressed in this report.

2. METHODS

Chondrichthyan fishes are defined as all the cartilaginous fishes, and include sharks, skates, rays, and chimaeras. Elasmobranchs are cartilaginous fishes excluding the chimaeras so they are a subset of the chondrichthyans.

Published and unpublished literature were searched for studies carried out on non-fishing impacts on chondrichthyans. Information was sought on the following impact categories:

- Noise
- Development and dredging
- Power generation
- Aquaculture
- Ecotourism

There is a real dearth of information on how these human activities affect chondrichthyans, and almost none of it is from New Zealand (although some studies included species that occur in New Zealand waters). Furthermore, most of the available international literature is unpublished and in the form of reviews that were carried out as part of environmental impact statements; very few original studies have actually tested the effects of human activities on chondrichthyans. Consequently, locating and accessing relevant literature was difficult and much of it was repetitive. Rather than attempt a comprehensive review of all available literature, we focused on original studies where possible, plus a representative sample of the more comprehensive reviews.

Identified sources were synthesised into concise, informative summaries that included a bibliographic reference, list of the species covered, a description of the methods, and the major results and conclusions. This short, simple layout was used to facilitate ease and speed of scanning for relevant information. A full list of the references is provided, and readers are referred to the original sources for further details.

3. RESULTS

3.1 Noise

Myrberg, A.A. (2001). The acoustical biology of elasmobranchs. *Environmental Biology of Fishes 60*:31–45.
a) Species: Elasmobranchs.
b) Methods
  • Reports on the auditory capabilities and their associated functions of elasmobranchs.
  • Brief review of the physics of underwater sound as it relates to hearing by fishes.
c) Results and conclusions
  • The inner ears of elasmobranchs possess structures that are no different from other fishes, except they have an enlarged macula neglecta.
  • Sharks have demonstrated the highest sensitivity to low frequency sound (40 Hz to approximately 800 Hz).
  • Any sound can result in immediate withdrawal by sharks from a source, if its intensity suddenly increases 20 dB (10 times or more) above a previous transmission.
  • Sound follows the same physical principles when traveling through air or water, but differences in its structure and behaviour occur due to differences in density and compressibility, such as wave-speed and wave-length.

Hastings, M.C.; Popper, A.N. (2005). Effects of sound on fish. *California Department of Transportation Contract 43A0139 Report*. 82 p.
a) Species: Fish.
b) Methods
  • Examines the effects of sound (pile driving) on fish, any areas of uncertainty, and future research needed.
  • Brings together technical reports and peer-reviewed articles to provide a rationale to establish interim guidance for impact thresholds, for the purpose of protecting listed and commercially important species.

c) Results and conclusions

- Studies of hearing capabilities (albeit very limited and very much in need of replication) suggest that sharks and rays probably do not detect sounds at frequencies above 800 to 1000 Hz.
- The effects of sound on fishes are variable and, as yet, there are no rules as to what sounds will affect fish and how they will be affected.
- A limited number of quantitative and qualitative studies and observations show mortality related to pile driving, and also provide some data pertaining to the effects of sound on fishes.
- Results based on sound signals (other than pile driving), indicate that some exposures to sound will cause a change in the hearing capabilities of some test fish species, or will damage the sensory structures of the inner ear.
- There are suggestions that exposure to sound has the potential for affecting other aspects of fish physiology, and that these effects may range from the macro (destruction of the swim bladder) to the cellular and molecular.
- Data from explosive blast studies (not pile driving), indicate that very fast, high-level acoustic exposures can cause physical damage and/or mortally wound fish. Lesser effects might also occur, but these have not been well documented.
- The number of species studied in tests of the effects of explosives is very limited with no investigations to determine whether blasts that do not kill fish have had any impact on short- or long-term hearing loss, or on other aspects of physiology, or behaviour.
- There are no peer-reviewed studies that examine the effects of pile driving on fish hearing, there are only a few non-peer-reviewed reports about effects on non-sensory structures.
- The degree of damage to fish is not related directly to the distance of the fish from the pile, but to the received level and duration of the sound exposure.
- The use of a bubble curtain to separate an explosive sound source from caged bluegill significantly reduced mortality of this freshwater species.
- It is difficult to extrapolate to pile driving from studies of other types of noise (pure tones or air guns), unless the signal is described in a format used to describe pile driving (e.g., acoustic energy flux or acoustic intensity over time).
- Only additional well-controlled peer-reviewed studies of behavioural and physiological responses to pile driving, will provide clear scientific support in the development of criteria to assess the effects of pile driving on fishes.

