CHALMERS

ECOLOGICAL HAZARD IDENTIFICATION OF THE MINESTO 'DEEP GREEN COMMERCIAL' TIDAL STREAM TURBINE

Master of Science Thesis

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CHALMERS UNIVERSITY OF TECHNOLOGY
Goteborg, Sweden, 2012

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Cover:

Minesto Deep Green tidal energy converter (© Minesto)

To maggs and chief – the first repayment, from your son “the engineer”

Abstract

This study focuses on determining potential environmental interactions of the full scale “Deep Green Commercial” Minesto tidal energy converter through a hazard identification process using ecological risk assessment methodology. Minesto, a tidal energy developer, is currently testing a prototype 1/10th scale device with the aim of manufacturing the first full scale Deep Green Commercial in 2013. To prepare for this, comprehensive environmental assessments must be conducted to study the environmental interactions of the device with its local environment. This study takes the first steps, through a scientific paper literature review, industry case study, key industry actor interviews and prototype sea-trial study, to identify potential interactions in the form of stressors-endpoint interactions that will need further addressing. It was found that there are several stressors unique to the Minesto device associated with the tether component and flight path that require further investigation. These results require that Minesto adopt a reactive approach since no previous work has been published on these potential interactions. Finally, the highlighted potential interactions are discussed in light of the emergence of the tidal energy industry and the effect this has on the environmental assessment process as a new Technological Innovation System (TIS) is developed.

Keywords: hazard identification, ecological risk assessment, tidal energy, tidal turbine, Minesto, Deep Green Commercial, Technological Innovation System, stressor, endpoint.

Acknowledgements

I would like to sincerely thank Linus Hammar, my academic supervisor, for all his time spent reflecting and advising on possible directions for the work of this thesis, for introducing me to the Swedish “fika” coffee break and for patiently and enthusiastically guiding me during this process.

I would also like to extend my gratitude to Anders Jansson and the Minesto team, who offered me the opportunity to get a look inside the daily operations of a renewable energy start-up, to take the time to teach me about business and to allow me to gain valuable experience in the tidal energy sector.

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Nomenclature

ASSI	Area of Special Scientific Interest
DGC	Deep Green Commercial
ECO-RA	Ecological Risk Assessment
EHS	Environment and Heritage Service
EMF	Electromagnetic Force
EMP	Environmental Monitoring Program
EPA	Environmental Protection Agency
FEPA	Food and Environment Protection Act
HAZID	Hazard Identification
IEMA	Institute of Environmental Management and Assessment
IPCC	Intergovernmental Panel on Climate Change
IUCN	International Union for Conservation of Nature
MALT	Marine Assessment and Licensing Team
MCT	Marine Current Turbines
MW	Mega Watt
MWh	Mega Watt Hour
NIEA	Northern Ireland Environment Agency
OTEC	Ocean Thermal Energy Conversion
RAMSAR	Int'l treaty for the conservation & sustainable utilisation of wetlands
RE	Renewable Energy
SAC	Special Area of Conservation
SPA	Special Protection Area
TIS	Technological Innovation System
TTS	Temporary Threshold Shift
UNFCC	United Nations Framework Convention on Climate Change
WMO	World Meteorological Organisation

1.0 Study Introduction

An increasing focus on climate change has lead to a renewed concentration on ocean energy. New concepts are being developed in the wave and tidal energy sectors and are in varying stages of commercialisation. Although ocean energy is generally considered to be environmentally neutral, as there are no carbon emissions directly attributed to the energy extraction processes, there are in fact local stressors associated with the energy converter devices on the eco-systems where they are operating (Pelc and Fujita, 2002). As more ocean energy converter concepts near commercialization, greater focus must be placed on their associated potential environmental hazards.

Minesto is a Swedish based tidal energy developer that is currently working on a unique type of tidal technology that utilises the flow of tidal currents to generate electricity. Currently in prototype (SeaKite II) sea-trial stage, the Minesto technology is drawing closer to the commercialisation phase. The first commercial device "Deep Green Commercial" (a.k.a. DGC) is scheduled to deploy in 2013 but before reaching this target, potential environmental impacts of the deployment of such a device on the local eco-system must be considered.

This thesis examines the potential environmental impacts that may occur as a result of a DGC installation. The thesis investigates all the possible interactions but with a primary focus on what may be technology-specific potential environmental impacts unique to the Minesto device. Due to a lack of empirical data for the commercial device (the first DGC is scheduled to be manufactured in 2013), the results from this study should be viewed as indicative. Any results obtained can be utilised when seeking to prioritise further studies in this field. Utilising Ecological Risk Assessment methodology, this study will focus on the "Scope and Hazard Identification" stage. A comprehensive data collection process utilises a literature review of scientific papers and a case study of empirical data gathered from an industry leader, complemented with interviews with key industry actors and an overview of a surveying study of the deployment of the Seakite II prototype in Strangford Lough, Northern Ireland, to gather data for this thesis.

1.1 Purpose and aim of this study

This study focuses on answering the following research question:

What are potentially adverse environmental interactions associated with the full scale Minesto device and which stressors are currently unique so that Minesto must directly address them?

The aim of the study is to:

- Complete a literature review of relevant scientific papers and industry reports with the view to compiling and categorizing the currently identified environmental impacts of tidal stream turbines.

- Identify potential impacts from the unique, never-before-tested Minesto tidal turbine concept through conducting interviews with key industry actors and preliminary reports documenting potential environmental impacts of the prototype sea-trial.

- Complete a comparative analysis based on the findings from the literature review, interviews and prototype sea-trial.

- Analyse the role of environmental assessments and studies in the process of the birth of the emerging new tidal industry.

1.2 Benefits of Study

The Minesto Deep Green technology is unique. Such a tidal energy converter based on the Deep Green principle has never been deployed on a full scale in an ocean environment. This study will shed light on potential environment hazards that must be considered that could affect the selection of a site for a Minesto farm (tidal converter array) or even affect the overall development of Minesto technology on a commercial scale. The study will identify and prioritise potential impacts that can then be comprehensively examined in future studies.

Such a study is beneficial to both industry and academia. Minesto will benefit from initiating the first steps of an environmental impact assessment of the commercial technology. For academia, this study will contribute to the body of knowledge of the much unknown topics of the environmental impacts of the tidal industry and especially of the never before examined DGC technology converter type.

This study approaches the issues of potential environmental impacts in a proactive way. Instead of designing the technology first and then examining what effect it may have on it environment as is the conventional way, this study takes proactive measures to identify future potential impacts of a full-scale Minesto device although currently the technology is only in 1/10 scale prototype sea-trial phase. The results of this study will highlight potential environmental issues before they occur and this proactive approach will allow full-scale designs to be modified and adequate sites to be selected to ensure these identified potential impacts can be minimized.

1.3 Data Collection

This study involves four main methods of data collection. Results from these various methods will be compiled and categorised. Once this is completed, a comparative analysis of the results is performed in order to interpret the results and identify any general trends or overlap between the varied data sources.

Table 1.1 - Methods of Data Collection

Scientific Paper Literature Review	A literature review of scientific papers discussing the identified environmental impacts of existing tidal stream technologies.
Industry Report Case Study	A summary of recently published industry reports from a leading tidal turbine developers that discuss environmental considerations and impacts of their technology
Industry Actor Interviews	Industry actor interviews aiming to develop a list of potential impacts for the unique Minesto tidal turbine technology.
Prototype sea-trial study	Review of preliminary studies of SEAKITE II, conducted by consulting firms on behalf of Minesto, will allow for a greater understanding of the topic.

2.0 Tidal Energy Background & Industry

2010 was the warmest year ever recorded.

This is according to the report published by the World Meteorological Organization in June 2011 (WMO, 2010). It is believed that rising global temperatures are attributed, at least in part, to climate change. The United Nations Framework Convention on Climate Change (UNFCC) defines climate change as:

"A change of climate that is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and that is in addition to natural climate variability observed over comparable time periods" (IPCC, 2007a).

The combustion of fossil fuels, a human activity, is a dominant force when it comes to climate change. This combustion releases emissions that impact negatively on the environment. These emissions have a high global warming potential and as a result sea levels are rising, polar ice caps are melting, and cases of extreme weather are becoming more commonplace. Current and future energy policies are exploring alternative energy sources to fossil fuels. As well as the detrimental environmental effects of fossil fuels, their diminishing supply and hence rising fuel prices, and security of supply issues, many factors have contributed to an investment in a more diversified energy mix.

The intergovernmental Panel on Climate Change (IPCC) predicts that unless there are substantial energy policy changes, project emissions of energy-related CO_2 emission in 2030 will be 40-110% higher than in 2000 due to a rising global population and increasing energy demand (Rogner *et al.,* 2007).

The call to action, to combat climate change and rising global temperatures and sea levels, is on a global scale. International panels, climate groups, committees and conferences are urging the global community to expand its energy portfolio to include a variety of sustainable and renewable resources thereby detaching from a fossil fuel dependence. Targets are being put in place to increase the percentage of renewables in every country's energy portfolio. For example as part of the EU 20-20-20 initiative, the European Union has put measures in place to achieve a 20% increase in renewables compared to 1990 levels by the year 2020 (SEC, 2010). As well as other forms of renewable energies such as solar, onshore wind and biomass, ocean energy (offshore wind, wave, tidal, OTEC) will contribute to reach this target.

2.1 Tidal Energy

As mentioned above, there are a number of renewable energy technologies that are technically mature, have been commercially implemented and are already contributing to energy supply portfolios. However there are other sectors such as the ocean energy sector that are in an earlier phase of technical maturity. In 2008 Ocean energy accounted for only 0.002% of the total global primary energy supply (IPCC, 2011). An overview of the breakdown of energy sources for total primary energy supply in 2008, shown below, displays the proportions of the contributions of the main global energy sources.

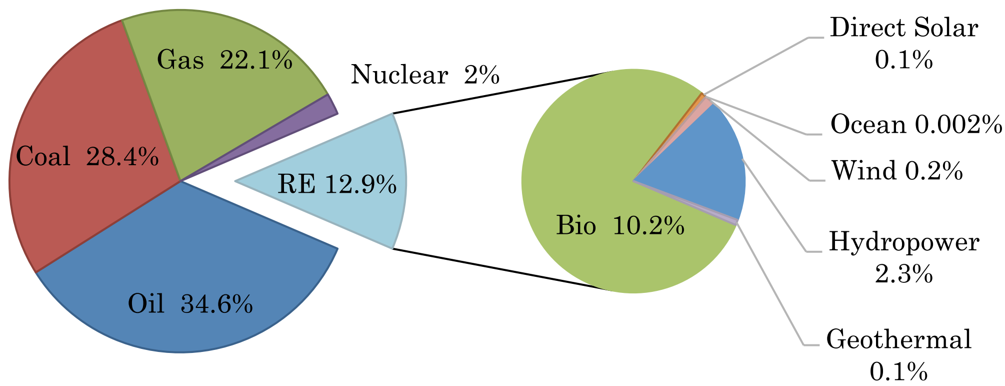

Figure 2.1: Shares of energy sources in total global primary energy supply in 2008 (IPCC, 2011)

Despite its current limited use, ocean energy has great potential. According to the UK Marine Foresight Panel (European Ocean Energy Association, 2010):

"*If 0.1% of the renewable energy available within the oceans could be converted into electricity it would satisfy the present world demand for energy more than five times over*".[1]

2.2 Tidal Energy Converter Types

This study will focus on tidal energy alone. Tidal energy technologies utilize the natural ebb and flow of tidal waters. The interactions of the gravitational fields of the moon, earth and sun provide the force (RenewableUK, 2011).

Tidal currents can be classified as thalassic, estuarine or fluvial - derived from oceans, estuaries or rivers respectively (Charlier, 2003). For the purpose of this study, only thalassic tidal current technology will be considered although there is great potential for other tidal current classes as well as ocean currents.

There are various different types of tidal energy systems that can be adopted for converting energy into electricity. As with all types of technology, there always exist

[1] This includes all generated low temperature heat absorbed. The energy in waves and tides is much less.

a variety of solutions to perform a particular task, in this case the extraction of energy from tidal currents (Grübler, 1998). For the context of this thesis only tidal stream (as known as tidal current) converters will be considered.

Table 2.1 - Tidal Energy Converter Types and Descriptions

Tidal Steam/Current	Tidal stream converters usually work like wind turbines by capturing the kinetic energy from the tidal currents.
Tidal Barrage [2]	This is one of the most common types of tidal energy extraction. In this method, a body of water is usually closed off at high tide and electricity is generated when the water is released through a turbine. The potential energy is captured much like a hydropower dam.
Tidal Lagoon	A tidal lagoon acts like a tidal barrage but the release of water is controlled to allow for power to be produced in constant flow.

2.3 Minesto Deep Green Device

This study focuses on Minesto, a tidal energy start-up based in Gothenburg Sweden. Starting life in 2007 as a spin out from the Saab group, Minesto develop a tidal stream converter called Deep Green that was originally based loosely on the principles of a wind kite energy converter.

2.3.1 Device Overview

The Deep Green converter is a unique tidal energy technology that utilises hydrodynamic forces to generate lift in low-velocity tidal steams and ocean currents. As the tidal flow moves over the hydrodynamic-shaped wing, a lift force is generated which propels the device forward. The device is attached by a tether to the ocean bed floor. A control system is used to steer a rudder in a pre-defined trajectory that optimises the flow of water through the turbine. As the water flows through the turbine, electricity is generated via a direct drive generator located in the wing. The electricity is then transported through the electrical cables within the tether to a transmission line and fed onshore to a land based transformer station before being fed

[2] Tidal barrages are considered to have more environmental impacts than tidal stream turbines. In a barrage, a high-speed turbine is mounted in a tunnel through which water flows at high speed and pressure. The entrained organisms have little opportunity to avoid the turbine blades due to the strong flow. In turbine stream turbines however, the turbines are located in an open flow field allowing organisms a much greater opportunity to avoid direct contact with the blades (Frid *et al*., 2011).

to the grid. The unique design allows it to operate in low velocity streams, an advantage that cannot be claimed by competitors.

Figure 2.2: Simulation of the Minesto Deep Green tidal energy converter (© Minesto)

2.3.2 Device Parts

The main components of the "Deep Green" design are the wing, tether and swivel, and the turbine. Together these parts allow the device to generate a driving force that is larger than the opposing drag force generated by the body of water.

