SeaGen Environmental Monitoring Programme

Final Report

Marine Current Turbines

16 January 2011

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EXECUTIVE SUMMARY

The SeaGen tidal turbine is a free stream tidal energy device that converts energy from tidal flow into electricity. The device comprises twin 16m diameter rotors connected to a generator through a gearbox, with a rotor system supported on the end of a cross beam. The cross beam is, in turn, supported by a 3m diameter pile. The cross beam can slide vertically up and down the pile to allow access to the rotors, generator and gearbox for servicing and inspection.

In 2004, Marine Current Turbines Ltd (MCT) identified the Narrows of Strangford Lough, Northern Ireland as their preferred location for the deployment of the SeaGen device.

An Environmental Impact Assessment (EIA) was undertaken by Royal Haskoning, and completed in June 2005 with the production of an Environmental Statement (ES).

Based on the consultation responses and requirements of EU Directives and Northern Ireland environmental legislation, a conditional FEPA marine construction licence was issued to MCT on 15 December 2005. Subsequent variations of the licence have taken into account the increased scientific knowledge built up through the ongoing monitoring program and the adaptive management approach adopted by MCT.

The issue of the licence required MCT to establish an Environmental Monitoring Plan (EMP) and a number of mitigation measures. Data collection began, pre-installation, in April 2005 and formed the basis of an Environmental Baseline Report, against which all future monitoring during installation, commissioning and decommissioning could be compared.

The results from each of monitoring strands of the EMP were evaluated regularly to ensure that any impact of SeaGen on the marine environment in Strangford Lough could be detected at an early stage. Using an adaptive management approach, the data collected has provided evidence to support reduction in mitigation requirements.

A small dedicated ‘Science’ Group was set up to advise on the detailed management of the EMP and mitigation measures, while a wider ‘Liaison’ Group was established, to whom progress on the project and decisions of the Science Group would be reported.

Both Science and Liaison groups have operated well since 2006, meeting the requirements of both their memberships, and of the project.

The SeaGen EMP was designed to:

- Detect, prevent or minimise environmental impact attributable to the turbine installation and operation; and
- Provide an ongoing monitoring strategy to determine any immediate or emerging adverse impacts on the habitats, species and physical environment of Strangford Lough.

Overarching objectives for the SeaGen mitigation programme are that: *the presence of the turbine does not have a significant detrimental impact on*:

(a) *the integrity of the breeding harbour seal population;*

(b) *the abundance, diversity, integrity and extent of the benthic biological communities associated with the submerged rocky reefs;*

(c) *the population of breeding seabirds*

A series of operational objectives have been establish which provide the means by which the overarching objectives can be achieved.

For each monitoring or mitigation element one or more key questions, linked directly to the operational objectives frames the critical concerns which the EMP is designed to address. These key questions are then answered based on the data collected.

Data confidence has also been considered and refers to the ability of the data to provide a reliable indicator of change and answer the key questions.

The three main receptors considered within the EMP are:

- Marine Mammals;
- Benthic Ecology; and;
- Tidal flow and energy.

To answer the key questions in relation to marine mammals the EMP comprised a number of data collection methods including:

- Shore based survey;
- Passive acoustic monitoring (T-PODs);
- Carcass post mortem;
- Aerial survey;
- Harbour seal telemetry;
- Underwater noise monitoring; and
- Data collection during mitigation (active sonar).

Analysis of the data collected during the EMP has provided the following key findings:

- No major impacts on marine mammals have been detected across the 3 years of post-installation monitoring.
- Porpoise activity declined during installation; however there have been no long term changes in abundance of either seals or porpoises which can be attributed to the presence or operation of the device.
- A few of the metrics monitored were naturally highly variable and therefore comparisons between phases lacked suitable statistical power to confidently rule out undetected changes – this was particularly the case for grey seals and porpoise sighting rates from the shore based visual observation. However, given

the wide ranging nature of these species it is unlikely that any changes at this spatial scale would have a significant effect at the population level.

- Seals and porpoises regularly transit past the operating turbine, clearly demonstrating a lack of any barrier effect.
- The only changes observed after three years of operation of the device have been relatively small scale changes in the behaviour and distribution of seals and harbour porpoises, suggestive of a degree of local avoidance of the device.
- Overall the seals transited at a relatively higher rate during periods of slack tide, indicating avoidance but also this slack water window when the turbine is not operating or is moving very slowly, ensures that there is always an opportunity for transit past the turbine.
- This avoidance reduces the risk of any direct interactions with the moving rotors and suggests that both seals and porpoises have the capacity to adjust their distributions at local scales in response to a potential hazard.
- The benthic ecology was monitored using diver survey. The data collection and analysis are robust in determining that the changes observed appear to be gradual and in line with natural variation. Colonisation of the device since its installation has replaced the community lost at the device foundations during construction.
- Changes to tidal flow were measured using Acoustic Doppler Current Profiling (ADCP). The data showed no evidence of significant change to the ambient velocity or flow direction within the Lough, subsequent to the installation of the turbine. The findings show that it is unlikely that marine traffic between Strangford town and Portaferry has been affected. The wake which can be observed on the water surface is not propagated into the water column which may explain the absence of any significant changes to the benthic ecology.
- Although not a key feature of the EMP, bird data was collected in combination with the shore based marine mammal surveys. The data showed that, while some fine scale displacement of birds had been recorded in the immediate vicinity of the device, the overall numbers in the Narrows remained stable.

The findings of the EMP provide confidence that SeaGen can continue to operate with no likely significant impacts on the marine environment in Strangford Lough.

SeaGen is on track to complete 5000 hours of operation by the end of January, generating around 3GWh of electricity.

The SeaGen EMP has provided the key case study for tidal energy, informing policy and guidance in the UK.

As the first project of its kind, the SeaGen EMP provides an ambitious plan beyond what might be expected of future projects now that more knowledge is available.