Popper, A.N.; Hastings, M.C. (2009). The effects of human-generated sound on fish. *Integrative Zoology 4*: 43–52.

a) Species: Fish.

b) Methods

- Discusses the potential effects of sound on fish, including short-lived very loud sounds and longer lasting but less intense sounds.

c) Results and conclusions

- It is nearly impossible to extrapolate from results with one sound source, one fish species, or even fish of one size, to other sources, species, or fish sizes.
- Many marine organisms use sound to communicate as a prelude to or during mating, in aggregating, or in warning of danger. It also provides animals with a 3-D view of their world that often extends far beyond the other senses.
- A visual scene is often limited to relatively short distances, depending on environmental clarity and brightness. An auditory scene might extend much further than the visual scene and provides animals with a very broad view of their world.
- Many studies have focused on measuring the lowest sound level an animal can detect, its ‘absolute threshold’.
- Sound is critically important to aquatic animals for all aspects of their lives. Anything that interferes with the detection of sound has the potential to have a significant impact on the lives of these organisms and affects not only individual animals but also reproduction and the survival of species.
- The aquatic acoustic environment is not limited to biotic and natural abiotic sources. Natural abiotic sounds include a wide range of human-generated sounds. There is growing concern that

these sounds are not only affecting animal hearing and the ability to communicate, by increasing masking levels in the environment, but that they might also have more immediate and substantial effects such as animals moving from feeding sites, or their immediate death.
• The sources of anthropogenic sounds are extensive and include boats, ships, seismic exploration devices, construction activities, and active sonars. They range from very loud sounds to sounds that are less intense but long lasting.
• Exposure to intense sound sources is usually relatively brief because they occur in localised areas. The long lasting sounds such as harbours or aquaculture facilities cannot easily be avoided.
• At this time, virtually nothing is known about the damage or death that would result from pile driving.
• Cites studies that looked at the effects of a seismic exploration on fishing success for haddock and Atlantic cod. They found that, compared to pre-seismic catches, there was a significant decline in the long-line catch rate during and after the seismic study. The catch rate did not return to normal for at least five days after the end of the seismic study.
• There is limited data on the effects of sonar. There is no evidence of fish mortality or tissue damage, although low-frequency sonars might produce temporary hearing loss in some species.
• Fish that are hearing-specialists experience temporary hearing loss when exposed to increased background noise levels for 24 hours or more. Fish that are hearing-generalists do not necessarily show hearing loss. It is likely that a sound pressure level has to be at least some level above a fish's threshold before any hearing loss occurs.
• The response to sounds by fish might range through a change in behaviour, a mild awareness of the sound, a startle response, small temporary movements for the duration of the sound, larger movements that might displace fish from their normal locations for short or long periods of time, or sounds that may change the migration routes of fish.

3.2 Development and dredging

Feldheim, K.A.; Edrén, S.M.C. (2002). Impacts of dredging on marine communities - the Bimini lemon shark. *Bahamas Journal of Science 5*: 28–35.
a) Species: Lemon shark (*Negaprion brevirostris*).
b) Methods
• Discusses the effects of construction and dredging in the Bahamas during the building of a casino, marina, and condominiums, on the marine ecosystem (notably the lemon shark).
• Studied lemon sharks using PIT tags, microtags and genetic methods.
c) Results and conclusions
• Neonate and juveniles use mangrove habitat. Removal of mangrove trees during construction reduced the habitat available for young lemon sharks and increased their chances of predation.
• Juvenile recapture dropped from 34 to 11 after intense dredging in North Sound.
• Adult lemon sharks use Bimini as a spawning and mating area. Annual output of pups birthed in Bimini has drastically declined since the dredging has occurred.

Jennings, D.E.; Gruber, S.H.; Franks, B.R.; Kessel, S.T.; Robertson, A.L. (2008). Effects of large-scale anthropogenic development on juvenile lemon shark (*Negaprion brevirostris*) populations of Bimini, Bahamas. *Environmental Biology of Fishes 83*: 369–377.
a) Species: Lemon shark (*Negaprion brevirostris*).
b) Methods
• Identification of potential effects from a large development (a 930-room hotel, 3000 m^2 casino, 18 hole golf course, and two marinas) in the Bahamas on juvenile lemon shark growth and survival at three nurseries (North Sound nearest the development, and two others further away).
• Used before-after, control-impact (BACI) analysis, estimated survival rates, and compared habitat structure.
c) Results and conclusions
• North Sound was subjected to intermittent periods of dredging during development.
• No significant difference among growth rates was observed at the three nurseries before and after impact.

• There was a significant decrease in first-year survival rate (by 23.5%) at North Sound after impact.
• Habitat structure changed with seagrass percentage cover declining by 17.7%.
• Decline in seagrass bed cover and juvenile survival rates were correlated with increased dredging activity.

3.3 Power generation

Marra, L.J. (1989). Sharkbite on the SL submarine lightwave cable system: history, causes and resolution. *IEEE Journal of Oceanic Engineering 14*: 230–237. (Abstract only viewed)
a) Species: Deepwater sharks.
b) Methods
• Includes nature of the shark bite, teeth morphology, hypothesis on why sharks bite cables, development programmes for resolving shark-bite issues.
c) Results and conclusions
• In some situations undersea cables can attract sharks.

Dadswell, M.J.; Rulifson, R.A. (1994). Macrotidal estuaries - a region of collision between migratory marine animals and tidal power development. *Biological Journal of the Linnean Society 51*: 93–113.
a) Species: Skate.
b) Methods
• Models the effect of low-head underwater turbines on migrating fishes and one skate (Raja) in the Bay of Fundy, Nova Scotia.
c) Results and conclusions
• A skate was found below the Annapolis River STRAFLO turbine with its body sliced.
• Mechanical strike rather than pressure, cavitation, or shear, was considered the only likely cause of mortality of sharks (and presumably skates) longer than 1.5 m. [It seems likely that the incidence and impact of mechanical strike would depend on the design of the turbines.]