The hydrodynamic shape of the wing ensures that a lift force is generated as a flow of water moves past it. This is the same principle that the aerodynamic wing of an airplane capitalizes on as air moves past a plane on takeoff. The wing is strong and lightweight design. Inside the wing, a buoyancy system is housed which allows for the device to be floated to the surface for maintenance or removal. The wing is watertight to ensure that the electronics, sensors and other components housed inside are kept dry.

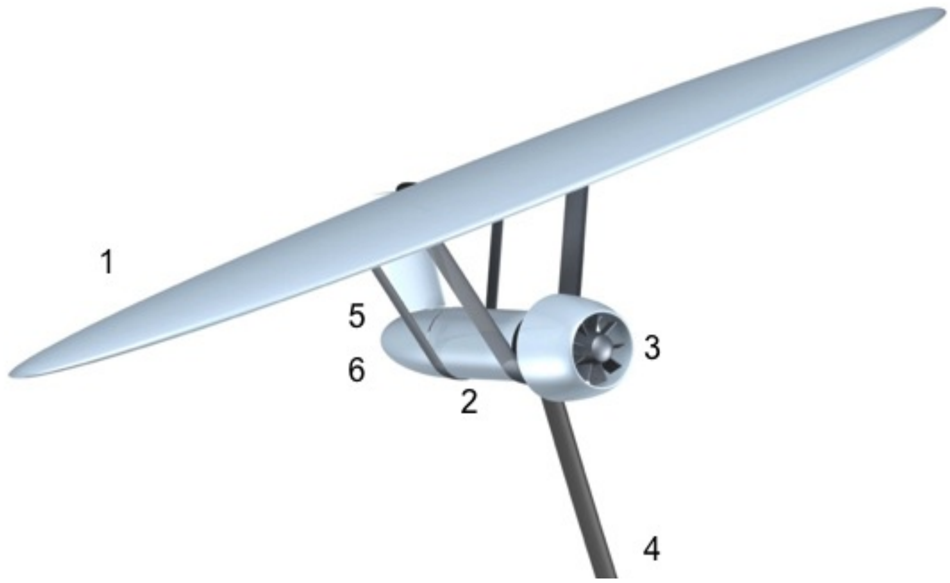

Figure 2.3: 1. Wing 2. Nacelle 3. Turbine 4. Tether 5. Rudder 6. Rear Cone (© Minesto)

The tether is a force-bearing element that has been designed to take the high loads created by the movement of the wing through the water. The tether, in this application is currently unique to the Minesto tidal energy converter. As well as ensuring that the device remains fixed to the sea bed the tether has another very important duty – to house the cables that will transmit the electricity generated by the device's movement to the seabed and then to a unit on the shore. Like the wing, the tether is hydrodynamically designed to ensure minimal drag, maximizing the device performance. The swivel is mounted at the base of the structure, atop the foundation. It acts the anchoring point between the device tether and the foundation. The design of the swivel allows for the device to move smoothly in all directions and to follow the optimized path set out by the control system.

The turbine, located at the front of the nacelle, allows for water to move through it when the device is moving. The turbine converts the kinetic energy of the moving water into mechanical energy through the rotation of the rotor blades. This mechanical energy is converted into electrical energy in the generator and transmitted to the shore via the tether.

2.3.3 Device Operation

The force diagram shown below illustrates the principle on which the Deep Green technology is based. As water flows over the hydrodynamic wing, a lift force is generated which allows the device to move smoothly through the water and for the turbine to rotate hence generating electricity.

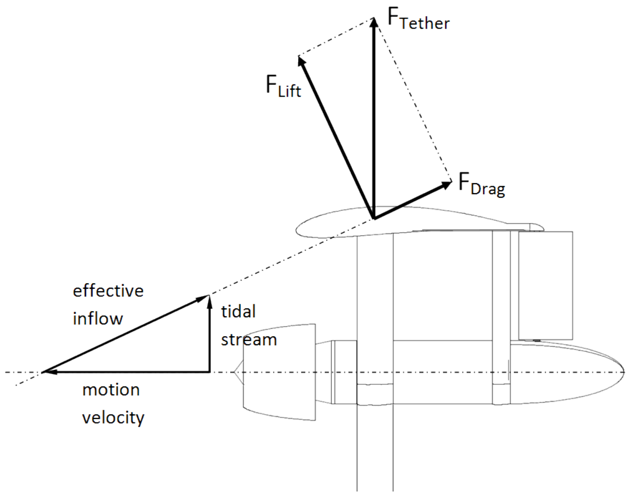

Figure 2.4: Force diagram for Minesto's Deep Green Technology (© Minesto)

As mentioned above, the Deep Green technology utilises low velocity currents as opposed to other technologies that compete for tidal hot spot locations. A tidal hot spot can be defined as an area where velocities are in excess of 2.5 m/s (Black & Veatch, 2005). Other stationary tidal energy devices cannot operate in the low velocity locations, as the flow of water is not sufficient to generate a useful flow of electricity. However, the hydrodynamic principle on which the technology is based allows for the kite to move at speeds of up to ten times that of the flow of water it is operating in thus unlocking many more potential tidal farm sites than its competitors.

Currently it is planned that the technology will be available in four different sizes. The characteristics and specifications of these four different options can be seen in the table below. It is evident that these devices utilize water velocities (1.2-2.2 m/s) that are below the hot spot velocities (>2.5 m/s) required for other technologies. Further technical specifications of the Minesto 12m DGC device can be found in the Appendix.

Table 2.2 - Deep Green technology specification options

Wing span *m*	Depth *m*	Desired Vel. *m/s*	Lower Cut off vel. *m/s*	Upper Cut off vel. *m/s*	Rated *kW @ m/s*	Weight *Ton*
8	50 - 65	1.2 - 1.8	0.5	2.5	120 @1.3	2
10	60 - 80	1.4 - 2.0	0.5	2.5	220 @1.4	4
12	75 - 100	1.4 - 2.2	0.5	2.5	500 @1.6	7
14	90 - 120	1.4 - 2.2	0.5	2.5	850 @1.73	11

The Deep Green technology has been proven at concept stage and in November 2011 sea trials began. After initial sea trials, Minesto will look to begin development of a commercial sized unit at a chosen tidal site. Before development of a commercial site it is essential to understand any potential environmental impacts the device may have on a local eco-system.

3.0 Study Methodology

It is important in any academic study to spend a sufficient amount of time ensuring that the correct and most suitable methodology is implemented and that boundaries for the scope of the study are clearly identified when attempting to research any topic. The study boundaries and methodologies implemented for this thesis are described in this chapter. The reasons for selecting these boundaries and methodologies, the sources and a summary of the key points of the methodology can be found below.

3.1 System Boundaries of the Study

It is of primary interest to Minesto, as development advances, to understand what environmental concerns there may be when initiating a project such as the installation of a full-scale device. The source of this interest is not only from the desire to uphold the best interests of the environment but also due to the fact that it is mostly environmental concerns that come to the fore when applying to any government or agency for seabed leasing opportunities. It is for this reason that this study is structured around environmental concerns and not concerns of another nature (technical etc.). Of the potential environmental concerns, it is the potential impacts on ecology that is the primary focus. It is well understood that tidal turbines have a positive effect on the environment in a broader sense – in that they generate electricity by utilising a renewable resource and that this electricity can be used to substitute electricity that would be generated from carbon emitting sources. However, what is less clear is the effect that tidal turbines may have on their immediate surroundings such as the local ecology with which they will interact. Therefore, it is ecological concerns that will be examined.

It has been shown that Ecological Risk Assessment (Eco-RA) framework can be used as a suitable tool for providing structure to eco-system based assessments of emerging ocean energy technologies (Hammar & Gullström, 2011). However, it is of paramount importance when adopting an eco-system level of approach that the system boundaries of the study are clearly and explicitly defined. A danger of eco-system level approaches is that they "must include everything" (Hammar & Gullström, 2011). By correctly defining the system boundaries, time and effort can be saved so that the most important issues can be explored. In order to create a reasonably manageable study, several defining system boundaries must be implemented.

The primary focus is placed on the unique, technology-specific environmental impacts of DGC technology. Of course, environmental impacts of generic tidal turbines will be discussed but only in light to provide a basis from which unique impacts for the DGC can be defined. The principle reason for only exploring unique potential impacts is that there is deemed to be sufficient published academic data on generic issues and in order to contribute to the overall body of knowledge on this issue – new, unique issues are primarily explored.

Although a site has not yet been selected for the deployment of the first commercial scale DGC device, it is assumed that the site will be Strangford Lough in Northern Ireland. There are several principle reasons that this site has been selected for this study. This is the site for the sea-trials of the SeaKite II prototype and the site on which the preliminary environmental studies have been performed on behalf of Minesto. It is here that MCT, the developer that will be used as a case study for this thesis, is operating its commercial device. And finally, the interviewees that will be contributing to this work all operate close to this location and have completed work before on projects in these waters. They are therefore all familiar with the local ecosystem of Strangford Lough.

3.2 Ecological risk Assessment Framework

This study utilises 'Ecological Risk Assessment' methodology. Although no consensus definition of Eco-Ra exists (CCME, 1996) - the Environmental Protection Agency (EPA) of the United States defines an Ecological Risk Assessment as a way to evaluate the adverse effects that human activities and pollutants have on the plants and animals that make up our eco-systems (EPA, 1998). In short, it is a way to assess human-induced impacts on the environment (Jorgensen, 2010). Jorgensen's book on Ecotoxicology explains that the use of Eco-RA's is motivated by the increasing levels of legislation that require strict control over disturbance levels to the local ecology. Eco-RA can be used as a useful risk management tool to highlight the largest risks to allow for proper resource allocation, to explicitly identify environmental values of concern and to identify critical knowledge gaps, thereby helping to prioritise further research where deemed necessary (SETAC, 1997). Jorgensen discusses how the methodology is often undertaken by private industry (Minesto, MCT etc.) to determine future risks and liabilities associated with the development, use and disposal of new or existing products (Jorgensen, 2010).

3.2.1 Risk

One of the principle reasons that the Eco-RA framework was selected for this study was due to the fact that risk is an important parameter that must be judged on a daily basis in every decision a company such as Minesto makes. It is an ever-present factor, especially in the work that is carried out by early-stage technology developers. Since the subject of this study is to explore potential environmental concerns or "risks" that may affect the development of the Minesto technology, this framework is fitting.

Risk, the measure of the probability and magnitude of adverse consequences of an event, is inherently linked with the introduction of new technologies (Hope, 2006). Venturing into the unknown, with a lack of hard experience and empirical data, requires that some method of identification and assessment of risks be implemented. Using the Eco-RA methodology in this study allows for an investigation into the risks associated with deploying a unique technology into the vast, unknown and complex ocean environment. The Eco-Ra methodology can aid in decision-making required for such a project (Moraes, 2002). Risk undoubtedly comes in many different shapes and forms from economic and social risk, to structural and health risks. This study focuses solely on the ecological risk of potential impacts from the introduction of the DGC into the ocean environment.

This study will adopt this methodology and associated frameworks as a structured method for proactively assessing risks from implementing Minesto DGC technology in the ocean environment. Examining potential risks using this methodology will allow for the Minesto team to understand if there will be any future potential risks posed by environmental impacts that may hinder or even stall progress of the Minesto technology.

3.2.2 Stressors, Pathways, Endpoints

The Eco-RA framework is based upon identifying stressor sources, exposure pathways and endpoints. A stressor source is defined by the US Environmental Protection Agency as any factor (chemical, physical or biological) that may harm plants or animals (EPA, 1998). An endpoint, also known as a receptor, is "an explicit expression of the environmental value that is to be protected". Pathways are paths between the stressor sources and the endpoints. A quick example supports these definitions; a turbine rotor could be a stressor source that could affect fish (the endpoint). The pathway in this example could be the collision of the fast moving rotor blade with the fish.

3.2.3 Framework Steps

The main steps of an ecological risk assessment are scope and hazard identification, exposure assessment, effect assessment, risk characterisation and risk evaluation (Suter, 1993).

The first step of this framework is the "Scope and Hazard Identification" step. Within this step the system boundaries and assessment endpoints are defined. An inventory of relevant stressors is also drawn up. Due to the early nature of the unique technology examined in this thesis, the work of this thesis will focus on this step in the form of extensive data collection through literature reviews and industry interviews. The hazard identification is laying ground for subsequent exposure and effects assessments (pathways) and ecological risk characterization (not included in this thesis).

In his book "Risks and Decisions for Conservation and Environmental Management" Burgman states that a good hazard identification and assessment phase makes use of as many tools as possible, in an attempt to form as complete a list as possible (Burgman, 2005). It is for this reason, as will be shown in the next Chapter, that four different methods of data collection are performed for the hazard identification.

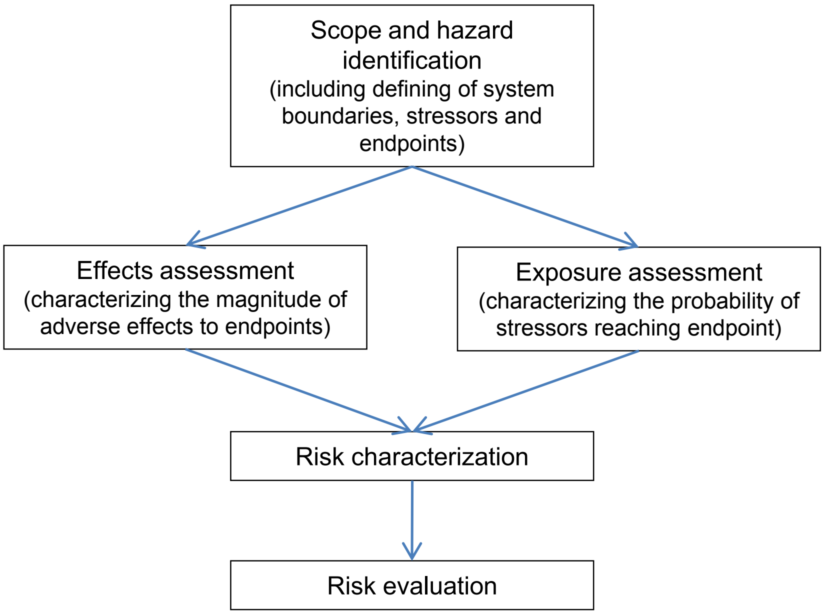

Figure 3.1: Ecological Risk Assessment Framework (adapted from Hammar and Gullström, 2011).