CONTENTS

1 INTRODUCTION

In 2004, Marine Current Turbines Ltd (MCT) identified the Narrows of Strangford Lough, Northern Ireland as their preferred location for the deployment of the SeaGen tidal turbine. The site presented many advantages for the deployment of the world's first commercial scale open stream tidal turbine, including:

- Significant tidal resource;
- Suitable grid infrastructure near to the site;
- Convenient location of expert environmental research facilities and technical of Queens University Belfast at Portaferry Marine Laboratory;
- Existing coastal management structures for Strangford Lough (Strangford Lough Management Committee), which has responsibility for management of the Lough including the proposed site;
- Skilled workforce, both locally (vessel support and ongoing maintenance) and in the region (fabrication and construction support) for a range of project elements.

The site is designated locally, nationally and internationally for the bird and seal populations as well as for its benthic and coastal habitats. The Environment Heritage Service for Northern Ireland (now the Northern Ireland Environment Agency (NIEA)) advised MCT that the designations should not constitute a barrier to development, so long as such development was undertaken in appropriate manner, and the decision was taken to investigate further the possibility of deployment at the site.

SeaGen is on track to complete 5000 hours of operation by the end of January, generating around 3GWh of electricity.

1.1 Project History

1.1.1 Environmental Impact Assessment

An Environmental Impact Assessment (EIA) was undertaken by Royal Haskoning, and completed in June 2005 with the production of an Environmental Statement (ES). The ES concluded that the potential impact of the SeaGen marine current turbine on some designated features was uncertain, although the potential to adversely impact site integrity was considered to be unlikely. Because of this uncertainty of impact on the features of the Strangford Lough Special Protection Area (SPA) and Special Area of Conservation (SAC), an adaptive management approach to deployment, with integrated mitigation and monitoring was proposed and accepted by the Department of Environment, Northern Ireland.

1.1.2 Licensing

At the time of consenting for the project, deposits in the sea were controlled under the Food and Environment Protection Act, 1985, Part II, Deposits in the Sea (FEPA). Although FEPA is a UK-wide act, the licensing function under the Act was a devolved matter and was carried out by the devolved authorities. NIEA was the competent authority for FEPA in Northern Ireland, and is the competent authority for the new marine licensing regime under The Marine and Coastal Access Act 2009. The licensing and enforcement function is carried out by the Water Management Unit, within the

Environmental Protection Directorate of NIEA. The UK licensing authorities meet regularly to ensure that there is a consistency to the regulatory process across the UK.

In determining whether to issue a licence under FEPA, the licensing authority:

(a) shall have regard to the need to –

(i) to protect the marine environment, the living resources it supports, human health; and

(ii) to prevent interference with legitimate uses of the sea; and

(b) may have regard to such other matters as the authority considers relevant.

(FEPA Part II, section 8 (1))

NIEA issues marine construction licences for projects like harbour developments, long-sea outfalls etc. and sea disposal licences for the disposal of dredged material.
The placement of a tidal turbine in Strangford Lough required a FEPA marine construction licence.

Based on the consultation responses and requirements of EU Directives and Northern Ireland environmental legislation, a conditional FEPA marine construction licence was issued to MCT on 15 December 2005. Subsequent variations of the licence have taken into account the increased scientific knowledge built up through the ongoing monitoring program and the adaptive management approach adopted by MCT and overseen by NIEA.

The issue of the licence was predicated upon MCT supplying a robust Environmental Monitoring Programme and a number of mitigation measures to reduce perceived uncertainties, before installation.

1.1.3 Environmental mitigation and monitoring

Following the approach proposed in the ES, a detailed Environmental Monitoring Programme (EMP) and associated suite of mitigation measures were established as a condition of the FEPA Licence. The aim was to ensure that significant impacts on the features of the designated sites did not occur, while allowing any changes in the environment to be monitored (EMP), with the aim of adapting the management of the turbine on the basis of actual data derived from the monitoring programme. Data collection began, pre installation, in April 2005.

The results of the EMP, pre-installation, formed the basis of an Environmental Baseline Report, against which future monitoring during installation, commissioning and decommissioning could be compared. An Environmental Action and Safety Management Plan (EASMP) was prepared to advise as to the implementation of actions and mitigation measures identified within the ES. The EASMP plan was later fully developed into a detailed procedural template for action if and when necessary.

MCT recognised that the project and findings of the EMP would be of interest to a number of important stakeholders who have either conservation interests in Strangford Lough or a wider interest in marine current technology. It was clear that structures for ongoing consultation throughout the life of the project were necessary, so in June 2005 Dr. David G Erwin OBE, a marine scientist with many years of experience in Strangford Lough, was invited to recommend suitable structures for such consultation, and to occupy the role of chair of any bodies which were set up.

In addition to various *ad-hoc* wider public consultations, two formal 'nested' bodies were established to meet on a regular basis. A small dedicated 'Science' Group was set up to advise on the detailed management of the environmental monitoring programme, while a wider 'Liaison' Group was established, to whom progress on the project and decisions of the Science Group would be reported.

Both Science and Liaison groups have operated effectively since 2006, meeting the requirements of both their memberships, and of the project. The terms of reference for the Science Group are outlined below.

Terms of reference for the Science Group

The SeaGen Marine Current Turbine Project is undertaking an Environmental Monitoring Programme (EMP) to comply with the conditions of the Food and Environmental Protection Act (FEPA) 1985: Part II (as amended) Licence reference DU 115/05 issued by the Environment and Heritage Service (EHS) of the Department of Environment, Northern Ireland for the SeaGen project in Strangford Lough implemented by Marine Current Turbines (MCT) Ltd.

MCT recognise that the delivery of a sound and effective EMP is critical to the success of the SeaGen project and as such, has established a Science Group consisting of the core organisations responsible for the delivery of the EMP and regulation of the project.

Members of the SeaGen Science Group share the common goal of safeguarding the environment of Strangford Lough from any potential significant environmental impact that might be caused by the SeaGen project; To identify, assess and manage accordingly any effects before they cause adverse impact; To provide scientific input through data collection, reporting, advice, and guidance to support the environmental monitoring program designed to ensure that the installation, operation and decommissioning of the SeaGen Marine Current Turbine operates in a way which is compatible with the conservation objectives of the Strangford Lough SAC and SPA."