Gill, A.B.; Taylor, H. (2001). The potential effects of electromagnetic fields generated by cabling between offshore wind turbines upon elasmobranch fishes. *Countryside Council for Wales Contract Science Report 488*. 60 p.
a) Species: Elasmobranchs.
b) Methods
• Literature review of published peer reviewed papers, and web published reports on electroreception in elasmobranchs, offshore wind developments in Europe and associated environmental effects, and the biology of British elasmobranchs.
• Undertake a pilot study on the lesser spotted dogfish (*Scyliorhinus canicula*), to compare behavioural responses to electric fields simulating prey and a typical power transmission cable.
c) Results and conclusions
• Active electroreception in electric fish has received a lot of attention but only two studies were concerned with active electrolocation by elasmobranchs. The behaviour of elasmobranchs in regard to their electric sense has, to date, been widely neglected.
• Information regarding the electromagnetic fields (EMFs) emanating from underwater power cables used for offshore wind farms is very limited. Environmental Impact Assessments have a limited amount of information on the specifications for undersea cabling and the potential effects of EMFs on receptive organisms has only been referred to briefly. No published research was found regarding the effects of EMFs produced by undersea cables on fish.
• The lesser spotted dogfish showed an avoidance response to electric fields at 10 μV/cm (simulating the maximum predicted to be emitted from 3-core undersea 150 kV, 600 A cables), and an attraction response to fields at 0.1 μV/cm, 10 cm from the source (simulating prey).
• The avoidance response of the dogfish to 10 μV/cm electric fields was highly variable among individuals.

Walker, T.I. (2001). Review of impacts of high voltage direct current sea cables and electrodes on chondrichthyan fauna and other marine life. *Marine and Freshwater Resources Institute Report 20*. 68 p.

a) Species: Chondrichthyans.

b) Methods

- Literature review of the effects of EMFs on marine fauna (particularly sharks). Places those findings in context with the current understanding of shark biology such as migration and breeding in Bass Strait. Determines ranges and threshold levels of response to EMF's (by sharks and other fish, and macro-invertebrates) and predicts impact responses for ranges of electric and magnetic field strengths.

c) Results and conclusions

- Animals in their natural environments experience a complex mix of electric fields and magnetic fields. Sensory receptors have evolved to provide the animals with information about their environment from the naturally occurring electric and magnetic fields.
- Depending on species, very weak electric fields (0.002–100 $\mu V\ cm^{-1}$) of low frequency (from close to DC to more than 15 kHz) of both biological and non-biological origin are detected with ampullary receptors. Ampullae of Lorenzini in chondrichthyans are used for detecting DC electric fields (through their movement or the movement of their prey) and the low frequency components of oscillation AC fields, both of which are emitted by prey animals. The lowest threshold values reported are 0.002 $\mu V\ cm^{-1}$ for chondrichthyans, 1–10 $\mu V\ cm^{-1}$ for lampreys, and approximately 70 $\mu V\ cm^{-1}$ for teleosts. A second type of electroreceptor (tuberous receptors) which occurs only in weakly electric fishes, functions for social communication and electrolocation using high-frequency electric fields generated by electric organs.
- One hypothesis for geomagnetic navigation is that as an animal swims through the geomagnetic field it experiences electromagnetic induction and can use this to determine its direction and speed by deriving directional information from the oscillating electric field that results as the ampullae on the head move back and forth.
- Gummy sharks are epibenthic and more likely to be affected by HVDC cables than school sharks which occur throughout the water column.
- Includes details of the HVDC Basslink cable electric field and magnetic fields, and how these change with burial.
- Chondrichthyans are repelled by strong electric fields and attracted by very weak varying electric fields. The electric fields from the Basslink electrodes are likely to repel chondrichthyan species, but will not be strong enough to cause electrotaxis.
- The electric field strength induced by ions moving with tidal flow through the magnetic field created by the Basslink cables will be highly variable depending on the tidal cycle. For most of the time, the magnitude of the induced electric fields will fall within the range of the high variation in the naturally occurring electric fields normally experienced by marine animals. These electric fields will be detected by chondrichthyan species, but the fields will not be strong enough to repel these species. For chondrichthyans close to the seabed crossing the Basslink interconnector during strong tidal flow, there may be some distortion to the electrosensory information received by the animals for navigation purposes.
- Sharks will probably learn the high signal areas and swim around or above them. This has occurred in many tests where a voltage was used to attract sharks to determine their level of sensitivity. As a shark first detects a signal from a distance, it appears attracted and swims in the direction of the signal. When reaching a distance where the signal is too high, the shark immediately turns and rapidly swims away from the area.
- Chondrichthyan species moving along the seabed navigating by naturally induced electric fields may become temporarily disorientated as they approach the induced electric field in the magnetic field of a cable. There are no observational data to support or reject this proposal.
- Chondrichthyan species may avoid crossing the Basslink cable. There are reports of animals avoiding magnetic fields. This may cause a reduction in the mixing between populations of species. This would be less disruptive if there were breeding sites on both sides of the cable.