4.0 Data Collection

The main research and data collection for the work of this thesis is outlined in this chapter. The data collection is comprised of four separate and distinct blocks of information. The first block is comprised of a literature review of a diverse range of scientific journals. The second block focuses on gathering information in the form of a case study on reports from the developer of the first commercial tidal turbine, Marine Current Turbines (MCT). The third block is a series of interviews with key industry actors that are familiar or worked with Minesto. In the fourth block of information, there is a review of a preliminary environmental report of the Minesto SeaKite II prototype.

4.1 Scientific Paper Literature Review

The scientific paper literature review is based on an extensive keyword search of the ScienceDirect database (SciVerse, 2011). The keywords selected were: "*tidal power*" or "*tidal turbine*" and "*environmental impact*".

4.1.1 Overview

The search yielded 476 articles. The results were sorted by relevance. The first 50 available papers were reviewed. Of the 50 papers reviewed, papers discussing tidal barrages were excluded. Only papers that had a direct reference to or identified stressors, affected endpoints and associated pathways were included. After the first 50 papers, sorted by relevance, the depth at which the papers addressed tidal power and environmental issues declined. Therefore the cut off was set at 50.

A weighting method was created to distinguish between the sources of data that was presented in the scientific papers. A score of 4 was given to data that was measured, 3 for modeled data and 2 for referencing data from another study and 1 for hypothetical suggestions.

Table 4.1 – Weighting scores for various data sources

Source	**Grade**
Measured	4
Modelled	3
Referenced	2
Suggestion	1

A large portion of the relevant papers acknowledged the young nature of the tidal energy industry and that little hard empirical data was available (Ahmadian *et al*., 2011; Langhamer *et al*., 2010). The general theme found in the papers is that the consequences of encounters between marine organisms such as cetaceans and tidal power technologies are as yet unknown (Dolman & Simmonds, 2010). Of all the hazards identified in the scientific papers, most are only estimates of impacts. Most of the papers acknowledge that more accurate assessments will not be realised until empirical data and environmental monitoring programmes of installed devices can be obtained.

Ahmadian *et al*. (2011) highlight the high level of research currently being conducted in experimental modelling studies of turbine design and performance that can complement empirical data for assessments of future tidal turbine technologies (Myers *et al*., 2005; Bryden *et al*., 2006; Bahaj *et al*., 2007; Batten *et al.*, 2008; O'Doherty *et al*., 2009; Willis *et al*., 2010). It is hoped that once more detailed models of interactions are obtained then it will be easier to forecast potential impacts of tidal turbine technology on their local environment. Langhamer *et al*. note that cooperation between the wave and tidal energy and even the wind power industries in addressing potential environmental concerns will have benefits in speeding up application processes and reduce the need for repeating studies (Langhamer *et al*., 2010).

As noted earlier, the papers noted that tidal stream technologies have reduced environmental impacts in comparison with tidal barrage technologies (Pelc & Fugita, 2002; Kadiri *et al*., 2010). However, the depth at which the reviewed papers addressed environmental concerns was minimal. The majority of the papers included environmental concerns as a sub-section or in concluding comments only.

However, Dolman & Simmonds directly address the impacts of tidal stream devices. Installation noise, increased vessel activity, increased turbidity and re-suspension of sediments due to device operation, presence of device leading to collisions, presence of structures and foundations, operational noise, operational vibrations, anti-fouling releases, electromagnetic impacts due to cabling, maintenance vessels and decommissioning practices were all stressors stated by Dolman & Simmonds. These highlighted stressors are recurring throughout most literature in this field of study.

4.1.2 Stressor-Endpoint Interactions

The results of the literature review of scientific papers are summarised in the bar chart below. The main stressor that was identified was the overall presence of a tidal stream device, followed by installation, foundations and cabling and finally the turbine rotor.

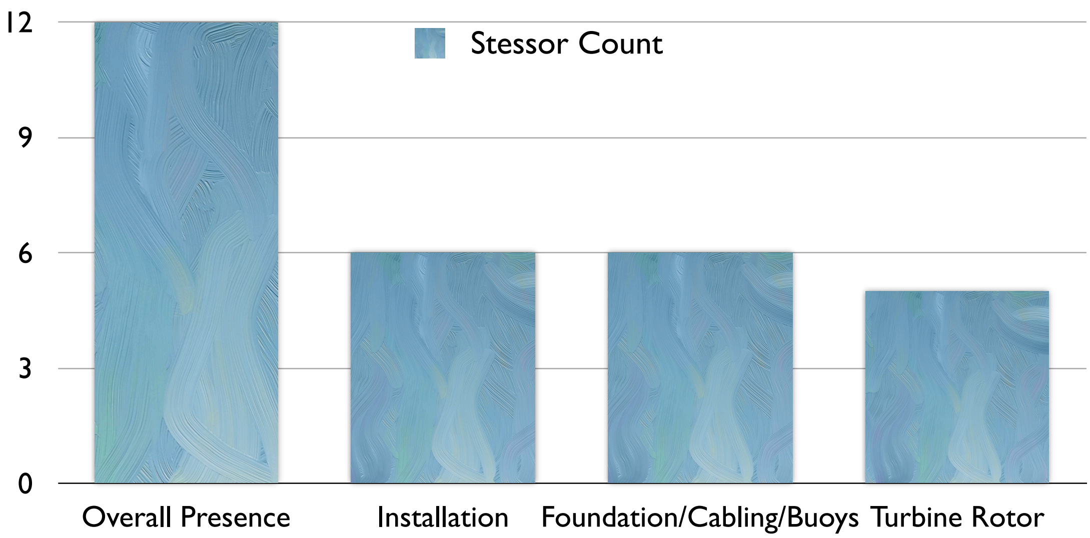

Figure 4.1: Stressor count bar chart from literature review of selected papers

Overall Presence

The majority of stressors that were identified in the papers were related to the overall presence of a tidal turbine in the ocean environment. These stressors ranged from operational noise (Güney & Kaygusuz, 2010) and habitat degradation from released toxins from anti-fouling agents (Dolman & Simmonds, 2010) to fish populations being altered from no-fishing zones (Langhamer *et al*., 2010) or altering water flows to affect the benthic community (Frid *et al*., 2011).

Installation

The installation process of a tidal turbine was noted as being a source of many potential stressors. Langhamer *et al*. discuss how increased noise levels attributed to installation activities could potentially adversely affect marine organisms (Langhamer *et al*., 2010). Langhamer et al. cite a paper that states that the noise that is produced as a result of drilling, cable laying, boat traffic etc. can damage the acoustic system of species within 100m from the source and that this could lead to species avoiding the area (Newell *et al*., 2005). They also cite studies by FaberMaunsell and Erbe that report that increased noise levels can mask important natural noises that organisms rely on or can cause stress (FaberMaunsell, 2007; Erbe, 2002). It also noted however that habituation (the process by which habitants could get used to the novel structures, noise and human presence) should not be ruled out. Lugli *et al*. note that the reaction of marine mammals to noises that could be experienced during installation processes (drilling, movement of installation vessels etc.) are highly variable (from attraction of certain types of dolphin, to no reaction, to population displacement) since marine organisms are often exposed to many different noise-sources (Lugli *et al*., 2003). Finally, Langhamer et al. note that real empirical data from field observations would require ships, divers or even permanent platforms or expensive advanced technologies to monitor noise levels remotely such as sonar (Langhamer *et al*., 2010). However as Fernandez et al. point out, the use of sonar to examine noise levels may have adverse effects elsewhere such as the stranding of whales who become disorientated by the sonar (Fernandez *et al*., 2005). Other installation activities that may be the source of stressors are the movement of vessels that can disrupt the sediment (Defne *et al*., 2011) and an increase in pollution due to the presence of the installation vessels (Dolman & Simmonds, 2010).

Foundation and Cabling

There are also noise issues associated with the practise of pile driving for foundations. Pile driving is the process of mechanically pushing piles into the seabed to provide foundation support for the tidal turbine structure – shown in Figure 4.1. Degradation and loss of benthic habitat, direct injury and displacement from habitat are all consequences of this process (Dolman & Simmonds, 2010). Dolman & Simmonds cite a study on pile driving from offshore wind farms that reports that animals within ranges of several hundreds to thousands of metres of piling activities are at risk of a type of potentially recoverable auditory damage called temporary threshold shift (TTS) (SMRU, 2008). Similar to pile driving cabling processes will also result in degradation and loss of habitat as well as adverse noise effects. It is interesting to note however that Defne *et al*. comment on the possibility that transmission cables may serve as suitable structures for invertebrates and macro-algae through the development of an artificial reef, citing a report by Devine Tarbell & Associates as the source (Defne *et al*., 2011; Devine Tarbell & Associates, 2006).

Turbine Rotor

Finally, the turbine rotor was highlighted in the reports as a strong potential stressor. Ahmadian *et al*. state that rotors can affect bacteria concentrations through the absorption of kinetic energy that causes changes to the velocity of the water and the suspended sediment levels (Ahmadian *et al*., 2011). One of the main pathways that the rotor will act as a stressor is through collision (Langhamer *et al*., 2010; Pelc & Fugita 2002; Dolman & Simmonds, 2010; Frid *et al*., 2011). Dolmans & Simmonds note that whilst marine mammals are generally highly mobile with excellent sensory capabilities it might not always be possible for them to avoid collision with tidal turbines given the sizes of many of the designs (15-20m) and the number (tidal farms will contain many devices in succession) of devices on the seabed (Dolman & Simmonds, 2010). They also note that the likely sites for many of the arrays will be restricted passages that have high water velocities. These restricted passages will reduce the possibility for avoidance. Certain species, such as basking sharks, are known to be attracted to such restricted passages to forage (Carter *et al*., 2008).

Although it is known that fish will be impacted by the possibility of collision with turbine rotors, there is insufficient data to state definitively how they may be affected (Frid *et al*., 2011). Frid *et al*. state that are large data gaps on the topic of collision risk between tidal stream turbines and marine mammals. They do however cite studies completed by the US Department of Energy that suggest that the probability of cetaceans failing to detect a stationary tidal turbine structure is extremely low, especially for species that echo-locate and that are agile and quick-moving (US Department of Energy, 2009).

As well as fish, the rotor blades could also act as a stressor to diving birds (Frid *et al*., 2011) although the impacts are reported to be small (Anon, 2008). According to Thaxter *et al.* Only diving birds such as auks, guillemots and shags that regularly dive to depths of 45-65m are at risk (Thaxter *et al*., 2010).

The results of the performed hazard identification (HAZID) of the selection of scientific papers are compiled in the table below.

Table 4.2 – Summary of HAZID results from scientific paper literature review

Stressor	**Endpoint**	**Interactions**	**Paper**	**Grade**
Turbine rotor	Bacteria concentrations	Absorption of kinetic energy causes changes in velocity and suspended sediment levels	Ahmadian *et al.* (2011)	**3**
Overall presence	Fish population	Hinder commercial fishing	Langhamer *et al.* (2010)	**2**
Turbine rotor	Fish population	Collision	Langhamer *et al.* (2010)	**2**
Buoys	Migrating species	Migration barriers	Langhamer *et al.* (2010)	**2**
Installation activities	Marine organisms	Noise disturbance	Langhamer *et al.* (2010)	**2**
Cable Laying	Marine organisms	Noise disturbance	Langhamer *et al.* (2010)	**2**
Installation activities	Marine mammals	Sonar	Langhamer *et al.* (2010)	**2**
Turbine rotor	Fish population	Collision	Pelc & Fugita (2002)	**1**
Overall presence	Benthic community	Disturbance of habitat	Güney & Kaygusuz (2010)	**2**
Overall presence	Marine organisms	Noise	Güney & Kaygusuz (2010)	**2**

Overall presence	Marine mammals	Migration barriers	Güney & Kaygusuz (2010)	**2**
Installation activities	Marine mammals, fish	Installation activities and vessel movements cause disturbance to sediment	Defne *et al.* (2011)	**1**
Overall presence	Marine organisms	Increased shelter due to exclusion zones	Defne *et al.* (2011)	**1**
Cabling	Invertebrates and macro-algae	Positive effect leading to habitat creation	Defne *et al.* (2011)	**2**
Pile Driving	Cetaceans	Physical damage and noise disturbance	Dolman & Simmonds (2010)	**2**
Installation vessels	Cetaceans	Increasing local water pollution	Dolman & Simmonds (2010)	**2**
Overall presence	Cetaceans	Habitat degradations and population displacement	Dolman & Simmonds (2010)	**2**
Overall Presence	Cetaceans	Operational noise leading to disturbance	Dolman & Simmonds (2010)	**2**
Turbine Rotor	Cetaceans	Collision with exposed blades	Dolman & Simmonds (2010)	**2**
Antifouling Component	Cetaceans	Release of biocides causing toxic effects	Dolman & Simmonds (2010)	**2**
Maintenance or Decommissioning Vessels	Cetaceans	Disturbance	Dolman & Simmonds (2010)	**2**
Overall presence	Benthic Community	Altering water flows	Frid *et al.* (2011)	**2**
Overall presence	Benthic community	Altering substrate composition	Frid *et al.* (2011)	**2**
Overall presence	Benthic community	Altering sediment dynamics	Frid *et al.* (2011)	**2**
Foundations	Benthic Community	Alter water flow	Frid *et al.* (2011)	**2**
Overall presence	Fish population	Predation of fish attracted to artificial structures	Frid *et al.* (2011)	**2**
Turbine Rotor	Fish	Mortality as a result of direct collision	Frid *et al.* (2011)	**1**
Overall	Diving birds	Collision	Frid *et al.* (2011)	**2**

presence				
Installation	Marine Organisms	Noise	Frid *et al*. (2011)	**2**
Cables	Turtles	EMF	Frid *et al*. (2011)	**2**

It is clear that there is a diverse range of impacts that are suggested. Evidence from the table indicates that most of the results are suggested or based on another papers as opposed to being directly measured by the author.

4.2 Industry Hazard Identification Case Study

This case study focuses on two industry reports from Marine Current Turbines (MCT). The first is a pre-installation environmental statement from 2005 that attempts to quantify the magnitude and duration of potential environmental impacts of the SeaGen project. The second is an updated biannual report from late 2010 that is part of an MCT environmental monitoring programme to review if potential or other impacts were actually realised.