The organisations and staff involved in the SeaGen Science group, their role(s) and responsibilities are outlined in Table 1.1 below.

Table 1.1: SeaGen Science Group membership and responsibilities

Organisation	Role	Responsibility
Independent (David Erwin)	Independent Chair	Chairing meetings +
Northern Ireland Environment Agency (formerly Environmental Heritage Service, Northern Ireland)	Government regulator and nature conservation advisor	Ensure compliance with environmental legislation and advise MCT and Science Group.

Organisation	Role	Responsibility
Royal Haskoning	Project managers of Environmental monitoring	Oversee EMP and ensure all monitoring is undertaken as planned and managed accordingly. Mitigation measures and adaptive management in light of monitoring data.
Marine Current Turbine Ltd. (MCT)	Project Developers	Responsible for MCT project execution and guidance on project development.
Sea Mammal Research Unit / Sea Mammal Research Unit Ltd, St. Andrews University (SMRU)	Marine mammal data collection and research	Scientific monitoring of marine mammals.
Queens' University, Belfast (QUB) Portaferry Marine Laboratory	Primary project data collection and research	Scientific monitoring of benthic ecology and bird.
Council for Nature Conservation and Countryside (CNCC)	Guidance and advice	Provide appropriate input and advice
Joint Nature Conservation Committee (JNCC)	Renewable Advisor	Provide appropriate input and advice
Ulster Wildlife Trust (UWT)	Chair of UWT	Provide appropriate input and advice

The environmental monitoring programme and associated mitigation measures are discussed further in Section 1.3, below.

1.2 Industry Context

The SeaGen EMP has provided the key case study for tidal energy, informing policy and guidance in the UK.

As the first project of its kind the EMP provides an ambitious plan beyond what might be expected of future projects, now that more knowledge is available.

1.3 The SeaGen Device

SeaGen is a free stream tidal energy device that converts energy from tidal flow into electricity. The device comprises twin 16m diameter rotors connected to a generator through a gearbox, with a rotor system supported on the end of a cross beam. The cross beam is, in turn, supported by a 3m diameter pile. The cross beam can slide vertically up and down the pile to allow access to the rotors, generator and gearbox for servicing and inspection, thus minimising the requirement for diver intervention.

The top of the pile is approximately 9m above the average sea level (Figure 1.1). The twin rotors begin to generate electricity at a current speed greater than 1m/s. At a predetermined maximum tidal speed the rotors start to adjust their pitch to limit the maximum rotational speed to 14RPM, resulting in a peak rotor tip speed of around 12m/s.

Figure 1.1: The SeaGen turbine, Strangford Lough, Northern Ireland.

Figure 1.1 shows SeaGen and the installation foundation, a four-footed structure, 18m by 12m in footprint area. Each corner of the foundation is supported on a 1m diameter pin pile. The base of the structure is raised approximately 2m above the seabed on pin piles, thus resulting in a much smaller seabed footprint than the original monopole design.

Figure 1.2 provides a diagram of the SeaGen device along with labels of the parts of the structure discussed in Section 3, Benthic Ecology.