• The Basslink main cable will pass approximately 30 km to the east of the important feeding ground for young white sharks. The effects of the Basslink cables on these young animals are difficult to predict.

Gill, A.B.; Kimber, J.A. (2005). The potential for cooperative management of elasmobranchs and offshore renewable energy development in UK waters. *Journal of the Marine Biological Association of the United Kingdom 85*: 1075–1081.

a) Species: Elasmobranchs.

b) Methods

• Reviews the potential impacts on elasmobranchs in UK waters from offshore renewable energy developments. Suggests cooperative management strategies for elasmobranch conservation and offshore renewable energy development. Impacts of electro-magnetic fields are reviewed and discussed.

c) Results and conclusions

• Potential short-term impacts of offshore renewable energy developments include construction and decommissioning. These stages may cause habitat disturbance, increased prey availability for opportunistic species, and short term displacement.

• Potential long-term impacts may arise from energy generation, energy transmission, areal extent, and decommissioning. These factors may affect elasmobranchs through low frequency noise, electric fields, magnetic fields, barriers to transit routes, collision, long term displacement, habitat removal and decrease in habitat heterogeneity.

• Positive effects may also occur, such as generation of new habitat, and closure of water bodies around power stations which will then act as marine reserves.

• Empirical studies on the impacts are very rare, but this study provides a good review of the main theoretical effects of the impact factors.

• Cooperative management strategies could include the timing of offshore developments, relocation of offshore developments, cable design and development, habitat improvement, and protected areas.

Scottish Executive (2007). Scottish marine renewables SEA. *Environmental Report Section C SEA Assessment: Chapter C18 EMF*. 21 p.

a) Species: Chondrichthyans.

b) Methods

• Summarises the outputs from the Collaborative Offshore Wind Research into the Environment (COWRIE) programme.

• Lists electrosensitive and magnetoreceptive species from United Kingdom coastal waters.

c) Results and conclusions

• The EMF’s generated by submarine cables such as those associated with offshore wind farms are within the range of detection by certain aquatic species.

• The electric fields produced directly by power cables are, for the most part, contained within the cable envelope by the screening effect of the sheath and armouring. Electric fields can, however, be induced in nearby electrical conductors such as seawater, within the area influenced by the cable’s magnetic field.

• Magnetic fields are produced from AC or DC current passing through the conductor and these emanate outwards from the cable in a circular plane perpendicular to its longitudinal axis. The field strength produced as a result of the operation of electricity transmission (AC or DC) decreases rapidly with distance away from the source (the decay curve follows the inverse square law).

• Electrical and magnetic fields generated by the operation of wave and tidal devices are likely to be small and within the variation range of naturally occurring fields in the North Sea, but detectable to electro/magnetosensitive species. Burial of the cables will offer a protective barrier to electro/magnetosensitive species from the strongest magnetic and induced electric fields generated next to the cable.

Öhman, M.C.; Sigray, P.; Westerberg, H. (2007). Offshore windmills and the effects of electromagnetic fields on fish. *Ambio 36*: 630–633.
a) Species: Elasmobranchs.
b) Methods
- Overview of the types of submarine cables that are used for electric transmissions in the sea, describe the character of the EMF's produced, and review the effects that magnetic fields have on fish.

c) Results and conclusions
- In windfarms, different types of cables are used for between turbine (array-to-transformer), and transformer-to-shore transmissions. It is the electric current in these cables that produce electric and magnetic fields (EMF's).
- At present, there is limited evidence that fish are influenced by EMFs that underwater cables from windmills generate.
- A magnetic field is characterised by magnetic flux density (B) measured in Tesla (T) (1T = 10,000 Gauss). The magnetic field is induced by electric currents and characterized as either alternating (AC) or static (DC). In the DC case the magnetic field exists without an accompanying electrical field, while for the AC case both fields coexist simultaneously.
- The Earth's magnetic field is a DC magnetic field. This field has a flux of about 60 µT at the poles, and 30 µT at the equator. There is also a naturally occurring low frequency AC magnetic field generated by ocean motion and disturbances of the ionosphere.
- Types of submarine electric cable are i) telecommunication cables, ii) different configurations of high voltage direct current cables (HVDC), iii) alternating current three-phase power cables, and iv) low voltage cables. The HVDC cables are commonly used in the sea.
- Elasmobranchs can gain spatial information by detecting fields created by movements of ocean currents and by the movements that they make themselves through the Earth's magnetic field. They also have sensitive electro-receptors usually located on the head, around the mouth, and along the body.
- Studies have shown that some fish species are magnetosensitive and that magnetic fields could affect their orientation.