Marine Current Turbines were the first tidal turbine developer to install a commercially operational tidal turbine. As such, they have begun to explore the unknown. They have accumulated several years of experience in the field of environmental impact assessments of tidal turbines having had to submit numerous applications and fulfil many requirements for environmental agencies. Throughout the process they have documented environmental studies and reported environmental impacts from the 1.2 MW SeaGen turbine. A detailed analysis of the environmental impacts of the stationary tidal turbine will provide valuable insight when discussing the potential impacts of DGC in the future. Many of the features are the same (rotating turbines, installation base) and there are also differences (DGC is in constant motion, DGC has a tether attaching it to the sea-bed etc.).

4.2.1 Overview – Environmental Statement

This first industry report, from 2005 was prepared by Royal Haskoning Ltd., an engineering and environmental consultancy that was commissioned on behalf of MCT to investigate the environmental consequences of installing such a turbine in the Strangford Lough (MCT, 2005). The final report was released on 21 June 2005, before the installation of the SEAGEN turbine. It provides a good overview of the work performed by MCT **before** the installation of the turbine. It assesses and categorizes potential environmental impacts that may occur as a result of the project.

The design of the MCT turbine is typical of general tidal turbine designs but with some extra features. It consists of a twin rotor device mounted on a central monopole with two 16 m diameter rotors on either side. The twin rotors develop a combined rated power of 1.2 MW at a current velocity of 2.4 m/s. According to MCT it has the capability to deliver approximately 10 MWh per tide (roughly 6,000 MWh per year) that is comparable to the energy extraction from a 2.4 MW rated wind turbine. Each rotor drives a generator via a gearbox. The blades are designed to allow for a pitch of 180 degrees to ensure that they can generate electricity both during the ebb and the flow of the tide. Another feature of the installation is that the twin rotors can be hydraulically raised up the monopole so as they are above the sea level during maintenance procedures. This reduces the associated maintenance costs as the routine work can be carried out without the need for professional divers. The selected installation site for the 1.2 MW Marine Current Turbine was in Strangford Lough, Northern Ireland. It operates with a swept area of 402 sq. meters.

4.2.2 Selected Endpoints – Environmental Statement

A baseline study was first performed by MCT to investigate what were the main endpoints that could be affected. The study assessed the local ecology to examine what the local environment is comprised of and how the components of this environment could be impacted. The selected endpoints for the pre-installation study are summarized in the table below:

Table 4.3 – Summary of potential endpoints identified by MCT in baseline study

Endpoints	**Notes**
Benthic Biology	The site is host to a range of floral and faunal species living on the seabed, but is limited by the powerful current of the Strangford Straights. The bedrock is densely covered in ascidians (sea squirts) and hydroids (moss) with sponges and barnacles present in spots.
Fisheries	Studies have shown that the area is home to lobsters, prawns, crabs, horse mussels, scallops, dog cockle, curled octopus and sea trout (Coull *et al*. 1998).
Marine Mammals	Due to their large size and mobility seals are considered to be a primary focus for studies into potential impacts of the tidal turbine. A study by the Environment and Heritage Service in 2004 indicates that otters are present in Strangford Lough (EHS, 2004).
Marine Mammals (Cetaceans)	Any interaction between these cetaceans and a tidal turbine could have catastrophic consequences and as such they too are classified as endpoints that require extensive investigation.
Basking sharks and Elasmobranches	The Marine Conservation Society has noted that Strangford Lough could be a hot spot for basking sharks. These sharks are the largest fish in British waters and the second largest in the world. They are a protected species and global status of 'vulnerable' according to the International Union for Conservation of Nature (IUCN). Elasmobranches utilise electric fields for prey detection and navigation. It has been noted that electromagnetic fields created by underwater cabling could impact these navigation systems.

Birds	Strangford Lough is a designated special conservation site for several types of bird. For the MCT report, species that dive into the ocean to obtain food are the central focus. Terns, gannet, cormorant, shag, red-breasted merganser, black guillemot, razorbill and the common guillemot are all recorded inhabitants of the area.
Alien Species	Installation activities could result in the introduction of alien species that are foreign to the local environment, for example certain types of weeds or grasses. The introduction of such species could have an effect on existing species as they compete for habitat areas.

4.2.3 Expected Stressor Sources – Environmental Statement

For the pre-installation, proactive study, MCT identified the following as potential stressors that could occur throughout different phases of the project that could affect the above endpoints:

Table 4.4 – Summary of stressors identified by MCT in baseline study

Stressors	**Notes**
Drilling	During installation, a hole will be drilled into the seabed for the monopole. As well as the foundation hole, a barge will have to be positioned over the site that will be supported by 8 legs on the sea floor. These legs will also impact the seabed. There is a 4m-diameter impact zone around each leg. Combining these impacts with the monopole impact, it is expected that an area of 100 m^2 with direct loss of habitat for the benthic community. However, loss of habitat due to the barge legs is assumed to be short term with full recoverability possible after the installation phase is complete. The drilling will result in a direct loss of feeding habitat for fish. There is a risk that marine mammals will collide with the drilling machinery during the installation phase. Finally, the drilling process could result in the introduction of alien species.
Particulate Emissions	Particles released in the installation phase could affect the light penetration of sunlight to the seabed. As a consequence of this the benthic community could be adversely affected as a result of a decreased level of sunlight.
Accidental Spillage	There is a risk that during the installation phase, an accident could lead to an oil leakage or spillage. Such an action would result in pollution of the water that would adversely impact the benthic environment. Fish, marine mammals and other inhabitants of the

	local environment would be directly affected by spillages also.
Physical Presence of Turbine Structure	There are several distinct and separate stressors that derive from the general presence of the technology that will have an effect on the benthic community. These include the alteration of the tidal velocity due to energy extraction, due to downstream turbulence, from changes in water quality, and the risk of spillage of operational contaminants such as lubricants. The actual physical presence of the turbine will act as a physical obstruction to fish and other inhabitants as they navigate the waters
Noise & Vibration	The installation phase will involving drilling and hammering (pile-driving) processes as well as the presence of barges and various boats. These activities will result in a change in the levels of vibration and sound waves that are diffusing through the water. A prolonged increase in noise and vibration could result in fish and other inhabitants vacating the site depending on the volume and frequency. This will indirectly affect the feeding patterns of diving birds.
Rotor Blades	Direct collision with the rotor blades would result in the maiming or killing of fish and other inhabitants.
Electro-Magnetic Fields	The presence of underwater electrical cables could adversely affect the sensors the elasmobranches use to detect prey and navigate. Studies into this effect are limited and MCT highlighted the need for continued research.

The second industry report, dated December 22 2010, utilised in this case study is an updated biannual report of the SeaGen environmental monitoring programme. The purpose for the inclusion of this report is to examine whether the expected potential impacts discussed in the 2005 report were realised or not and to see if there were any unexpected additional impacts. It is important to note that the report contains empirical data that can be used to validate judgements made in the pre-installation scoping study.

Once again Royal Haskoning Ltd, on behalf of MCT, compiled this report. The report provides a comparative analysis of all the environmental data collected during the pre-installation period (Environmental Statement 2005) and successive Environmental Monitoring Programme biannual reports during the installation, commissioning and operation phases. This report is the most up to date report available.

4.2.4 Overview – Environmental Monitoring

The report is the latest in a series of biannual reports by Environmental Monitoring Program at MCT. Each six months since the initial 2005 environmental statement report, MCT issue an updated version. The objective of the EMP is to (MCT, 2010):

Detect, prevent or minimize environmental impact attributable to the turbine installation and operation; and

Provide an on-going monitoring strategy to determine any immediate or emerging adverse impacts on the habitats, species and physical environment of Strangford Lough

The biannual reports focus on those impacts that have been identified to be the most severe and with the most likelihood from the initial environmental statement report of 2005. These are defined as "*key overarching objectives"* or impacts in the biannual reports. The identified key overarching objects of the SeaGen mitigation programme are that the presence of the turbine does not have a significant detrimental impact on:

- *The integrity of the breeding harbour seal population*
- *The abundance, diversity, integrity and extent of the benthic biological communities associated with the submerged rocky reefs*
- *The population of breeding seabirds*

The assessment is framed through the use of key questions and data confidence scales. The potential for a given impact is phrased as a key question (*Is marine mammal density and behaviour in Strangford Narrows significantly modified by the SeaGen turbine?).* This question is then asked across all phases of the project (*installation, operation etc*.). The question is answered and a data confidence scale is applied. The data confidence scale is a measure of the ability of the data to provide a reliable indicator of change and answer the key questions.

4.2.5 Stressor - Endpoint Interactions – Environmental Monitoring

The monitoring report reduces the range of selected endpoints from the earlier pre-installation report to include only those that are deemed most important: Marine Mammals (Seals), Benthic Ecology and Birds.

It is interesting to note that the MCT report does not include fish as a selected endpoint that needs addressing although fish were an endpoint that featured frequently in the scientific papers. A study by Wilson *et al*. which uses a model to assess the potential encounter rate between 100 horizontal axis 8 m radius turbines (similar in size to the MCT turbines) operating off the Scottish coast and existing populations of herring and harbour porpoises predicted that 2% of the herring population would encounter a rotating blade (Wilson *et al.*, 2007). The study claims that encounters

would be greater still for sharks (also not included as endpoints in the updated MCT 2010 study).
The following table uses the same grading scale as laid out in Table 4.1.

Table 4.5 - List of Stressor-Endpoint Interactions

Stressor	**Endpoint**	**Interaction**	**Grade**
Operational Noise	Seals	Disturbance of seal communication	4
Operational Noise	Seals	Hearing damage	4
Operational Noise	Seals	Seal behaviour	4
Installation	Benthic Ecology	Destruction of habitat	4
Operation	Benthic Ecology	Destruction of habitat	4
Operation	Birds	Disturbance of food source	4
Workers	Birds	General Disturbance	4

Operational Noise - Seals

A number of studies were commissioned to examine what, if any, stressor sources were impacting the local seal community. One study examines the potential stressor of noise impact on the seals (Kongsberg, 2010). By measuring the noise output of the turbine during operation, data was collected to examine at what distance seals could hear the turbine, the effect the additional noise may have on seal communication, prediction of seal behaviour responses could be made and potential of hearing damage could be assessed. With a medium data confidence level, results from the EMP state that the density and behaviour of the seal population has not been significantly modified and the number of sightings in the region has not decreased.

Complementing the noise study, there are on-going aerial surveys, carcass monitoring, passive acoustic monitoring and active sonar monitoring programmes in place that show with medium to high confidence that the local seal population is not being adversely affected by the SeaGen.

Overall Presence - Benthic Ecology

Dive surveys are on going to examine the effect of the SeaGen on the local benthic ecology. The main objective of this monitoring programme is to detect if there is broad change (large shifts in dominant species) in the benthic community structure as a result of the installation and operation of the turbine. The divers use underwater video cameras to survey sections of the seabed. With a high confidence level, the results show that no significant change in the benthic community is noticeable.

Overall Presence – Birds

For the local birds, records were taken of the position and activity of the diving birds. These records have been taken every month since the initial 2005 report. It has been noticed that tern birds are attracted to the SeaGen at high tidal speeds due to the wake that is created. It is reasoned that an additional food source may be brought to the surface as a result of this wake. Surveys also showed that tern sightings were low during SeaGen operation but it was reasoned that the physical presence of humans on the SeaGen for the bird studies may be deterring the birds and not the actual turbine itself.

Surveys show a decrease in the number of birds in the immediate local area however there does not appear to be any biological significance to these changes. As such the results from the EMP state with medium and high confidence that the turbine does not have a biologically significant impact on seabird activities nor does it displace diving birds from the region.

4.3 Key Industry Actor Interviews

These next two blocks of data collection focus on the Minesto technology specifically. As has been mentioned previously, a tidal energy converter of this type has never been implemented at a commercial scale before. Therefore there are no documented empirical results for such a converter type. This means that the actual environmental impacts are presently still unknown. For this study, where potential impacts are being investigated, it was decided that a good method to gather information on potential interactions was to interview and document interviews with key industry actors, area specialists and research experts in this field. Their opinions can be compiled and categorized to allow for a speculative outlook of any potential impacts. An overview of the interviewees and their organisations can be found in the Appendix.

In accordance with academic protocol, a specific and established interview style is adopted for these series of interviews. Based upon previous research conducted in this field, it was decided to follow suit with the same interview style as found in previous studies – semi-structured and open-ended (Burgman, 2005). Open-ended techniques were the preferred choice to allow the actors freedom to consider all impacts that might arise however certain close-ended questions were used for clarifying facts and controlling the conversation. The interviews were recorded and later transcribed for further analysis. All of the actors are deemed to have relevant knowledge of the tidal energy industry and/or surrounding environments.

4.3.1 Overview

The following is an overview and summary of the main observations noted by the interviewees during the interview stages of this study.

Young Industry

A recurring observation brought to light by many of the interviewees was the young nature of the tidal energy industry (McSherry Interview, 2011; Harper Interview, 2011; Dr. Brewster Interview, 2011). Based on initial reactions to the Minesto device, the majority of the interviewees did not envision any immediate barriers to development but noted the need for empirical data to make a full and comprehensive assessment before such conclusions could be drawn (Dr. Brewster Interview, 2011; McSherry Interview, 2011; Harper Interview, 2011). Michael McSherry of Global Maritime Alliance was confident that environmental impact of the Minesto DGC would be minimal. McSherry emphasised the controlled development of the Minesto technology, the careful environmental documentation (Marenco, 2010) for the Minesto prototype sea-trials in Strangford Lough and the studies already completed by MCT as a positive attribute that would be positive force to ensure that Minesto has a high probability of reaching full-scale production without any major barriers of an environmental impact nature (McSherry Interview, 2011). Dr. Brewster reasoned that if other tidal turbine devices could be implemented into our society, then he saw no major reason on first impression that the Minesto device would not continue along its path of development (Dr. Brewster Interview, 2011).