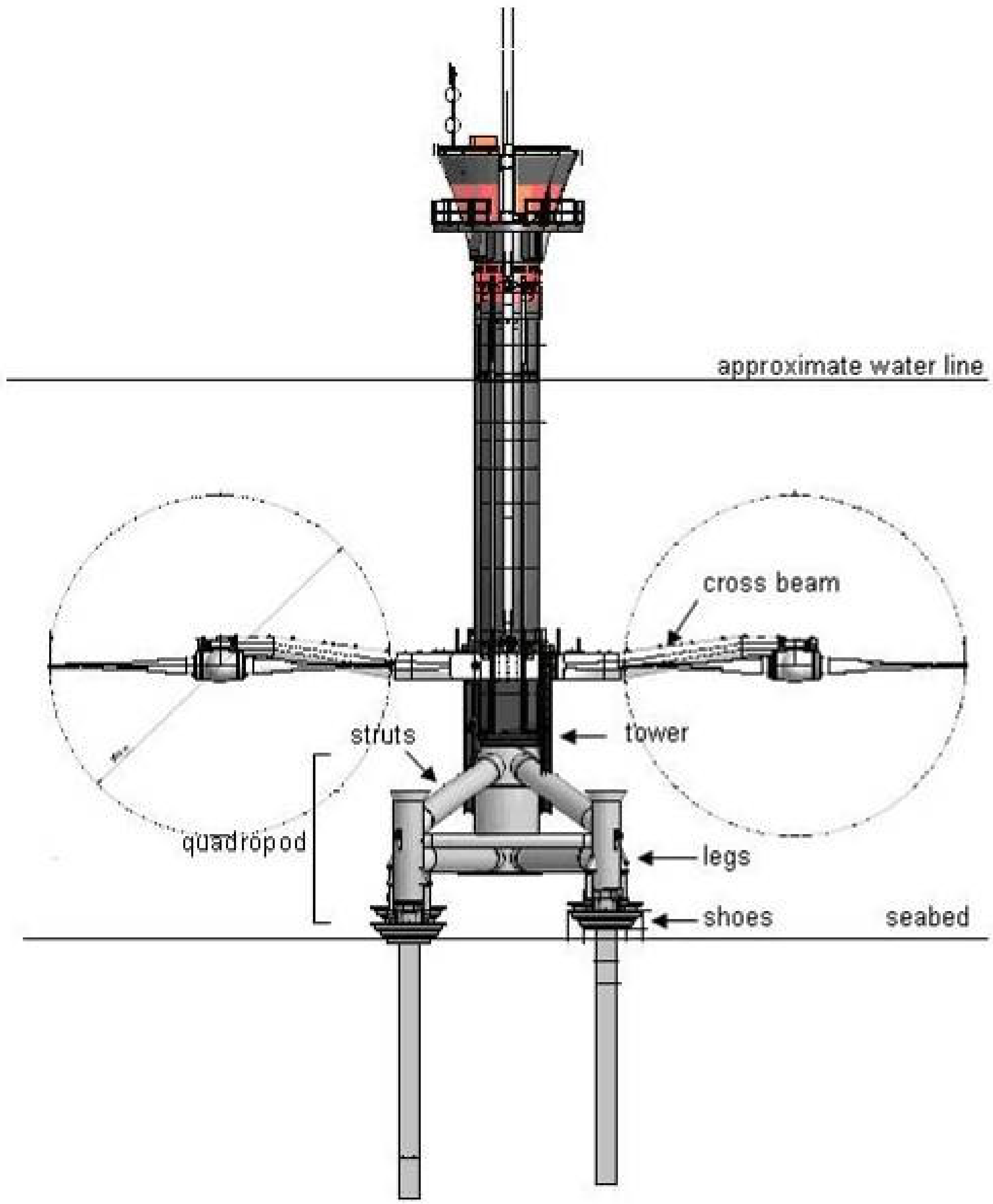

Figure 1.2: Diagram of the SeaGen device

1.4 Environmental Monitoring Program

1.4.1 Objectives

The SeaGen environmental mitigation with the associated research and monitoring programme was designed to:

- Detect, prevent or minimise environmental impact attributable to the turbine installation and operation; and
- Provide an ongoing monitoring strategy to determine any immediate or emerging adverse impacts on the habitats, species and physical environment of Strangford Lough.

In support of this, the research programme is focused on ensuring that the status of the important ecological elements most likely to be influenced by the presence of the turbine is established and monitored using credible scientific methods. To provide a transparent and logical direction for the research and monitoring programme, a series of management action-specific or "operational" objectives have been developed which are also intended to act as a framework for the environmental reporting.

Strangford Lough has been identified as a site which supports internationally important examples of particular marine and coastal habitat and species features and has accordingly been given the dual status of a European Special Area of Conservation (SAC) and a European Special Protected Area (SPA). Three of the site features have been identified as potentially vulnerable to activities and impacts associated with the installation of the SeaGen turbine.

Accordingly, key overarching objectives for the SeaGen mitigation programme are that: *the presence of the turbine does not have a significant detrimental impact on*:

(d) the integrity of the breeding harbour seal population;

(e) the abundance, diversity, integrity and extent of the benthic biological communities associated with the submerged rocky reefs;

(f) *the population of breeding seabirds*

The Operational Objectives (Table 1.2) provided below establish the means by which the overarching objectives are to be achieved, alongside further measures for species which carry additional protected status. This table is derived from the EMP task matrix.

Table 1.2: Operational objectives / mitigation measures for the SeaGen environmental monitoring and mitigation programme

Element	Objective / mitigation measures	Measurement
Marine Mammals (General)	No marine mammal mortalities occur as a consequence of physical interaction with the turbine rotors[1].	1. Regular surveillance for carcasses until 2010 2. Post mortem evaluation of carcass stranding and assessment of cause of death.
	The turbine operates in such a way as to stop when marine mammals are within 50m from the rotors.	1. Assessment of the combined surface and sonar detection events with manual shutdown when a mammal is within 50m of turbine rotors. 2. Post mortem evaluation of carcass stranding and assessment of cause of death.
	Establishment of an active sonar system which detects marine mammals at sufficient range from the turbine to allow a precautionary shut-down to occur automatically.	1. Number of sonar detections and shut-down events.
	The SeaGen turbine does not present a barrier effect to the free passage of marine mammals through the Strangford Narrows.	1. Pile based marine mammal observations (ceased 21/08/09). 2. Active sonar operations allowing targets to be observed moving passed the turbine during periods of operation. 3. Land based visual observations pre- and post installation to examine any change in use of the area around the turbine. 4. Seal telemetry studies 5. T-POD measurements for harbour porpoise activity.
	Relative abundance of marine mammals in Strangford Narrows is not significantly modified by the operation of the SeaGen turbine.	1. Number of marine mammals underwater recorded in close proximity (~ 50m) to the SeaGen turbine per hour 2. Wider contextual data from shore based observations.

[1] The circumstances and significance of any mortality will be investigated by the SeaGen Science Group, as detailed in the EASMP (Royal Haskoning 2008)

Element	Objective / mitigation measures	Measurement
	Sub-surface noise generated by the turbine does not cause a level of disturbance to marine mammals sufficient to displace them from areas important for foraging and social activities.	1. Measurement of zone of audibility and zone of disturbance at full power operation. 2. Number of marine mammals underwater sighted in close proximity (~ 50m) to the SeaGen turbine per hour 3. Sightings frequency per hour watched within grid squares close (within ~ 50m) to the SeaGen turbine.
Marine Mammals: harbour seals	The number of harbour seal adults and pups does not decrease significantly as a result of the installation and operation of the SeaGen turbine.	1. Population estimates derived from aerial survey and set within the context of historical data. 2. Population distribution and haulout behaviour from telemetry data. (Number of harbour seals using the Lough based on boat counts from NIEA can also supplement these data)
	The SeaGen turbine does not cause a significant change in the use of important harbour seal haul out sites within the Strangford Lough SAC.	1. Haul out site seal numbers from aerial and boat-based survey. 2. Population distribution and haulout behaviour from telemetry data. (Number of harbour seals using the Lough based on boat counts from NIEA can also supplement these data)
	The SeaGen turbine does not present a barrier effect to the free passage of harbour seals through the Strangford Narrows.	1. Transit routes derived from telemetry data from the seal tagging programme. 2. Land based observations and pile based marine mammal observer (MMO) data.
	The SeaGen turbine has no significant effect on harbour seal movements through the Strangford Narrows	1. Harbour seal transit rates derived from telemetry data from the seal tagging programme.