OSPAR Commission (2008). Background document on potential problems associated with power cables other than those for oil and gas activities. *OSPAR Commission Report*. 50 p.
a) Species: Chondrichthyans.
b) Methods
- Summarised previous research to show the potential problems from undersea power cables.

c) Results and conclusions
- Undersea power cables use either Alternating Current (AC) or Direct Current (DC) transmission. Modern submarine telecommunication systems are fibre optic cables using pulses of light to transport information. Coaxial cables are the former standard, and are sporadically still in service.
- There are no clear indications that underwater noise caused by the installation or operation of undersea cables poses a high risk of harming marine fauna.
- Calculations of the temperature effects of operating cables are consistent in their predictions of significant temperature rise in the sediment around the cables.
- EMFs are detected by a number of species and many of these species respond to them.
- Emission of magnetic fields is best limited by an appropriate technical design (three-phase AC, bipolar DC transmission system). Directly generated electric fields are regarded to be controllable by adequate shielding, induced electric fields generated by the magnetic field do occur.
- Release of contaminants from the cable itself can occur if they are not removed after decommissioning.
- Disturbance effects related to undersea power cables are in general expected to be temporary and localised.

• Table 4.6 shows data on EMF strength from various cables, monopolar DC, Bipolar DC, AC (3-phase), and natural conditions. These were often greater than natural levels near the cables but declined to background levels with increasing distance from the cables.

Gill, A.B.; Huang, Y.; Gloyne-Philips, I.; Metcalfe, J.; Quayle, V.; Spencer, J.; Wearmouth, V. (2009). COWRIE 2.0 Electromagnetic Fields (EMF) Phase 2: EMF-sensitive fish response to EM emissions from sub-sea electricity cables of the type used by the offshore renewable energy industry. *COWRIE-EMF-1-06*. 128 p.
a) Species: Thornback skate (*Raja clavata*), spiny dogfish, lesser-spotted dogfish (*Scyliorhinus canicula*).
b) Methods
• Acoustic tracking was used on three elasmobranch species to determine responses to EMFs of the type and magnitude produced by offshore wind farm transmission cables.
• Measured the electric and magnetic fields produced by two existing wind farm underwater cables.
c) Results and conclusions
• The thornback skate and lesser-spotted dogfish studied can respond to the presence of EMFs that were of the type and intensity associated with undersea cables. The responses recorded were not predictable and did not always occur. When they did occur, they appeared to be species dependent and individual specific.
• The main result of lesser-spotted dogfish being found nearer to the cable and moving less when a current was flowing is consistent with the area restricted searching that is associated with feeding in this benthic dogfish. The responses of some skate individuals suggests a greater searching effort during cable switch on.
• EM-sensitive species were predicted to encounter fields at or above the lower limit of their detection 295 m from a cable.

Fisher, C.; Slater, M. (2010). Effects of electromagnetic fields on marine species: a literature review. *Ocean Wave Energy Trust Report*. 23 p.
a) Species: Elasmobranchs.
b) Methods
• A literature review of the effects of EMF's on marine species.
c) Results and conclusions
• Electromagnetic sensitivities vary significantly among species. Elasmobranchs were noted to have extreme sensitivity to low frequency AC electric fields, including the range between 1/8th Hz to 8 Hz, with some species sensitive to levels as low as 1 nV/m (1 x 10^{-9} volts/meter). No references were found for elasmobranch sensitivity to magnetic fields.
• Teleost fish, including salmonids, also have an electric field sensitivity but it is orders of magnitude less sensitive than in sharks.
• Reviews or summarises a limited number of elasmobranch papers.
• Responses of elasmobranchs to EMFs included repeated circling, attacks on the source of the field, effects on cardiac and respiratory rhythms, and impacts on ability to orient. Table 1 summarises these impacts. It includes sharks (general), blue sharks, *Mustelus canis*, large dogfish, skates (general), *Raja clavata*, and stingray (general). The response tested for, B-field (Magnetic field), E-field (Electric field), frequency, and shown effects are tabulated.

Olsson, T.; Larsson, A.; Bergsten, P.; Nissen, J. (2010). Impact of electric and magnetic fields from submarine cables on marine organisms - the current state of knowledge. *Vattenfall Ocean Energy Programme Final Report*. 64 p.
a) Species: Chondrichthyans.
b) Methods
• Provide an up to date knowledge base for the environmental effects in the marine environment due to EMF and underwater cables from wave power farms and off shore wind power farms.
• Includes the technical background to EMFs, the EMFs created from submarine power cables and wave energy converter units, mechanisms for detecting EMF's, effect of EMFs on marine

life and environmental impact assessments requirements for EMF impacts from some northern hemisphere countries.

c) Results and conclusions

• Electric and magnetic fields within the magnitude expected from marine renewable energy lie within the detection range of some electroreceptive marine organisms and within the assumed detection of magnetoreceptive marine organisms.

• Behavioural effects have been shown in experiments on elasmobranchs that use electric fields for detecting prey. The noticed effects have been considered too small, or the results have not been possible to use, for evaluation of any potential environmental impacts.

• From a literature review no results were found that suggested that present sub-sea power cables posed a threat to the marine environment due to EMF.

• Different countries have different environmental impact assessment consent processes, suggesting that the mechanisms and impacts of EMF's are not fully understood.

• Electroreception is believed to be closely linked to mechanisms involved in finding prey, locating conspecifics (i.e. other individuals), finding mates and in some instances for navigation while magnetoreception is believed to be primarily linked to navigation and homing.

• Based on the differences of the fields generated by AC and DC current, fish are most likely to perceive static and alternating magnetic fields in different ways. The field generated from a DC cable will be perceived as a static amendment to the geomagnetic field while the field from an AC cable will alternate.