Proactive vs. Reactive

Another main topic raised in several of the interviews was the differences between a reactive and proactive approach to mitigating potential environmental impacts of tidal technology. Dr. Brewster commented on the fact that the youthful nature of the emerging tidal energy industry meant that a reactive approach had to be taken when commissioning new projects. A trial-by-error approach, although not ideal, is the only option until hard empirical data can be collected from environmental monitoring programmes (Dr. Brewster Interview, 2011). Dr. Savidge of Queens University Belfast acknowledged the initial reactive approach that was necessary for MCT (the first tidal developers to achieve full-scale commercialisation) to take when accessing potential environmental impacts of tidal turbine technology. He reasoned that the initial and comprehensive work carried out by MCT in documenting and reporting results from environmental monitoring programmes has allowed other future turbine developers to adopt a proactive approach by forecasting issues based on the MCT data (Dr. Savidge Interview, 2011). He commented that this allows for mitigation plans to be implemented and for impacts to be designed and engineered out of the technology to a greater degree. McArdle noted that a proactive approach to environmental concerns could result in mitigation of identified potential impacts (McArdle Interview, 2011).

Concern

There were some initial concerns highlighted too. In an interview with Trevor McQuoid of the Northern Ireland Environment Agency (responsible for marine permits) McQuoid states that upon first review of the Minesto tidal device, some concerns were raised about the fact that the device is not static and what an effect an array of moving devices could have (McQuoid Interview, 2011). Although he did point out the almost organic nature of the device in that it could potentially fit in nicely in an aesthetic sense with its surroundings due to its movement, another concern raised during initial impressions was the effect the tether on a full-scale device could have on the local environment. Finally, noise issues were raised. McQuoid notes the rising levels of concern for tidal turbine devices regarding potential noise impacts.

Novel Design

Paul McArdle (of Marenco environmental consultants) recalled that initially, on first review, the novel design stuck out, especially compared to generic designs. However, McArdle stressed the fact that Marenco only take on projects they believe will be successful in gaining appropriate marine licences and they were confident that Minesto would not be hindered by potential major environmental impacts (McArdle Interview, 2011). Harper commented on the fact that the potential environmental impacts of the Minesto device may be different but not of a higher order of magnitude provided appropriate sites are selected (Harper Interview, 2011).

Perceived vs. Actual Impacts

Throughout the interviews, the difference between perceived impacts and actual impacts was noted several times (McQuoid Interview, 2011; McArdle Interview, 2011. McQuoid touched upon the difference between perceived impact and actual impact. He noted that the fact that the Minesto device is located underwater would minimize visual pollution and the perceived impacts by the general public would be reduced. Engaging the local community is a priority according to McQuoid to inform the communities and ensure perceived impacts are in line with actual potential impacts (McQuoid Interview, 2011). McArdle also noted the difference between perceived and actual impacts. He commented that public engagement and public relations were important to ensure successful Minesto device installations (McArdle Interview, 2011).

Site Selection

McArdle stressed the appropriate site selection was crucial in mitigating potential environmental impacts (McArdle Interview, 2011). He reasoned that site selection outside of designated zones would allow for less stringent licensing requirements and potentially less impacts due to the lower diversity of such locations. Harper noted the fact that the Minesto device would be operating in deeper waters, compared to conventional tidal turbines, would result in a different spectrum of issues (Harper Interview, 2011).

4.3.2 Selected Endpoints

The potential endpoints that were selected by the interviewees are summarized in Table 4.6 below.

Table 4.6 - List of Identified Endpoints

Endpoint	Reference	Count
Marine Mammals	McSherry, Savidge, Harper, Brewster, McQuoid, McArdle	6
Birds	McSherry, Harper, McQuoid, McArdle	4
Benthic	McSherry, Savidge, Brewster, McArdle	4
Fish	McSherry, Savidge, Brewster	3
Elasmobranches	McQuoid, Savidge	2
Fisheries	Savidge	1

Marine Mammals

Potential impacts on marine mammals were mentioned by every one of the interviewees with varying degrees of concern. McSherry pinpointed marine mammals as being key potential endpoints but stressed the lack of knowledge regarding interactions with tidal turbines and marine mammals (McSherry Interview, 2011). However, he did acknowledge the ground-breaking work that MCT have performed in addressing this issue and performing monitoring studies (MCT, 2010). McArdle, McQuoid and Dr. Savidge commented on the fact that marine mammals are high profile in terms of public perception and can provoke more emotive reactions for the general public and NGOs when assessing potential impacts of technology compared to other potential endpoints (McArdle Interview, 2011; McQuoid Interview, 2011; Dr. Savidge Interview, 2011). Interestingly, Dr. Savidge expressed less concern for seals with the Minesto device when compared to other stationary devices since marine mammals are less common in the deeper waters that the Minesto device will operate in (Dr. Savidge Interview, 2011). Harper felt that potential impacts on marine mammals were no different than for any other generic tidal device (Harper Interview, 2011). Dr. Brewster also acknowledged marine mammals as a potential concern but commented that this endpoint was also common to most other generic turbines (Dr. Brewster Interview, 2011). Like McSherry, McArdle also made reference to the MCT SeaGen and the work they are performing in monitoring seals and also experimenting with deterrents that will notify marine mammals of the presence of the device in the hope that they will be deterred from closer investigation. He felt that the daily experiences of seals that deal with ferries and fishing vessels as well as fishing nets and other disturbances will allow them to acclimatise better to the tidal technology device (McArdle Interview, 2011).

Diving Birds

Birds were the second most commented on potential endpoint. McSherry highlighted the point that many device developers overlook the potential impact of their device on birds (McSherry Interview, 2011). He did however point out that the Minesto full-scale device should have sufficient clearance (distance between tip of wing and surface) to nullify this issue. McQuoid also referred to diving birds (potential collision with device) but pointed out the that consultation would have to occur with the Natural Heritage, the statutory organisation under the Habitats Directive and Birds Directive, to fully understand the main endpoints of a potential site in Northern Irish waters.

Benthic Community

The benthic community was highlighted several times as being a potential endpoint. It was generally acknowledged that most generic tidal turbines would have an impact on this endpoint. McSherry believes that for the Minesto device, the impact will be minimal due to the small size of the foundation and the fact that the seabed environment can be recovered once the foundation is removed after decommissioning (McSherry Interview, 2011). Dr. Savidge noted that benthic communities could be affected from changes in current velocity as a result of energy extraction (Dr. Savidge Interview 2011). It is interesting to note that Dr. Savidge highlighted the need for more studies to investigate the relationship between the change in current velocity and the change in benthic communities. He believes a more comprehensive understanding of this relationship is essential for understanding the potential impacts of a marine device.

Fish

Dr. Brewster commented on the effect exclusion or no-fish zones could have on local fish populations surrounding a Minesto tidal array. He reasoned that no-fish zones would have a minimal impact on the overall environment in relative terms. Dr. Savidge noted that the local fish populations may increased due to the designation of "no-take" areas surrounding a tidal array that could allow a place of refuge for bottom dwellers in the benthic communities (Dr. Savidge Interview, 2011). He stressed that all these impacts were associated with all tidal turbines in general. Dr. Brewster did not think that exclusion zones could have a positive impact on the local environment like some studies suggest (Dr. Brewster Interview, 2011).

It is interesting to note that the primary concern raised was the effect that no-take zones could have on fish populations and not that fish could collide with turbines (a collision risk that was raised in the scientific papers).

4.3.3 Expected Stressor Sources

A summary of the identified potential stressors can be found in Table 4.7 below.

Table 4.7 - List of Expected Stressor Sources.

Stressor	**Reference**	**Count**
Tether (Total)		7
Noise	*Savidge, McQuoid*	*2*
Flow Regime	*Savidge, McQuoid*	*2*
Vibration	*Savidge*	*1*
Collision	*Brewster*	*1*
Slack	*McArdle*	*1*
Rotor Blades - Collision	McSherry, Brewster, McQuoid, McArdle	4
Overall Presence - Collision	McSherry, Savidge, Harper, McQuoid	4
Flight Path - Swept Area	McSherry, Harper, McQuoid	3
Cable Installation	McSherry, Harper, McArdle	3
Foundations	McSherry, Brewster, McQuoid	3
General Installation	McSherry, Savidge	2
Operational Noise	Savidge, Harper	2
Energy Extraction	Savidge, McQuoid	2
Surface Piercing Substation	Harper	1
Wing - collision	Brewster	1
EMF	McArdle	1
Overall Presence–Flow Regime	Savidge	1

Tether

Many of the interviewees focused in depth on the device tether when discussing potential key stressors of the Minesto technology.

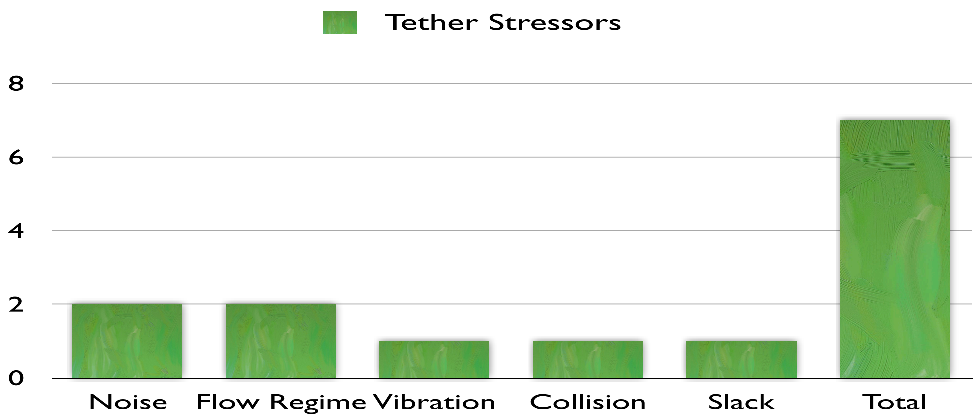

Figure 4.2: Breakdown of the suggested potential stressors associated with the tether– (number of mentions by interviewees on the y-axis)

Dr. Savidge pinpointed three main ways in which the tether could act as a stressor: disturbance of the flow regime, generation of noise, and vibrations from tether movement through the water (Dr. Savidge Interview, 2011). According to Dr. Savidge, the water column will be directly disturbed by the presence of a tether by a change in the flow regime. This disturbance could influence the settling of particles through the water column affecting the distribution of food (organic particles) as well as inorganic particles. Such a shift in food distribution could affect the benthic community and have other knock-on affect up the food chain. Dr. Savidge noted the diameter of the tether to be a critical element in the design of the full-scale device. Dr. Savidge also noted that the tether, under tension, could create a noise spectrum additional to the operation noise of the tidal turbine. This could produce high frequency acoustic waves that adversely affect local fish and mammal populations. Dr. Savidge advised for future studies to be commissioned by Minesto to investigate this issue through acoustic measurement and monitoring programmes. He especially noted that there could potentially be a non-linear amplification effect for tidal arrays. Since the Minesto device will be working under lower energy conditions, with less background noise, these noise issues could be more of an issue for Minesto than for other tidal developers operating in higher energy conditions according to Dr. Savidge.

Dr. Brewster commented on the movement of the tether through the water as being a potential stressor. He noted that collision risk was the biggest concern when commenting on interactions between the tether and the local environment (Dr. Brewster Interview, 2011).

At full scale McArdle noted the tether to be a potential stressor if slack. Much like the anchor line of a boat, if during slack waters the tether were to be slack and dragging along the sea-bed this would lead to damage and scouring of the benthic community. McArdle, however did not consider it to be a limiting factor to the progress of development at Minesto (McArdle Interview, 2011).

Rotor Blades

Collision with the device rotor blades was a commonly highlighted stressor. Michael McSherry of Global Maritime Alliance pointed to rotor blade collision as a stressor that is common to all tidal energy devices as well as others such as disturbance of surf zone, cable installations, installation of foundations, general installation works and overall structure presence (McSherry Interview, 2011).

Dr. Brewster also pointed to the rotating turbine blades of the device as being a potential stressor. He added that this stressor was common in the industry and reasoned that the smaller, enclosed rotating turbine blades of the Minesto device could have a reduced potential impact (Dr. Brewster Interview, 2011). McQuoid also noted the smaller, enclosed nacelle reducing the chances of collision with the rotor blade of the Minesto device (McQuoid Interview, 2011).

McArdle commented on the potential collision risks from the rotating turbine rotor blades as being a potential key stressor. He highlighted the rotor blades as being the primary collision concern. He felt that the marine organisms had the ability to avoid collision with the overall device structure (McArdle Interview, 2011).

Overall Structure Presence

According to Harper, the high speed of the device (15 m/s), relative to the seabed, will increase collision risks with marine mammals (Harper Interview, 2011). McQuoid referred to potential barriers for migration of marine species when discussing collision risk of the overall device and noted that the physical presence of the device in channels or straights could have a higher impact than in open waters (McQuoid Interview, 2011). Only Dr. Brewster highlighted the hydrodynamic wing specifically when commenting on the potential of collision of the overall device structure (Dr. Brewster Interview, 2011).

Flight Path – Swept Area

Several of the interviewees pointed to the flight path of the full scale device being a potential key stressor. The swept area of the DGC is larger than any other tidal energy device. The 12m wing span device has a swept area of 2000m^2 (Minesto Datasheet, 2011). McSherry reasons that an array of Minesto devices would occupy a larger area and marine mammals may or may not understand that they have less of a 'free-zone' to negotiate and navigate through or around a Minesto tidal array farm (McSherry Interview, 2011).

Harper and McQuoid also touched upon this potential stressor. Harper noted that the large swept areas would result in a lower energy density per area, possibly leading to issues for environmental assessments of potential sites. Larger areas would be more time-consuming and costly to acquire appropriate environmental data for – an example being the increased size and diversity of the benthic community (Harper Interview, 2011). McQuoid noted that the smaller rated capacity would increase the amount of devices in an array compared to generic tidal turbine farms and the overall spatial coverage will be increased due to the trajectory of the Minesto device (McQuoid Interview, 2011).

Energy Extraction

According to Dr. Savidge, the fact that the Minesto device extracts energy from low velocity currents means that it is located in local environments that are adapted to low velocity currents and have sandy or muddy sea beds which are more prone to stressors than the rocky and sparse seabed at high velocity current locations. Dr. Savidge believes the seabed at a low velocity current location will be far more susceptible to mechanical damage (Dr. Savidge Interview, 2011). McQuoid also noted that since the DGC would be operating in lower current density locations, the properties and environments of these low density areas would differ from the environments in which other generic, stationary devices operate – stating that the sandier, cobbled-based seabed's could be prime spawning grounds for pedagogic fisheries (McQuoid Interview, 2011).