Element	Objective / mitigation measures	Measurement
	Harbour seals are not excluded[2] from important foraging habitat or social areas within the Strangford Narrows as a result of the installation and operation of the SeaGen turbine.	1. Sightings frequency over space and time (from Shore-based visual operation) in pre-operational and post-operational periods). 2. Use of foraging habitat from telemetry data (i.e. amount of time spent foraging in different areas).
Marine mammals: grey seals	The number of grey seal adults and pups does not decrease significantly as a result of the installation and operation of the SeaGen turbine.	1. Population estimates derived from aerial survey and set within the context of historical data. (Number of grey seals using the Lough based on boat counts from NIEA can also supplement these data)
	The SeaGen turbine does not cause a significant change in the use of important grey seal haul out sites within the Strangford Lough SAC.	1. Haul out site seal numbers from aerial and boat-based survey. (Number of harbour seals using the Lough based on boat counts from NIEA can also supplement these data)
	The SeaGen turbine does not present a barrier effect to the free passage of grey seals through the Strangford Narrows.	1. Transit routes derived from telemetry data from the seal tagging programme. 2. Land based observations and pile based MMO data.
	Grey seals are not excluded from important foraging habitat or social areas within the Strangford Narrows as a result of the installation and operation of the SeaGen turbine.	1. Sightings frequency over space and time (from shore-based visual operation in pre-operational and post-operational periods).
Marine mammals: cetaceans	The SeaGen turbine does not displace harbour porpoises from the Strangford Narrows and the adjacent Strangford Lough SAC.	1. Echolocation events/ detection positive minutes (presence/absence) from T-POD monitoring. 2. Sighting data from shore and pile based observers.

2 In this case, “exclusion” needs to pass the test of “significance”, See discussion following this table.

Element	Objective / mitigation measures	Measurement
	The SeaGen turbine does not present a barrier effect to the free passage of harbour porpoises through the Strangford Narrows.	1. Echolocation events/ detection positive minutes between inner Lough, Narrows and outer Lough from T-POD monitoring. (Land based observations and MMO data should also contribute to the measurement of this element.)
	Cetaceans not excluded from important foraging habitat or social areas within the Strangford Narrows as a result of the installation and operation of the SeaGen turbine	1. Sightings frequency (from shore-based visual observations) over space and time in pre-operational and post-operational periods. (T-POD data can also supplement this as clicks can be associated with feeding behaviour).
Seabirds	The SeaGen turbine does not injure or displace foraging diving birds from important areas within the Strangford Narrows	1. Sightings frequency of diving birds from shore- based visual surveys 2. Sightings frequency/hour watched of diving and rafting birds within the pile-mounted observational grid area.
Hydrodynamics	The installation and operation of the SeaGen turbine will not impede or modify the flow dynamics, scour patterns or turbulence character of the Narrows in such a way that will cause a change to benthic community structure.	1. Vessel- or bottom mounted ADCP measurement, as appropriate, of upstream and downstream flow character and turbulence signature. 2. Diver video survey for scour effects.
Benthic hard communities	The installation and operation of the SeaGen turbine will have no significant impact on the abundance, diversity and integrity of the benthic communities within the Strangford Narrows.	1. Benthic species abundance at re-locatable video sample stations at a range of distance intervals from the turbine installation.

Element	Objective / mitigation measures	Measurement
Adaptive Management	Mitigation measures are regularly reviewed for effectiveness, consistency and suitability and they are modified or revised where changes are considered to provide increased benefit. (Subject to consultation and the terms of the FEPA licence).	1. Assessment of effectiveness at regular Science Group meetings.

Environmental risk thresholds

In developing these objectives a requirement has been identified for further discussion and subsequent agreement on how the term 'biologically significant' should be determined or defined for the purposes of conservation management. For example, SMRU has suggested that a level of >50% change from baseline in seal movements might be a reasonable measure of a potentially significant change (Iain Boyd, pers. comm. December 2008). There then remains a need to demonstrate that this level of change can be attributed to a turbine operation effect. The present set of measurements, in addition to considering the broader context of national trends in distribution and abundance, should provide a framework around which significant change can be determined and applied in the SeaGen monitoring programme.

Similarly, the use of the term 'important' when referring to sites of value for marine mammal foraging, social interaction or hauling out also requires further consideration and definition. The results of NIEA's ongoing site condition monitoring programme should also provide a valuable contribution to establishing important areas in this context in the future.

1.4.2 Biannual Reporting

Biannual reports are provided on the project website www.seageneration.co.uk/downloads.asp

Report format

The following volumes constitute an evaluation of the progress of all of the elements of the SeaGen Environmental Monitoring Programme (EMP), to allow an "at-a-glance" assessment of progress each section contains summary interpretation of the results and other main aspects of each programme. The more detailed descriptive components, together with methodological information and full recent progress reports are either provided in the Appendices or can be found in referenced literature.

The summary interpretation sections include the following:

Key questions

For each monitoring or mitigation element one or more key questions are presented. These are directly linked to the operational objectives presented in Table 1.2 and are the critical concerns which the monitoring programmes are specifically designed to address. Our ability to answer the key questions is discussed in the sections on detection of change and data confidence (see below) as well as accompanying volumes detailing the results of data collection for each receptor / element of the EMP.

In addressing the key questions, three distinct phases are recognised:

- Installation;
- Commissioning; and
- Operation.

There are four possible answers to the key question. In addition to the positive or negative responses an answer of 'unsure' is used where the monitoring results are ambiguous, where there is an element of methodological doubt, when no data are available or the analysis has not been completed or submitted. 'Not possible' is used when no data are available for the period in question.

During the Science Group meeting on the 7th December 2010 it was decided that some of the questions used in previous biannual reports were potentially ambiguous and do not allow a true reflection of the findings of the EMP. As a result some of the questions have been reworded

Significant change detection

This element provides an indication of whether a significant change has, or has not, been detected. Significance may refer to biological or statistical significance and will be worded as such. Biological significance is based on the expert opinion of the Science Group which includes scientists from a variety of backgrounds, including Regulators and scientists independent from the SeaGen project.