• Most organisms are unable to produce electricity voluntarily, but they all emit weak bio-electrical currents as a result of muscle activity. These emitted electric fields consist of both AC and DC fields, of which the AC fields are generally smaller than the DC fields.

• There are also some organisms that are known (or presumed) to use induced electric fields related to the natural geomagnetic field as navigation cues.

• Passive electroreception is when an organism can detect an emanating electric field from another organism (or another source emitting electric fields). It is the most common type of electroreception. Active electroreception is when an electric fish detects distortions in its own electric field caused by conducting and non-conducting objects within the field.

• The detection by the elasmobranchs of the electric fields is registered through a series of pores on the surface skin connected with canals filled with a conductive jelly to clusters of ampullae which enable them to detect small voltage gradients in the environment around them.

• A literature review and modelling showed that magneto- and electro-receptive species may encounter detectable EMFs emitted by a power transmission cable in a range of a up to a few hundred metres, depending on the species and the cable characteristics.

• Electric field thresholds for chondrichthyans (based on behavioural effects) were as low as 0.1 µV/m for hammerhead sharks (*Sphyrna lewini* and *S. tiburo*) and sandbar sharks (*Carcharhinus plumbeus*). The behavioural threshold for lesser spotted dogfish (*Scyliorhinus canicula*) was 2–150 µV/m, thornback ray (*Raja clavata*) 1–10, smooth dogfish (*Mustelus canis*) 1.8, round stingray (*Urobatis halleri*) 0.5, nurse shark (*Ginglymostoma cirratum*) 0.5–2.5, spotted ratfish (*Hydrolagus colliei*) 20 µV/m.

• Sharks that navigate over long distances are widely thought to use the Earth's magnetic field for navigation. Tiger sharks, blue sharks and scalloped hammerhead sharks have been found to swim in straight lines for long periods across open ocean, and the latter orient to seamounts where geomagnetic anomalies exist.

• Estimated magnetic field thresholds range between 10 nT and 50 nT in homing pigeons, sharks and whales. Modelled results showed magnetic fields in the range of 0.6–50 µT, this indicates the possibility that the emitted magnetic fields from off shore installations may be detected by magnetoreceptive organisms.

• Research conducted on elasmobranchs in various controlled environments exposed to EMF (that replicate EMF from subsea cables) shows that the emitted EMF may be detected by the fish. The response may be categorized as behavioural changes (the responses varied both between species and between individuals within the same species).

• Distances from the cable in which a shark may be able to detect an electric field (with a 100A load rating), lesser spotted dogfish 1–80 m, thornback ray 30–90 m, smooth dogfish 80 m, round stingray 120 m, nurse shark 60–120 m, spotted ratfish 15 m, sandbar shark 160 m, scalloped hammerhead 160 m, bonnethead shark 50–160 m.

Normandeau Associates Inc; Exponent Inc; Tricas, T.; Gill, A. (2011). Effects of EMFs from undersea power cables on elasmobranchs and other marine species. *U.S. Dept. of the Interior, Bureau of Ocean Energy Management, Regulation, and Enforcement, Pacific OCS Region, Camarillo, CA. OCS Study BOEMRE 2011-09*. 426 p.
a) Species: Chondrichthyans.
b) Methods

• Reviews available information on the types of power cables, and models the expected EMFs from different cable types. Summarises information available on electro- and magneto-sensitivity of elasmobranchs and other marine species. Combines modelled power cable EMFs with elasmobranch electro- and magneto-sensitivity to find knowledge gaps. Recommends future research priorities.

• Species examined were spiny dogfish, nurse shark, white shark, shortfin mako shark, catsharks (including New Zealand's carpet shark), hound sharks, blue shark, hammerhead sharks, electric rays, thornback rays, skates, stingrays, eagle rays, cownose rays, and a chimaera.

c) Results and conclusions

• AC power transmission cables are the industry standard for offshore renewable energy facilities in Europe and those proposed in the USA (mostly wind power). DC cables are likely to be used more often for future projects that are sited farther from shore. It is common practice to block the direct electric field from the external environment by using conductive sheathing over power transmission cables.

• The EMFs emitted into the marine environment from AC and DC power cables are the magnetic field and the resultant induced electric field.

• The EMF modelling provided a general reference for understanding the magnitude and characteristics of magnetic and induced electric fields from undersea power cables.

• Future research should focus on behavioural responses to exposure to power cables at which field strengths are known, and development of sensors capable of detecting AC or DC electric fields in the marine environment. Regulatory agencies should require that details of cable design, anticipated cable depth and layout, magnetic permeability of the cable sheathing, and loading (amperes) be provided early in the permitting process.

• The literature review includes annotations covering power cable characteristics, EMF impacts, general electro- or magneto-sensitivity, elasmobranch electric sense, and elasmobranch magnetic sense.

• Electrosense is well documented among elasmobranchs so knowledge about the effects of exposure to EMFs on one species can be cautiously applied to another species with similar behavioural patterns (e.g., preferred position in the water column, prey items, habitat preferences).