Others

Harper noted that since the Minesto technology is operating further offshore than conventional tidal devices, it may be a requirement to have a surface-piercing substation for large tidal arrays (Harper Interview, 2011). He also pointed out that the device might need more cables than conventional devices since a Minesto array may be more dispersed which would impact the local environment.

4.4 Prototype Preliminary Assessment Study

Since 2007, Minesto has been developing, testing and proving their technology using scaled prototypes and tow-tank testing. The SeaKite II 1/10 scale prototype began sea-trials in November 2011. Before trials could begin, Minesto commissioned a environmental consultancy firm "Marenco" to examine the potential impacts that could result from testing this scaled prototype in a marine environment.

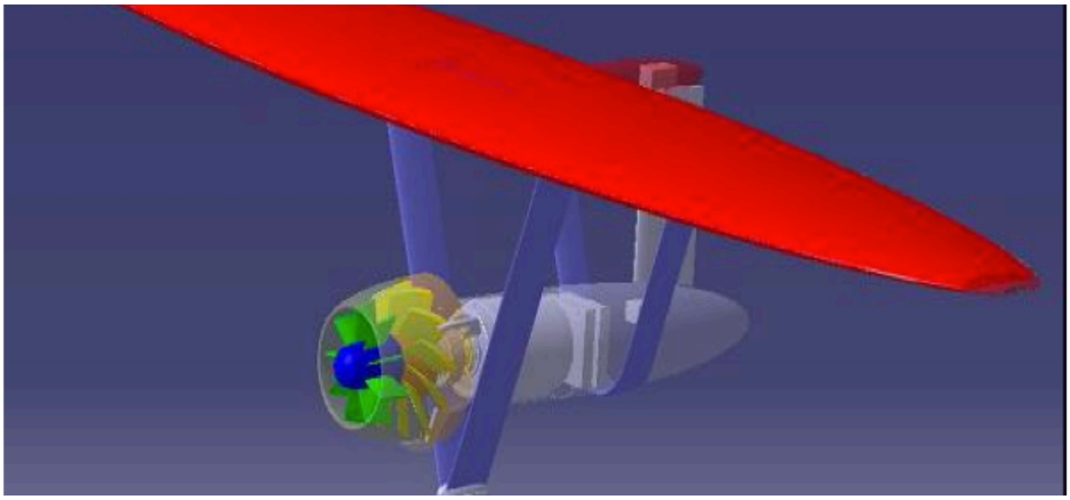

Figure 4.3: Computer Model of SEAKITE II (© Minesto)

4.4.1 Overview

In preparation for the Crown Estate application Minesto commissioned Marenco, an environmental consultancy firm based in Northern Ireland, to conduct a "test of likely significance". Marenco is a corporate member of the Institute of Environmental Management and Assessment (IEMA) and their core consultants are IEMA approved Principal Environmental Auditors. Working with Queens University Belfast, Marenco examined the design and the installation plans of the prototype in Strangford Lough waters, Northern Ireland. The results of the test are submitted to the Northern Ireland Environment Agency (NIEA) Marine Assessment and Licensing Team (MALT) in accordance with the Food and Environment Protection Act (FEPA 1985).

4.4.2 Selected Endpoints

The selected endpoints are specific to the site that was selected for the prototype sea trials. The Minesto team selected Strangford Lough, located in County Down, Northern Ireland. It is the largest inlet in the British Isles covering 150 km^2. The Lough is almost totally landlocked with a narrow tidal passage running 8 km in length connecting it to the Irish Sea. The narrow and dependable movements of the tide through the straight have attracted other tidal energy companies to the location too (In

2007 Marine Current Turbines installed commercial scale 1.2 MW tidal electricity generator called SEAGEN. In 2008 a 1/10-scale prototype developed by Ocean Flow Energy Ltd. called EVOPOD was tested).

Figure 4.4 – Minesto testing location, Strangford Lough, Northern Ireland

Strangford Lough is a designated Special Area of Conservation (SAC), Special Protection Area (SPA), Northern Ireland's first Marine Nature Reserve, a RAMSAR (international treaty for the conservation and sustainable utilisation of wetlands) site, and has five ASSIs (Areas of Special Scientific Interest) within its boundary.

Reefs, vegetation of stony banks, salicornia (a type of salt-tolerant plant) and other plants colonising mud and sand, Atlantic salt meadows (a type of vegetation that forms in the middle and upper reaches of saltmarshes, where tidal inundation still occurs but with decreasing frequency and duration), common seals, breeding seabirds (terns) and wintering waterfowl were all potential endpoints, in the selected environment, identified by Marenco.

4.4.3 Expected Stressor Sources

The following potential stressors were highlighted for investigation in this study although Marenco state at the outset that due to the scale of the project, it has been envisaged that there will be no discernable impacts (Marenco, 2010).

Table 4.8 - Expected stressor sources as indicated in Marenco study (Marenco, 2010)

Stressors	Notes
Installation Vessels	There is a potential for the noise and vibration generated from installation vessels throughout the installation phase and support vessels throughout the operational phase to adversely affect the local environment.
Operational Noise	It has also been noted that noise from the operation of the tidal energy converter may adversely affect the local environment.
Operational Vibrations	It has also been noted that vibrations from the operation of the tidal energy converter may adversely affect the local environment.
Turbine Blades	Direct collision with the rotor blades of the tidal turbine could negatively affect the local environment.
Foundation	The device mooring structure was pinpointed as a potential stressor that could damage benthic communities. A small amount of seabed material has to be displaced to ensure a flat surface for the mooring.
EMF	The potential effect EMF alterations could have on the local environment was noted

4.4.4 Expected Stressor-Endpoints Interaction

Operational Noise & Vibration

The potential of operational noise and vibration to impact wintering wildfowl, breeding terns, common seals and other marine mammals has been highlighted. However, Marenco have concluded that the scale of the prototype is not large enough to cause a disturbance.

Turbine Blades

The potential for collision with the rotating turbine blades was also noted. For the prototype, the wing will reach a maximum speed of 6 m/s and will complete one figure 8 cycle every 5-10 seconds. As well as the movement of the structure, the turbine blades will also be rotating at 2000 rpm. To address this potential issue Marenco refer to a study from the Scottish Natural Heritage Scientific Advisory Committee that suggests that the physical effects of rotating turbines can remove diving seabirds from the immediate vicinity of the blades hence avoiding a collision (Scottish Natural Heritage Scientific Advisory Committee, 2009). Regarding the potential for marine mammals to collide with the structure Marenco refer to studies performed by MCT on the stationary SeaGen technology that states the there have been no significant impacts to marine mammals (SeaGen, 2010). Marenco state that throughout trials there will be monitoring of the behavior of sea mammals and other species. Marenco however do not address the fact that the Minesto device as well as the turbines blades are in constant motion as opposed to the MCT SeaGen that is stationary or the fact that the MCT device was shut down every time a sensor detected a potential endpoint was approaching.

Foundation

It was predicted that the installation of the mooring would impact the benthic communities. To minimize this, a dive survey was undertaken to examine the seabed conditions. The site was selected to ensure a minimum amount of eelgrass was present.

EMF

The final expected stressor-endpoint interaction that was envisioned was the impact that electric currents may have when they pass through the underwater cables on species that utilize electromagnetic fields as a means of navigation. The power in the cables for the prototype trials will be low and therefore any EMF impacts were deemed negligible.

5.0 Comparative Analysis of Data

Here, a more in depth examination of the data gathered in the data collection phase is presented. Patterns and differences between the different data blocks are highlighted and discussed.

5.1 Data Quality

All but one of the scientific papers reviewed based conclusions on suggestions or references to other work. None of the papers used measured data. Only one had conclusions based on modelling work. There is a danger in the scientific community that due to the system of referencing that apparent impact data may be blown out of proportion. For example, if just one study cites that noise **may** be an issue that should be considered when examining **potential** environmental impacts of tidal stream turbines without actual, empirical data to back this claim up, other authors citing this paper will allow for a speedy and diverse diffusion of this potential impact amongst the scientific community due to the system of heavily focussing on references.

However, the data taken from the MCT industry reports is empirical data that has been collected from the on-going environmental monitoring programmes and studies that MCT are conducting. It is perhaps that case that the onus is on the technology developer, in this case MCT, to prove using empirical data that their device has minimal impact. Without having collected such data, it would be impossible for the developer to obtain permitting and leasing licenses for future projects. It is for this reason that the developer undertakes the costly and time intensive process of gathering actual, empirical data and not the scientific community.

5.2 Data Discrepancies

It is interesting to note that the Marenco study of the prototype does not identify the tether as a potential stressor on the local environment. However, the tether was the most identified key potential stressor that the majority of the interviewees felt needed further addressing. One explanation of this, upon further investigation, is that the tether was deemed to have minimal impact at a prototype scale and would only really be considered a key potential stressor at full scale.

Also interesting is that MCT reports never address fish as potential endpoints in very much detail. A potential implication for this is that fact that fish may have a lower social importance when compared with other potential impacts such as marine mammals. Much attention is allocated to ensure that marine mammals are not negatively impacted by any tidal installations. There are many research groups and advocates with large political and social voices that ensure impacts to marine mammals are not tolerated. However, the equivalent groups for fish are not present. The lack of social pressure to protect fish means that the developers will primarily focus on addressing potential impacts to those endpoints that are deemed most socially important. Spending time and money on addressing these issues first could allow for an easier application process when undertaking future projects.

5.3 Call for further studies

A large portion of the relevant papers acknowledges the young nature of the tidal energy industry and that little empirical data is available. The majority of the key interviewees and scientific papers also noted this point. Many of the interviews highlighted the changing roles and processes of environmental studies due to changing and developing nature of the newly emerging tidal energy industry. This point will be examined in more detail later in this thesis.

The need for dedicated models to assess the hydro-environmental interactions of operating tidal devices is stressed in scientific papers (Ahmadian et al., 2011) and in the interviews with key industry actors (Dr. Savidge Interview, 2011). The general feeling is that in order to better understand how a tidal turbine interacts with its local environment, there must be more focus on developing accurate hydro computational models. Once these models have been developed, it will be possible to forecast how a turbine will react with its environment and to model potential impacts before installation takes place. This greater understanding will allow for potential impacts to be minimized through adequate site selection and design modifications.

Although the general consensus is that tidal stream turbines have a small footprint (Ahmadian et al., 2011), the need to assess tidal stream turbines at an array scale examining the effects of the number, size and position of devices installed has been stated both in scientific papers (Ahmadian et al., 2011) and in interviews with key industry actors (McSherry Interview, 2011; Dr. Savidge Interview, 2011; Harper Interview, 2011; McQuoid Interview, 2011). As mentioned above, little is known about the interactions of a single tidal turbine but having a large quantity of turbines at a single site will have new and unique impacts different from the impacts of a stand alone unit. Models must be developed that can better understand how the flow of water will be affected as it moves through a tidal array. The interactions of the multiple turbine devices with the local environment as well as the interaction with each other must be better understood to give a clearer picture of potential impacts.

6.0 Results & Recommendations

Table 6.1 shows a summary of all the stressors highlighted throughout the 4 methods of data collection – the scientific paper review, the MCT case study, the Minesto prototype environmental report and the results from the interviews. Stressors highlighted in green indicate potential stressors that are common to most tidal turbine designs. Potential stressors that are currently unique to the Minesto device are marked in red. Minesto must adopt a reactive approach when addressing these potential stressors, as there is currently no published data on the impacts of such potential stressors that Minesto can utilise. This is discussed in more depth in section 6.1.

Table 6.1 - Potential stressors identified during all stages of data collection

Stressor	Scientific Papers	MCT Case Study	Minesto Prototype Assessment	Interviews
Accidental Spillage		+		
Buoys	+			
Cables	+			+
Drilling	+	+		
EMF		+	+	+
Energy Extraction				+
Flight Path				+
Foundation	+		+	+
Humans	+	+		
Installation	+	+	+	+
Noise & Vibration		+	+	+
Overall Presence	+	+		+
Particulate Emissions	+	+		
Release of toxins	+			
Substation				+
Tether - Collision				+
Tether - Flow Regime				+
Tether - Noise & Vibr.				+
Tether - Slack				+
Turbine Rotor	+	+	+	+

6.1 Difference between Proactive and Reactive Approach

It is clear from the table that Minesto share a lot of potential interactions in common with the results from the scientific papers and the MCT case study. Due to this overlap, Minesto can afford to take a proactive approach and utilise information from other early-stage technology developers as it is published on how best to address these issues. A proactive approach is a method of addressing issues that allows for Minesto to build on the work that has already been published by the industry and proactively seek solutions to a potential issue before it may occur instead of reacting to it. For example, collision of marine mammals with tidal turbine rotor blades is a potential interaction for most types of tidal turbines. The reactive approach that MCT adopted (out of necessity as they were the first to install a commercial turbine allowing for the collection of empirical data) highlighted this potential interaction and the subsequent monitoring studies and data that was published allows other tidal developers to take a proactive approach in addressing this potential issue, capitalising on the ground work of MCT.

However, there are also potential interactions that are unique to the Minesto device. Minesto must address these potential interactions by adopting a reactive approach whereby design alterations, trial-and-error and monitoring will reveal the magnitude of potential issues associated with these potential interactions. The following analysis focuses on those potential stressors that are deemed to be currently unique to the Minesto device and that Minesto must address head-on in order to ensure that any of the potential issues do not threaten further development.

6.2 Identified Potential Interactions - Reactive Approach

The results in Table 6.1 show that there are potential stressors unique to the Minesto devices that are not currently found in any other concept. These potential stressors are assessed further here and proposed methods for addressing these potential stressors are suggested.

6.2.1 Tether Interactions

The tether, connecting the DGC device to the foundation, is currently unique to the Minesto design. As such, no scientific papers or studies have addressed the potential environmental interactions of such a part for tidal turbines. Several separate potential stressors were identified for this component in the interview stage of this study. As mentioned in the comparative analysis stage of this study, the device tether was not selected as a potential stressor for assessment in the Marenco environmental assessment of the Minesto prototype device (Marenco, 2010). Further investigation of this fact revealed that the tether was deemed to have minimal impact at a prototype scale and was only considered a key potential stressor at full scale (McQuoid Interview, 2011). The identified potential stressors were: noise, disturbance of the flow regime, vibration, collision and tether slack, as shown again in the chart below.