In addition, two other reporting options are provided. In instances where there are indications of change, but methodological doubts, or issues over data confidence introduces uncertainty, an 'unsure' result is reported. Where the monitoring data are plainly unable to provide a level of resolution that will allow a measurement of change, or have not yet been collected, the status is indicated as 'not possible'.

As indicated in Section 4, issues over the determination of what constitutes 'significant' change remain to be addressed within the broader SeaGen monitoring strategy. In this report, where such issues arise, these are briefly explained in the results section.

It is important to point out that the detection of significant change does not necessarily signify an undesirable effect of the turbine installation. In many cases, perhaps most, we may simply be detecting a natural and cyclic variation related to seasonal or longer-term fluctuations, or even wider changes initiated by other influences such as climate change. If this is thought to occur a brief evaluation is included in the results section.

Data confidence

Data confidence refers to the ability of the data to provide a reliable indicator of change and answer the key questions. It is largely an expression of the broad quality status of the presently held dataset.

Four categories which have been used to define data confidence during the project:

High	The current data provide a good reflection of the element(s) being measured, are highly likely to provide an indication of change if it is occurring and will directly answer the key questions.
Medium	The current data provide a broad reflection of the element(s) being measured, may provide a sufficient level of resolution to detect change if it is occurring, but may also leave room for doubt when used to answer the key questions.
Low	The current data provide a poor or possibly inaccurate reflection of the status of the monitored element(s), are unlikely to be of sufficient power to reliably detect even large changes and cannot presently be used to answer the key questions.
Unknown	The current data have not yet been analysed, or are still undergoing collection.

Data confidence is, in many cases, likely to be linked to the frequency or time period over which the data have been collected and it is anticipated that monitoring programmes demonstrating a reduced level of confidence will improve with increased data collection.

In addition to the Key Questions table the results, timescale, and expectation during the next reporting period are discussed for each aspect of the EMP.

2 MARINE MAMMALS

2.1 Introduction

The main concern with respect to the impact of SeaGen on marine mammals was whether the turbine would have an impact on the integrity of the breeding harbour seal population. There were also potential impacts on grey seals and harbour porpoises in the vicinity.

A number of objectives were defined to address these concerns and a comprehensive monitoring and research programme was developed. The objectives of the EMP are described in Table 1.2. To allow on-going assessment of whether these objectives were being met, and to a allow implementation of adaptive management if any impacts had become apparent, a number of separate monitoring projects were developed. These provided the capacity to detect changes in the long-term at the level of the whole population within the region of Strangford Lough and the Northern Irish Sea down to changes in the very short-term representing changes in the fine-scale movements of animals in the presence of SeaGen. This scale-based approach meant there was a high probability of detecting effects from small and likely insignificant displacement of animals, through to population declines that would be considered to be a significant impact. The measurements used are listed below each relevant objective in the following section. Some monitoring projects were intended to address more than one objective so where this is the case, they have been repeated under each relevant objective below. In some cases these projects were continuations of studies carried out during baseline characterisation, in others bespoke methodology was designed and implemented.

Objectives of the EMP:

- Ensuring no mortalities of marine mammals as a result of physical interactions with the turbine rotors
  Methods:
    - A system of active acoustic monitoring was developed which detects marine mammals within 50m of the rotors and allows precautionary shut-down of the turbine
    - Carcass surveys and post mortem evaluation of all strandings implemented

- Ensuring that the turbine does not present a barrier to the free passage of marine mammals through the Strangford Narrows.
  Methods:
    - Pile based, incidental marine mammal observations carried out (from July 2008-August 2009) as part of a potential collision mitigation measure.
    - Seal telemetry studies implemented – tracking of individual harbour seals using GPS phone tags.

- Acoustic monitoring of harbour porpoise activity in the Narrows and Lough using TPODs.

- Ensuring that the relative abundance of marine mammals in Strangford Narrows is not significantly modified by the operation of the turbine
  Methods:
  - Shore based visual observation of marine mammals in the Narrows around the turbine site
  - Acoustic monitoring of harbour porpoise activity in the Narrows using TPODs

- Ensuring that the sub-surface noise generated by the turbine does not cause a level of disturbance to marine mammals sufficient to displace them from areas important for foraging and social activities
  Methods:
  - Measurement of operation noise and modelling how this noise travelled through water and prediction of likely impacts on marine mammals.
  - Sightings of marine mammals in close proximity to the turbine during operation from shore based visual observation, pile-based observation and seal telemetry.

- Ensuring that the number of harbour and grey seal adults and pups present within the Strangford Lough SAC does not decrease significantly as a result of the installation and operation of the SeaGen Turbine.
  Methods:
  - Aerial survey of population size and distribution (set within the context of historical data)
  - (Number of harbour seals using the lough from NIEA/NT boat counts can also supplement these data)

- The SeaGen turbine does not cause a significant change in the use of important harbour or grey seal haul out sites within the Strangford Lough SAC.
  Methods:
  - Aerial survey of population size and distribution (set within the context of historical data)
  - (Number of harbour seals using the Lough from NIEA/NT boat counts can also supplement these data)

- The SeaGen turbine does not displace harbour porpoises from the Strangford Narrows and the adjacent Strangford Lough SAC.
  Methods:
  - Acoustic monitoring of harbour porpoise activity in the Narrows and Lough
  - Sightings data from shore and pile based observers.

2.2 Main Findings

The Environmental Monitoring Programme associated with the SeaGen turbine has been a detailed and comprehensive study of marine mammal behaviour and activity in response to an anthropogenic impact, unrivalled anywhere in the world. As such, it has not only informed the development of the tidal energy industry, it has provided hitherto unknown insights into marine mammal behaviour in tidal environments. The adaptive nature of the EMP has allowed the project to develop and achieve success despite the existence of several uncertainties surrounding the potential environmental impacts of tidal energy devices, especially as the site proposed for SeaGen was in a protected area where the local harbour seal population was a key qualifying feature of the SAC designation.