• Behavioural responses to electro- or magnetic fields are known for some species but extrapolation to impacts resulting from exposure to undersea power cables is speculative.

• Demersal species (some elasmobranchs, other fish species, or decapod crustaceans) are more likely to be exposed to higher field strengths than pelagic species.

• Despite the fact that the available biological information allows only a preliminary level of impact assessment, modelling indicates that the EMFs emitted by undersea power cables are limited spatially (both vertically and horizontally). This spatial limitation must be considered in any impact assessment as it reduces the risk that any given organism will be exposed.

3.4 Aquaculture

Galaz, T.; De Maddalena, A. (2004). On a great white shark, *Carcharodon carcharias* (Linnaeus 1758), trapped in a tuna cage off Libya, Mediterranean Sea. *Annales Series Historia Naturalis 14*: 159–164.
a) Species: White shark.
b) Methods

- Lists occurrences of white sharks in tuna cages, towed and anchored.

c) Results and conclusions

- White sharks are occasionally reported caught in tuna cages from Australia, Mexico, and Libya. Some are found dead, others released, and some killed.
- Blue sharks and mako sharks have also been observed inside tuna cages in the Mediterranean.

Murray-Jones, S. (2004). Workshop on shark interactions with aquaculture. Proceedings of the Shark Interactions with Aquaculture Workshop and discussion paper on great white sharks. *Australian Government FRDC Report 2002/040*. 78 p.

a) Species: White sharks.

b) Methods

- Workshop in Australia to examine effective methods, techniques and technologies to prevent or minimise problems with marine animals.
- Two parts, i) shark interactions with aquaculture, and ii) risks to white sharks from interactions due to human use of the marine environment.

c) Results and conclusions

- How to get white sharks out of cages alive. An experiment involving a live removal of a white shark from a tuna cage is described.
- How to keep all sharks out of cages: use of shark shields, or rigid cages.
- Aquaculture cages do not appear to be attracting sharks to the region.
- Both sharks and seals can be a problem.
- The main factor triggering attacks is the presence of freshly dead fish in cages - this is a husbandry issue.
- Siting of cages. Need more information about patterns of shark movements in order to minimise interactions, or at least know when the main problems are going to occur. An excellent way of obtaining this would be the installation of listening stations around tuna cages, and fitting sharks with acoustic tags.
- Interactions with bronze whalers are more frequent than with white sharks. Interactions vary with site, season, and operator.
- More information on shark numbers, distribution and behaviour is urgently needed.
- More data on interactions is needed: reporting needs to be improved.

Papastamatiou, Y.P.; Itano, D.G.; Dale, J.J.; Meyer, C.G.; Holland, K.N. (2010). Site fidelity and movements of sharks associated with ocean-farming cages in Hawaii. *Marine and Freshwater Research 61*: 1366–1375.

a) Species: Sandbar sharks (*Carcharhinus plumbeus*), tiger sharks (*Galeocerdo cuvier*).

b) Methods

- Three year study to quantify shark site fidelity to ocean fish cage sites, determine whether fish cages are disrupting natural seasonal migrations of sharks, and determine whether sharks are frequently moving from fish cages to popular human use areas.
- Passive acoustic telemetry was used to monitor shark movements.

c) Results and conclusions

- About half the sandbar sharks showed site fidelity to the fish farms, with some individuals being detected repeatedly for 2.5 years. These same sharks continued their annual seasonal migrations, suggesting the farms were not disrupting the sharks’ natural seasonal movements.
- Tiger sharks were more transient than sandbar sharks, with shorter residence times at the fish farms, although some individuals returned sporadically to the cages over the 3-year period.
- Although threats to public safety are probably minimal, the ecological effects of aggregating top-predators are still unknown.

3.5 Ecotourism

Laroche, R.K.; Kock, A.A.; Dill, L.M.; Oosthuizen, W.H. (2007). Effects of provisioning ecotourism activity on the behaviour of white sharks *Carcharodon carcharias*. *Marine Ecology Progress Series 338*: 199–209.

a) Species: White shark.
b) Methods

- Acoustic tags and static acoustic receivers were used to determine whether white shark ecotourism boats in South Africa alter the behaviour of white sharks through offers of food (chumming).

c) Results and conclusions

- The goals of ecotourism are at odds with white shark behaviour. Ecotourism tries to attract as many sharks as possible to the surface and keep them at the surface as long as possible. White sharks naturally swim close to the seafloor trying to remain unseen to attack seals at the surface.
- No change in seal predation rate occurred during chumming periods.
- Ecotourism activity had an effect on the behaviour of some sharks, but this was relatively minor, and the majority of sharks showed little interest in the food rewards on offer.
- It is unlikely that conditioning would occur from the amount of ecotourism activity tested. The identified sharks showed a nearly ubiquitous trend of decreasing response with time.
- Moderate levels of ecotourism had only a minor impact on the behaviour of white sharks, and are unlikely to create behavioural effects at the ecosystem level.