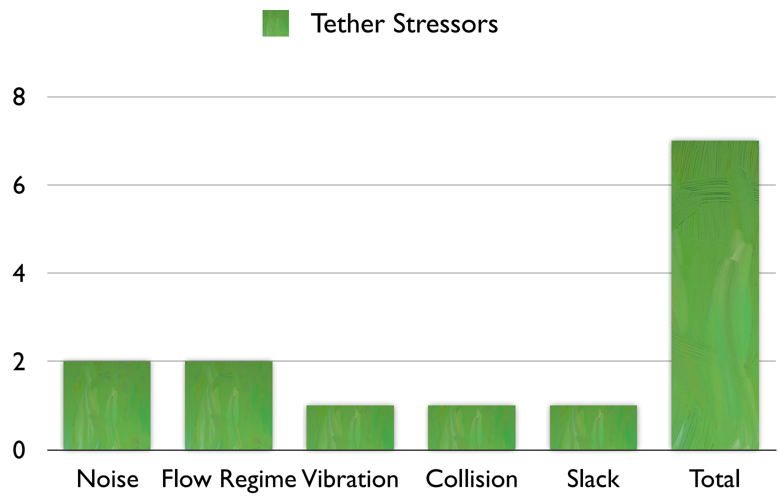

Figure 6.1: Breakdown of the suggested potential stressors associated with the tether – (number of mentions by interviewees on the y-axis)

Noise & Vibration

The tether is a load-bearing element that will be required to withstand the forces generated by the 7 ton device as it operates at speeds of up to 25 m/s in waters that are flowing at 2.5 m/s. This will create considerable tension in the line with resulting noise and vibration in the water. There are however, possible design modifications that can reduce such vibrations. Cable fairings can be attached to the tether to streamline the flow of water around it. This will not only reduce the drag by also reduce the vibrations that are caused by vortex shedding (the creation of vortices as the water flows around the cylindrical tether). A study undertaken by a Canadian Defence R&D team to determine the feasibility of towing a streamlined torpedo-like body at various depths and speeds states that cable fairing can prevent strumming, reduce drag and reduce mechanical fatigue (Dessureault and Miller, 2005). There are different types of cable fairing that can be used such as braided hair fairing, strip fairing and flexible hydrofoil-shaped fairing but in the Dessureault & Miller study, rigid hydrofoil-shaped fairing is used (Dessureault and Miller, 2005). According to the report, this type of fairing is suited for high speed towing applications with a drag coefficient in the order of 0.15-0.20. For comparison a sphere has a drag coefficient of 0.6, a bullet has a drag coefficient of 0.295 (Gemba, 2007).

Flow Regime

Both Dr. Savidge and McQuoid noted the potential for the tether to have an affect on the flow regime of the moving body of water and subsequent effects on the local environment (Dr. Savidge Interview, 2011; McQuoid Interview, 2011). As mentioned earlier, Dr. Savidge claims the water column will be directly disturbed by the presence of a tether by a change in the flow regime that in turn could affect the settling of particles through the water column and therefore the distribution of food in the form of organic particles as well as inorganic particles. Little is yet known of the exact influence a Minesto device will have on the flow regime. This is a potential impact that will have to be addressed further, especially when the effects an array of device will have on the flow regime is considered. By building computational models that can predict the flow regimes and allow for a better understanding of potential impacts that any alterations may have. The need for such models has already been highlighted and discussed as being a recurring observation in many of the scientific papers (Myers *et al*., 2005; Bryden *et al*., 2006; Bahaj *et al*., 2007; Batten *et al*, 2008; O'Doherty *et al*., 2009; Willis *et al*., 2010).

Collision

To analyse the potential stressor of collision risk associated with the tether, Minesto can look to make comparisons to mooring lines used for other ocean energy projects. One such study, completed by the US Department of Energy on the University of Maine's Deepwater Offshore Floating Wind Turbine Testing and Demonstration Project in the Gulf of Maine examines potential impacts of such a structure (US DOE, 2011). The comprehensive study completed by the US DOE cites numerous other studies to support the conclusion that it is expected that marine mammals will detect and avoid the mooring lines of the floating structures. For example a study by Akamatsu *et al*. in 2005 states that many toothed whales have the ability to detect through echolocation and avoid structures in the water (Akamatsu *et al*., 2005). In the same study it was found that finless porpoises inspect a distance of up to 250 feet ahead and swam less than 65 feet without using sonar (Akamatsu *et al*., 2005). The US DOE utilise studies by Schusterman and Balliet, and Mills and Renouf, to state the seals have well-adapted underwater vision and can detect vibrations in the water respectively as methods of reducing potential collision risks (Schusterman and Balliet, 1970; Mills and Renouf, 1986).

One difference that must be noted from the impacts of the mooring lines discussed for the offshore floating wind turbine platform is that those moorings will in general be stationary. However, the Minesto tether will be in constant motion. As such, experimental modelling and trial-and-error testing and monitoring studies are necessary to examine the actual collision risk associated with the tether. Aside from these methods to minimize impacts, proper site selection for the installation of a Minesto device will ensure that the quantity of marine mammals and other marine organisms in transit will potentially be minimized.

Slack

During low waters, depending on the final design, there is the potential for the tether line to drag along the seabed and disrupt the benthic community. This is a common problem with many sea structures that are moored or tied to the seabed by anchor lines. For example the grounding of floating docks and associated methods of mooring can lead to the alteration of the benthic invertebrate community and loss of grasses on the seabed (Nightingale and Simenstad, 2001). Anchor lines or heavy fastening chains can drag across the seabed as a result of tidal or wind events that can disturb vegetation and cause scouring (Williams *et al*., 2003). One study, when assessing the potential environmental impacts of oil and gas pipeline installation in the Gulf of Mexico claims that anchor damage is the greatest threat to live-bottom areas but that impacts from anchor chain sweeps (the dragging of slack chain along the seabed) would be much less severe with recovery possible because the impact was suggested to be to the surface of the seabed and no to the hard substrate itself (Cranswick, 2001).

Minesto can best address this potential stressor through design and subsequent monitoring studies. One potential design to address this potential interaction would be to design a component for the tether that retracts excess slack during low tides. There are currently patents on marker buoys that use such a technique to ensure an adequate length of line is released at all times to mark the position of a submerged object regardless of the position of the tides (Gram & Austin, 1989). Subsequent trial-and-error and monitoring studies would allow for an understanding of how the tether may move during low waters and whether or not it has an adverse affect on the sea bed.

6.2.2 Overall Presence – Collision due to Flight Path

The Minesto tidal energy converter is unique in that it is in constant motion during operation as opposed to other static tidal turbines that are fixed in place and require high tidal current velocities (> 2.5 m/s) for effective electricity generation. This restriction is not true for the Minesto device. It can operate in low current velocities since the motion of the device accelerates the flow of water through the turbine. Operating in a current velocity of 2 m/s, the main device structure (wing, nacelle, turbine) moves at a speed of approximately 20 m/s. There are potential impacts associated with the movement of a large submerged device (with a wing span of 12 m and a weight of 7 tons) at these fast speeds.

The closest parallel that can be drawn is to compare its presence with that of a submarine. The Alfa-class submarine is one of the fastest submarines and can operate at speeds of greater than 40 knots (20.5 m/s). It has a maximum width of 9.5 m and a length of 81.4 m (Rawool-Sullivan *et al*., 2002). Examining the large whale ship strike database, a database containing a total of 292 records of confirmed or possible ship strikes to large whales, reports only one incident where a breaching whale collided with and struck the bow of a surfaced submarine (Jensen & Silber, 2003).

However, it can be noted that the activity of nuclear submarines is rarely officially reported on and this may be a reason why only one incident has be documented.

However one important difference that separates the movements of a submarine from that of a Minesto device is the rate of change of the device direction. The Minesto device follows an figure of 8 path optimized for electricity generation by the control system. It is recommended therefore that further investigations be conducted into the possible collision risk of the Minesto device with marine organisms, especially marine mammals, due to the far-reaching flight path of the device.

7.0 Discussion

It is interesting to place these results in a wider context of the emergence of the tidal energy industry. Over time, the approaches that Minesto and all other tidal energy developers utilise when addressing potential stressors and interactions with their local environments will change as the industry progresses. What has started out as a largely reactive approach to addressing potential stressor issues will in turn become more proactive as the body of knowledge in the scientific and industrial communities is added to. Out of necessity, as early stage technology developers, companies like MCT have had to assess impacts in a largely trial-and-error approach whereby on-going monitoring studies and empirical data collection are used as methods to attempt to find answers about environmental impacts of tidal turbines that are, as of now, still largely unknown. This discussion focuses on analysing how the process of environmental assessments will advance as the industry as a whole advances and the effects of being an early-stage technology developer on the rate of development.

7.1 Implications of Potential Stressor-Endpoint Interactions

As is noted in the results section, there are potential stressors that Minesto must investigate further to determine their effect on the future development on the full-scale tidal turbine device. Some of the potential stressors can be dealt with through capitalising on the ground-breaking work of developers who are farther along the path of development and Minesto must deal with some stressors explicitly due to their uniqueness.

Due to ever increasing environmental awareness of today's society, it is evident that it will not be possible for Minesto to develop large-scale commercial tidal arrays until comprehensive environmental assessments have been completed that specific exactly what affect such an array may have on its local environment. Since so many of the potential stressors are shared amongst the main tidal turbine developers, it would make sense to join together and share data to help foster the growth of this new industry. The following sections discuss the effect the birth of this new technological innovation system will have on helping early-stage developers to progress and reach commercialisation.

7.2 Birth of a New Technological Innovation System

In the birth of any new technological innovation system such as the emergence of the tidal energy industry there is much uncertainty. This has been documented by Bergek *et al*. in the paper "Legitimation *and Development of Positive Externalities"* that discusses how the initial phases of implementation of a new technological innovation system (TIS) are characterized by high uncertainty in terms of technologies (there are currently many competing tidal turbine designs), markets and regulation (requirements for assessing environmental impacts) (Bergek et al, 2008; Kemp, Schot, and Hoogma, 1998; Van de Ven, 1993). This has also been shown repeatedly throughout this thesis as there is very little currently known of the local environmental impacts of tidal turbines.

Such a process is vulnerable and volatile during formation and development is a cumulative process, comprised of many small changes (Van de Ven and Garud, 1989). As the industry expands, there will be changes in development rates and benefits in the form of positive externalities from the increasing levels of work being carried out to assess the local environmental impacts of tidal turbines.

7.3 Positive Externalities – Proactive vs. Reactive Approach

7.3.1 MCT - positive for industry

The results of the data collection show that there are strong positive externalities associated with environmental assessments that certain tidal technology developers are carrying out on their technologies. Several of the key industry actors interviewed in this thesis stressed the significance of the reactive approach the MCT team took in addressing the environmental concerns regarding the impact of their technology on the local environment. This approach forced the team to conduct monitoring studies and diligently collect empirical data. It was not adequate to only take a proactive approach and forecast and estimate the potential impacts their technology might have since there was no data or previous projects on which to base these estimates. However, the tidal TIS developed and more tidal developers emerged, a positive externality was associated with the ground-breaking work performed by MCT. Other technology developers had the ability to reference the work by MCT and use the data collected to gain a better understanding of what potential stressors are associated with the MCT turbine and how it interacts with the local environment. It gave these new developers a better appreciation of what key potential stressors are and what endpoints in the environment were being affected.

7.3.2 Minesto – positive for tethered prototypes in future

Since the tether has been highlighted as a component in the tidal technology industry currently unique to Minesto and has been highlighted as a key potential stressor by this study, further studies will have to examine this component more comprehensively.

However, since no dominant design has been established in this emerging industry it could be the case that in the future many developers will design prototypes that utilise a tether. In this case, much the same as how MCT adopted reactive approach (as they were first to install a commercial project and collect empirical data), the reactive approach Minesto will be forced to take to examine the tether will have positive externalities associated. The initial work by Minesto will allow developers in the future to utilise a proactive approach, citing the Minesto studies and will allow the developers to forecast what issues may arise for their technology and give them the ability to design out or minimize the potential risks associated with the tether or use the Minesto studies as basis for site-selection to ensure that their technology remains distant from the identified endpoints that a tether can impact on.

7.3.3 Industry – Circles of Feedback

The overall work by the industry and all its key actors in addressing environmental concerns will contribute to the overall body of knowledge on how tidal technology impacts its local environment. As this body of knowledge grows and more and more experts are created, then there will also be a greater understanding of the mitigation procedures that could minimize these risks. As the TIS develops and matures, it will become smarter and better equipped to deal with mitigating potential environmental risks. These circles of positive feedback, where increasing levels of research will lead to increased knowledge which will help to increase levels of research further is a self-confirming mechanism that in time will ensure the tidal industry can effectively address local environmental impact issues with the aim of mitigating impacts. In this way, the positive feedbacks could ensure that designs with minimal local impacts (that incorporate the results of mitigation research) could be selected. There is however a counter-balancing argument that is also relevant. As the industry grows, there is the potential that it will gain momentum and become less sensitive to criticism. As it expands it could potentially have the ability to lobby against environmental regulations that they feel could be too strict.

Much like during the birth of the wind power TIS – little was known of the potential risks. A reactive approach was adopted and monitoring studies were conducted to examine and record the impacts of wind farms on their local environments. This was a lengthy and costly process for the emerging industry at the time. However, once there was a greater understanding of the impacts (collision with birds), they developed methods to reduce these risks through design and proper site selections. To give an example, turbines at the Foote Creek Rim Windplant were located away from the rim edge as baseline data showed that there was a pattern of raptor (a type of bird) use along the rim (Johnson *et al*., 2000).

7.3.4 Industry Clusters – Environmental Understanding

Another circle of positive feedback is the emergence of technology clusters and concentrations as explained by Brian Arthur in the paper "Positive Feedbacks in the Economy" (Arthur, 1990). As explained by Arthur, the first developer selects a site based on their preferences – tidal velocity etc. Next, a second developer selects a site based on preference that is modified by the benefits gained by locating near the first firm, and so on.

This can be seen in a real-world examples where the first technology developer to install a commercial project, MCT, selected Strangford Lough as the location for their project. Since 2003 MCT have been conducting studies and assessments of the local environment in order to gain a better understanding of potential impacts and to secure a lease from the governing authority. The environmental work that MCT have carried out has since attracted other tidal technology developers to test their devices in the same location. There are several reasons for this.