The multiple objectives of the EMP, driven mainly by several uncertainties surrounding the impact of this novel technology on marine mammals, necessitated the implementation of several strands of monitoring at a variety of spatial and temporal scales. The capabilities/confidence in each of the data strands for answering the key questions has been critically assessed at each stage in the process and much has been learned about monitoring marine mammals at tidal sites.

There have also been other, unforeseen benefits of the EMP. Increased surveillance as a result of concerns about direct interactions of marine mammals and the rotors of the turbine has resulted in the discovery of another major anthropogenic source of mortality, unrelated to SeaGen, in the seal population (corkscrew type injuries thought to be caused by ducted propellers - see Thompson *et al* (2010). It is likely that this would have remained undetected without the interest surrounding the project.

No major impacts of SeaGen have been detected on harbour seals, grey seals or harbour porpoises. Relative abundance of seals as measured by shore based visual surveys, or annual counts of seals at haul out and breeding sites have not undergone any detectable changes which can be attributable to SeaGen.

A minority of the comparisons between operational and baseline phases lacked the desirable level of statistical power to be absolutely sure of an absence of any underlying differences in the metrics measured. This was generally due to high levels of natural variation in the metrics measured and highlights the need to carefully consider the power of future monitoring programmes to detect biologically significant changes in the metrics under consideration.

Harbour porpoises appear to have been temporarily displaced from the Narrows during the construction of SeaGen, but activity in the inner Lough remained similar throughout. Porpoises returned to the Narrows after the installation period was complete and it is likely that this was a response to increased boat traffic and human presence rather than the construction per se. There was a small reduction in porpoise activity in the Inner Lough when the turbine was operating relative to when it was not operating; however, there was no difference in relation to turbine activity closer to the turbine in the narrows so the reason for this is unclear.

SeaGen has not presented a barrier to movement of seals or porpoises in and out of the Lough and animals are regularly sighted within the range of predicted behavioural avoidance as a result of noise.

The only detected changes in any of the metrics monitored have been relatively small and are largely suggestive of small scale changes in local distribution in relation to SeaGen presence and operation. Tagged seals continued to transit past SeaGen but transited further away from the centre of the Narrows than in the baseline period. Individual seals did transit slightly less often when the turbine was operating but this effect was relatively small. Overall the seals transited more at slack tide, indicating that there will always be opportunity for transit past the turbine. The observations from the shore also suggested that seals were redistributed during turbine operation although no change in relative abundance occurred. These modifications to behaviour are small in scale and are unlikely to have significant effect on animals' fitness or survival. In fact any avoidance of the operating turbine will serve to reduce the risk of direct interactions with the rotating blades, which was one of the main sources of concern.

2.3 Methodology

2.3.1 Shore-based marine mammals surveys

A fixed point watch station was established on the east shore of the Narrows 10m above Mean High Water. The site was chosen as it gave the optimum view of the proposed location of the SeaGen system in the Narrows. Observations involved continuous visual sweeps of the area with laser range finding binoculars and recording the identity and location of birds and mammals seen. During each month a total of 8x3-hour watches were carried out under different tidal states and at different times of the day.

Observations started in May 2005 and continued until December 2010. Additional observations were carried out during 2006 from a second observation point to investigate the effects of distance on the detection of animals. Analysis of these clearly indicated both that the proportion of animals detected declined with increasing distance from the observer and that there were substantial differences in the proportions of animals detected at equivalent distances from the two observation points. Thus the data provided a measure of the relative usage of the area of the Narrows visible from the observation point. The data did not represent the total absolute number of seals in Strangford Lough but they indicated relative numbers of seals using the area visible from the survey point. They provided an index of relative abundance which was used to examine temporal and spatial changes pattern of seal and porpoise use in the area.

2.3.1.1 Data analysis

Two issues with the potential to complicate the analysis of these data have been addressed here. These are:

Non-linearity of the effects of space and time on the numbers of animals observed. The data represent relative animal abundances collected over time, which are likely to be nonlinearly related to the model covariates. For this reason, Generalized

Additive-based Models (GAMs, Hastie and Tibshirani (1990)) were used to model mean animal abundances. GAMs with Poisson errors, a log-link and an offset term were fitted

Non-independence of the observations. The data comprised of observations collected close together in time and space, and consecutive observations are likely to be correlated. Part of this correlation in the data might be explained by including temporal and spatial information in a model but some residual auto-correlation will remain. Consequently, Generalized Estimating Equations (GEEs) were used to account for any residual auto-correlation and adjust GAM standard errors and *p*-values accordingly (Hastie and Hilbe, 2002).

The following lists the covariates considered for the model selection process and details how they were specified within each model:

- Date – month and year
- Spatial information – Survey area was discretised into blocks of approximately 175m×200m squares and observations for each hour in each grid cell were calculated.
- Time of day
- Tide state (flood, ebb, high water and low water)
- Turbine activity:
  - TurbineON: a fine scale binary covariate which signals when the blades were turning
  - TurbineDay: a coarser scale binary covariate which signals if the blades were turning at some point during that day (even if land-based observers were not present during turbine activity).

Power analysis

Throughout the monitoring period, consideration was given to whether the survey design and observation effort were sufficient to detect changes in the metrics being measured, should an impact occur. The following summarises the approach taken:

- Various sizes of turbine effect were simulated (a 5-20% reduction in relative abundance of animals), and detection of a statistically significant effect was sought from the models simulated from the historical survey data, after two time periods of additional monitoring. Simulated data contained the same variability as the historical data.
- The inherent statistical noise will mean small installation effects are difficult to detect over small time-periods, but become more detectable with more data. Large effects should be detectible sooner.
- The simulation process allows quantification of the probability of detecting an effect for various effect sizes and periods of additional monitoring.

2.3.2 Passive acoustic monitoring (T-PODs)

The TPOD (‘Timing POrpoise Detector’) or TPOD is a self-contained submersible unit that includes a hydrophone element, an amplifier, analogue electronic filters and a digital processor, as well as a battery pack and memory. The TPOD did not record sound but worked by logging the start and end of echolocation clicks of porpoises and dolphins. The basic metric they generated was expressed at detection positive minutes (DPM) which consists of any minute in which a porpoise click train was detected.