Bruce, B.D.; Bradford, R.W. (in press 2013). The effects of shark cage-diving operations on the behaviour and movements of white sharks, *Carcharodon carcharias*, at the Neptune Islands, South Australia. *Marine Biology*.
a) Species: White shark.
b) Methods

- Examined the spatial and temporal patterns of residency and behaviour of white sharks at the Neptune Islands in South Australia over an 11 year period (2000–2011) via shark cage-dive operator logbook data and the telemetry of acoustically-tagged sharks using receiver arrays deployed in the island system and throughout southern Australian waters.
- The 11-year period spanned a significant change in shark-cage diving effort and regularity at the Neptune Islands where operator activity increased from an average of 128 days per year prior to 2007, to 270 days per year thereafter.

c) Results and conclusions

- Comparisons between periods before and after 2007 revealed significant changes in shark behaviour and residency at the North Neptune Islands.
- Acoustic data confirmed that sharks continued to be temporary visitors to the Neptune Islands and that individuals undertake broad-scale movements across their Australian range consistent with known movement patterns.
- Logbook data indicated a significant increase in the number of sharks sighted per day after 2007. Sharks also significantly increased their periods of residency and the time periods spent within the areas where shark cage diving operations occur after 2007.
- There was also a shift in diel behaviour with the presence of sharks at cage-dive sites aligning with the overall daily timing of berleying (chumming) operations. This shift in diel behaviour also propagated to days when no cage diving operations occurred, suggesting a conditioned or anticipatory response by sharks to cage-diving activities as a result of provisioning.
- The study demonstrates that cage-diving can lead to long-term changes in the behaviour of highly vagile shark species which may need to be considered in the context of their conservation.

4. DISCUSSION

Little research effort has been directed towards assessing the impact of anthropogenic activities other than fishing on chondrichthyans. Although our study was far from exhaustive, we believe we found most of the significant original studies, and a representative sample of review studies, in this field. Most of the review studies highlighted the dearth of information available worldwide, and the few original field-based studies were conducted on only a handful of species. No studies were found for chimaeroids, so all literature considered here applied only to sharks and rays (elasmobranchs).

Different species probably respond differently to various stimuli in their environment so the validity of extrapolating the results from the available studies to other species and locations is dubious. Below we draw a few broad conclusions, but caution that they may not apply to some, and possibly many, species.

Elasmobranchs hear underwater sound best in low frequency bands (less than 1000 Hz). Noises in this range may be produced by shipping, underwater construction, pile driving, dredging, power stations and sonic surveys. Loud sounds in their audible range may repel elasmobranchs whereas low sounds may attract them (perhaps because they may mimic the sounds of struggling or injured prey). Thus the response of an elasmobranch may depend on its distance from the source and the volume of the source. Species-specific and probably location-specific studies are required to assess actual impacts.

Coastal development and dredging can affect elasmobranchs through reduction in habitat area, reduction in habitat quality (e.g. through increased sedimentation or removal of vegetation or shelter), removal or repulsion of prey, or increased noise and EMFs. Only two studies were found that addressed such impacts, both from the Bahamas, and they showed a clear reduction in shark abundance and survival in nursery areas following development.

Elasmobranchs have an extremely sensitive electromagnetic sense which they use to find prey (all living organisms emit small EMFs) and possibly also for navigation. EMFs can either attract or repel elasmobranchs in a similar fashion to noise. Sharks are attracted to and sometimes bite undersea cables because they emit EMFs that mimic those given off by prey. Power cables in the sea, such as those running between units in an array of power generating turbines (wind or tide), or from the power station to shore, typically generate relatively weak EMFs. Furthermore, EMF production can be reduced by shielding and burying the cable, and using DC rather than AC voltage. Although few direct studies have been conducted on elasmobranch responses to cables, modelling and theoretical considerations suggest that undersea cables can be designed to have minimal impact on elasmobranchs. In addition to EMF production, marine power stations may have physical impacts on elasmobranchs such as creating barriers to transit routes, collision, long-term displacement, habitat removal and decrease or increase in habitat heterogeneity.

Large sharks (and marine mammals such as sea lions) may be attracted to marine aquaculture facilities because of the concentration of potential prey (usually fish) and the odour trails created by their waste. Sharks may become trapped inside sea cages and may be killed by farmers attempting to remove them. More benign methods are being developed to release trapped sharks, and cage construction is evolving in an attempt to reduce the entrapment of sharks. The sparse available evidence suggests that aquaculture facilities may not affect the seasonal migratory behaviour of sharks, but further research in this area is required.

Shark-based ecotourism is now a popular activity in some countries, and is growing steadily. Only two studies were found that assessed the impact of tourism on sharks, and both involved the effect of shark-cage diving on great white sharks. The results were contradictory: in a South African study there was only a minor effect of the chumming on the sharks, and the sharks' response declined over time. By contrast, in an Australian study, significant changes in shark behaviour were observed to the extent that sharks became conditioned to the arrival times of the dive boats. Further work is required to determine what other factors might be important, such as the intensity of the tourism activity and the level of chumming.

Interactions between humans and chondrichthyans will undoubtedly increase in future. Our knowledge of the extent of such interactions, their impacts on the animals, and ways to mitigate such impacts, is sadly lacking. In New Zealand, resource consent hearings and Environment Court hearings are increasingly asking how human intrusions into the sea will affect marine animals including chondrichthyans, but currently we have few answers.

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