1. MCT utilised local third party environment consultants and dive teams when performing environmental assessments. The familiarity of these consultants and dive teams with tidal technology projects as a result of working with MCT have led to these consultants and teams being able to offer similar services to other tidal technology developers. The developers are attracted to the location as they now know that there are resources such as these consultants who are amongst the most knowledgeable in examining local environmental impacts of tidal technology due to their past experience with MCT. This is yet another example of a positive externality associated with MCT's environmental work that can benefit other tidal developers.

2. The empirical data collected by MCT and that is publically available is site-specific. This means that the data is relevant only for the Strangford Lough site and the endpoints assessed are unique to this site also.

Since certain stressors can be common to most generic tidal devices, for example, rotor blades, the other developers can utilise the empirical data to take a proactive approach in addressing potential impacts if they decide to select a site for their project close to the MCT site.

In this way a technology cluster can be developed, as can be seen today at Strangford Lough where there are several developers, including Minesto, testing and operating in the waters. There are also many environmental consultants, dive teams, academic institutes and local government authorities operating in the region that are now very familiar with tidal technology and addressing the issues of potential environmental impacts of tidal technology.

7.4 Social – Perceived vs. Actual impacts

There is much uncertainty during the emergence of a new TIS. Little is understood of the complex relationships an emerging technology may have in real world applications. One example of this is the social or public perception or understanding of the new technology. To many, especially those without a strong scientific background, the emergence of a new technology of which they are unfamiliar may lead to the perception that the technology could be dangerous to its surroundings. This is true of the tidal industry in general and of the novel and unique design of the Minesto technology.

The key highlighted potential stressors of the full scale Minesto technology may only be perceived impacts due to the fact that the stressors are currently unique only to the Minesto device and have not been seen before. At this stage of development, there is a danger that perceived impacts may be viewed as actual impacts. Many of the interviewees highlighted and stressed the importance of promoting public outreach programmes that will allow the public and technology developers to interact. Inclusion of the public in the development process will allow members of the public to become more familiar with the technology, to understand how it operates and what potential impacts it may actually have instead of what is perceived. Working in cooperation with the general public could be advantageous to any tidal developer. Gaining the approval of the public, through close interaction would help to foster a community spirit and help dispel any perceived impacts that may not be accurate.

Further assessments and studies which gather empirical data will allow for a better understanding if these key potential stressors have actual impacts on the local environment or not.

7.5 Current Site Leasing Application Process

There are many different technologies vying for market share and no one established dominant design since the TIS is in its formative phase. Each design has its own specific stressors that will have a unique impact on endpoints in its local environment different from any other design. As such, there are many various concerns regarding tidal technology as a whole. As a response to this the current application process for granting seabed permissions to install and test prototypes is not very streamlined. Unfamiliarity of the governing boards with the potential impacts of all these different type of designs slows down the process and forces the regulatory agencies to assess technologies on a case by case method. This is common during the formative phases of any new TIS. As the body of knowledge and experience develops, and as key industry actors such as government agencies, politicians, technology developers and the general public become more familiar with the components of this TIS, this process will become more streamlined.

7.6 Future adaptation to process

Initial steps are already being taken to develop a more streamlined process regarding the environmental assessment requirements for any new tidal installation. Efforts are being made to allow exemptions to small prototypes that are seen to have minimal environmental impacts due to their size and correspondingly have more in-depth application processes for larger commercial installations.

It is interesting to note that there are plans underway to construct zones for prototype testing that have previously been environmentally degraded and will have a low threshold regarding the need for environmental studies assessing the impacts of a prototype at one of these sites (McQuiod Interview, 2011). This will allow developers to increase their speed to market, as prototype testing will become easier which will allow a faster rate of development.

8.0 Conclusion

This study focuses on answering the following research question ”*What are potentially adverse environmental interactions associated with the full scale Minesto device and which stressors are currently unique so that must Minesto must directly address them?”* The investigation is framed in the form of a hazard identification (HAZID) process.

The HAZID study of the Minesto technology identified stressors that are common to most generic tidal stream devices and also stressors that are unique to the Minesto design. The Minesto device tether and flight path were highlighted as potential key stressor sources that would require further investigation. The main stressors were noted to be the potential of physical collision between an endpoint and the tether, the potential for noise and vibrations that may disturb the local environment, the potential for the tether to go slack when not in operation having an effect on benthic communities, the potential for the tether to disturb the flow of the water column and collision risk due to the flight path of the device.

Further research must be performed to give a better understanding of the potential implications of the Minesto device tether and flight path and how it may interact in its local environment during operation. As stated previously, this work will have associated positive externalities in that future developers that may incorporate similar tethers into their designs can utilise research from Minesto studies to help mitigate potential impacts.

It is clear that the tidal Technological Innovation System is still in its formative phases of growth. This is evidenced by the fact there is no dominant design within the industry and there are many competing technology developers. Little is currently known of the effects tidal stream technologies have on their local environment. Research must be continued into this topic at a greater depth and there must be continued and strengthened cooperation between industry and academics to build on the library of knowledge and increase the levels of empirical data.

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Appendix A – Interviews

Michael McSherry – Interviewed 2011-11-11
Global Maritime Alliance

Michael McSherry is the programme director at Global Maritime Alliance. GMA identifies itself as a facilitator in project management – the glue between ocean energy device developers and the supply chain companies. They work with developers to identify hurdles that hinder progress during the development phases of projects. The aim of GMA is to place the island of Ireland as a centre of excellence for the ocean energy industry. To achieve this GMA are working with key actors in all stages of the industry to offer a cost-effective bespoke solution through one single point of contact to a range of companies. GMA believe that acting together as a virtual corporation creates a significant competitive advantage and an ability to offer a complete range of services to clients in the wave and tidal energy market.

Dr. Graham Savidge- Interviewed 2011-11-15
Queens University Belfast

With a BSc. In Marine Biology and Physical Oceanography and a PhD. in Marine Phytoplankton Ecophysiology, Dr. Savidge is now the administrator at the Queen's University Marine Laboratory at Portaferry. Dr. Savidge was directly involved in the Marine Current Turbine SeaGen project that was installed in Strangford Lough, Northern Ireland and directly contributed to the MCT industry reports used in this thesis. His team at Queens University, together with the SMRU (Sea Mammal Research Unit) division of St. Andrews University, carried out a detailed environmental monitoring programme for MCT and the NIEA (Northern Ireland Environmental Agency) on the environmental impacts of the MCT tidal turbine. His current work integrates hydrodynamics with biology and focuses on the application of numerical modelling to the effects of marine energy devices.

Michael Harper – Interviewed 2011-11-16
B9 Energy

Michael Harper is the Managing Director of B9 Energy Offshore Developments Ltd. Based in Northern Ireland; B9 Energy was created in 1992 with the purpose of developing renewable energy projects. B9 highlight their heritage in the renewable energy sector, deep knowledge and understanding of legislation and ability to spot viable future technologies as core competences of their firm. B9 provide project development services to project developers. As well as project management, B9 have dealings relating to policies, environmental works, stakeholder engagements and commercial prospects.

Dr. Paul Brewster – Interviewed 2011-11-17
Pure Marine

Dr. Paul Brewster is the Technical Director at Pure Marine, based at their headquarters in Belfast, Northern Ireland. Pure Marine was founded in 2007 to develop the business, technology, and engineering solutions needed to harness the indigenous wave and tidal energy resources of Northern Ireland. The team, with a mix of commercial and technical expertise, are focussed on pre-commercial projects for tidal energy developers. Pure Marine have utilised support and funding from the Carbon Trust and InterTradeIreland to fast track the development of ocean energy technology solutions and site development activities.

Trevor McQuoid – Interviewed 2011-11-19
Northern Ireland Environmental Agency

Trevor McQuoid works at the Marine Assessment & Licensing Team (MALT) at the Northern Ireland Environment Agency. His team are working under the new marine licensing legislation that came into being in April 2011. This new legislation allows for development of marine technologies in a manner that minimizes adverse impacts on the local environment, human health and other sea users replacing the older Food and Environmental Protection Act. To obtain permission from the government to operate a tidal conversion device in Northern Irish waters, there are three licences that must be granted. A seabed licence must be obtained from the Crown Estate who controls the jurisdictions sea-beds. The MALT issue the marine licences. Finally, a licence under Article 39 to produce electricity must also be granted.

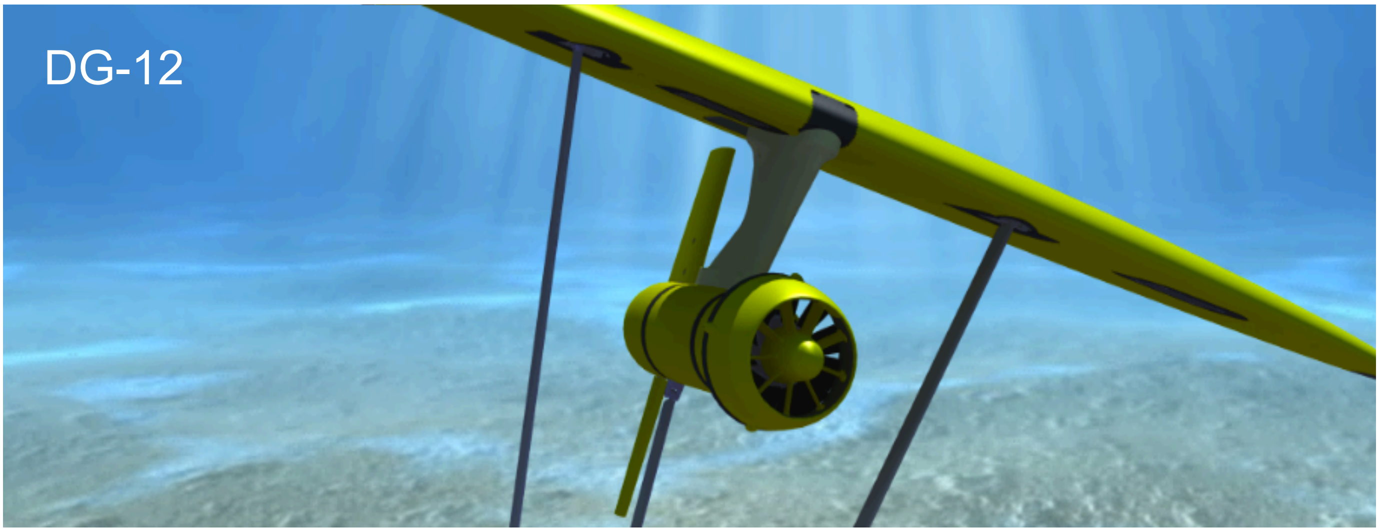
Paul McArdle – Interviewed 2011-11-24
Marenco Environmental Consultants

Originating within Queen's University Belfast Marine Laboratory, Marenco is an environmental consultancy firm based in Northern Ireland. From due-diligence and EMS installation to issue-specific environmental surveys Marenco offers comprehensive and large-scale science-based consulting services. Marenco have access to an extensive pool of specialist scientific consultants who come together on a project-by-project basis to form a highly skilled multi-disciplinary taskforce. They have close associations with specialists in landscape architecture, ecology, noise & air quality, archaeology, contaminated land & water, analytical services, and with Queen's University Belfast.

Paul McArdle, Director and Principle Consultant at Marenco, does extensive work in due-diligence assessment for acquisitions and mergers, and in addition has wide experience in environmental statement preparation; environmental licensing; expert witness representation; water chemistry; conservation management; and waste audits.

Appendix B – Minesto Datasheet 2011

Minesto
Tidal Energy Solutions



A unique technology that explores the vast, renewable & abundant ocean power resource

Minesto develops tidal and ocean current power plants called Deep Green. Based on a new principle for electricity generation, Deep Green offers several advantages compared to first generation plants. As well as being light and small, the power plant is applicable in areas where no other known technology can run cost effectively due to its ability to operate in low velocities. Minesto expands the total marine energy potential and offers a step change in cost for tidal energy.

Minesto
Tidal Energy Solutions

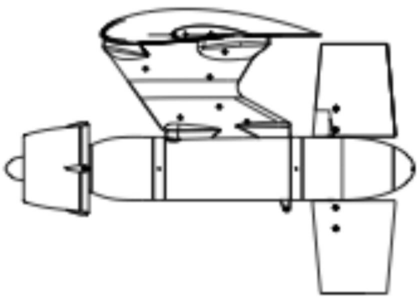
Quick Facts

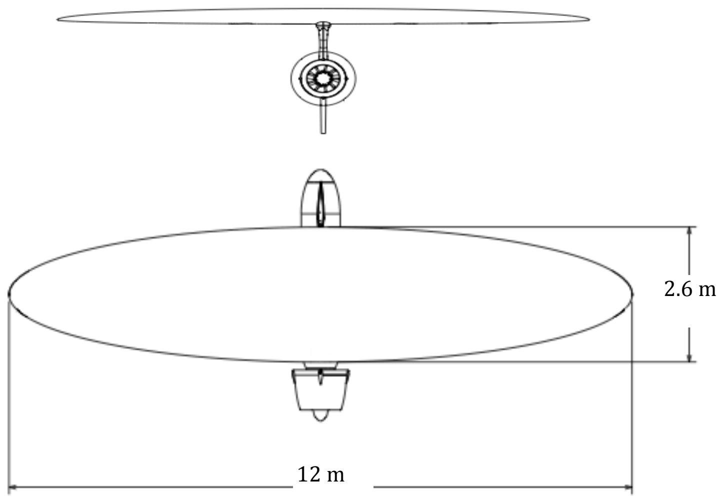
- Kite assembly
- Attached by a tether to a fixed point on the ocean bed
- Direct drive
- Lighter and smaller compared to other tidal solutions
- Low material usage & low cost of installation
- Cost effective at sites with low current velocities & large depths
- Unlocks a large global market - can operate on all continents, at low tidal velocities and with ocean currents

Contact us at:

Email: info@minesto.com
Ph: +46 (0) 31-760 21 02

Technical Specifications





Wing Span	12m
Rated Power	500 kW
Tether Length	85-120m
Depth	75-100m
Desired Speed	1.4-2.2 m/s
Lower/Upper Cut off current	0.5/2.5 m/s
Weight	7 tons
Devices/km^2	25
Clearance (tip to surface)	12-16m
Rotor diameter	1m
Swept area	2000m^2
Nacelle diameter	0.75m
Nacelle length	4.5m
Nacelle weight	4 tons