TPODS logged continuously 24 hours a day and were therefore useful for providing continuous data on porpoise activity within a radius of a few hundred metres. However, it is important to emphasise that they provided data on porpoise presence in a given area and did not provide a count of the number of porpoises present. Although they can't be used to estimate the abundance of porpoises they can be used to compare relative frequency of occurrence/echolocation activity between sites or through time.

A total of ten TPODs were deployed at the start of the monitoring period, with deployment locations chosen to provide the best acoustic sampling of the area. A number of losses occurred over the project, resulting in changes to the number and locations of the monitoring sites. Placing TPODs within the Narrows was a priority so early losses of TPODs from sites in the Narrows meant that the outer lough monitoring sites were sacrificed to ensure continual coverage of the sites closest to the turbine site. Encounter rates were generally very low in the outer Lough sites.

Four TPOD deployment sites in the Narrows were originally chosen to give best passive acoustic coverage of the area around the proposed turbine installation site. The choice of deployment location for these TPODs was constrained by a number of factors. TPODs needed to be an adequate distance away from the central navigational channel and from the Strangford-Portaferry ferry channel, to minimise the risk of a boat becoming accidentally entangled in the mooring ropes. Deployments also had to be placed in depths and areas that would allow easier deployment and retrieval by boat having taken into account tidal currents within the Narrows. The three TPODs deployed inside the Lough were placed in areas where porpoises had been seen previously.

2.3.2.1 Data analysis

Initial data processing was performed in TPOD.EXE (version 8.23), which allows visual analysis of all logged clicks and an assessment of how these clicks have been classified into different click trains. Processed data from the TPOD software were exported into spreadsheet and database programs for further analysis.

Analysis of the TPOD data required to take into account several key issues with the data:

- Non-linear responses to environmental variables
- Temporal autocorrelation in the TPOD data (detections in one time period were likely to be related to the detections in the preceding and following time period), thus violating the assumptions of most common types of statistical modelling.
- Unbalanced sampling design with respect to the other factors which could influence porpoise detections

Consequently, Generalised Additive Models (GAMs) built within a Generalised Estimating Equations (GEEs) model construct were used to explain harbour porpoise habitat preferences within Strangford Lough. As discussed in the previous section GAM is a method to analyse non-linear data responses using non-linear smooths of predictor variables, GEE's allow for the autocorrelation to be modelled appropriately.

Candidate covariates
Several other factors affect porpoise presence and abundance, if not properly accounted for in the analysis (especially given the unequal nature of sampling with respect to these covariates) then there would be a danger of inappropriately assigning variance in porpoise activity to turbine related effects and drawing inaccurate conclusions about the nature and significance of the impact of the turbine on porpoises. Consequently a range of candidate environmental and/or oceanographic covariates were considered for the models. These included time of year, time of day, location, different sensitivities between TPOD units, state of the tide, as well as turbine related variables – whether during baseline, installation or post-installation time periods, or during the operational stage, whether the turbine was operating or not.

2.3.3 Marine mammal carcass monitoring

A programme of shoreline surveillance covering key areas which were predicted to be hotspots for strandings based on local advice and hydrodynamics. These included Ballyhenry Bay, Mill Quarter Bay and Ballyhornan Bay. These were completed as walkover surveys by QUB until September 2009, when it was agreed by the Science Group that these surveys were no longer required. Plans were in place for any carcasses discovered to be subjected to a post-mortem by a Vet Pathologist to determine whether the cause of death has potential to have resulted from collision with the SeaGen turbine.

Throughout the duration of the project, NIEA have managed the post mortem of any carcasses reported in the wider area. MCT supported this process with a public awareness poster campaign.

2.3.4 Aerial survey

Aerial surveys of seal haul out sites along the Northern Ireland coast between Carlingford Lough and Belfast Lough, including Strangford Lough were carried out annually by SMRU specifically as part of the EMP since 2006. The information presented here also include reference to the number of seals counted during a previous survey, in August 2002 (Duck, 2003). This survey covered the whole of Northern Ireland and was funded by the Environment and Heritage Service of Northern Ireland (precursor to NIEA).

Surveys were carried out from a helicopter using a thermal imaging camera. The imager is sensitive to infrared radiation in the 8-14 μm wavebands, encompassing the electromagnetic emission range of mammals. The thermal imaging camera can rapidly detect seals hauled out of the water and is ideal for locating seals on rocky shores where they can be very difficult to see, enabling long sections of coastline to be surveyed in a relatively short time.

The aim of these surveys was to determine the overall numbers of harbour seals and pups and the locations of their haul-out sites between Carlingford Lough and Belfast Lough, including Strangford Lough. The surveys provide additional information on the number and distribution of harbour and grey seals both inside and outside Strangford Lough, complementing the monthly boat surveys carried out inside Strangford Lough by the Northern Ireland Environment Agency (NIEA) and National Trust (NT) staff.

The July survey aimed to provide more detailed information on the number and location of harbour seals breeding within the survey area and on the relative numbers of pups born in different areas. August (and September) surveys provided a minimum population estimate for harbour seals in line with standard SMRU survey procedures used elsewhere in Great Britain and Ireland. These were carried out during the harbour seal annual moult.

The surveys conformed to standard SMRU procedures: the helicopter operated at a height of 150-250m and a distance of 300-500m offshore to ensure that seals were not disturbed from their haul out sites. All surveys were conducted within +/- 2hrs of the local low tide times occurring between approximately 12:00hrs and 19:00hrs. Surveys were not carried out on rainy days as the thermal imager cannot ‘see’ through heavy rain and because seals abandon their haul out sites and return into the water in medium to heavy prolonged rain.

In general, species identification of individual seals is possible due to their different thermal profile, size, head-shape and coat pattern. When hauled out, their group structure also differs. Grey seals form tight and disorganised aggregations close to the water while harbour seals have greater inter-individual distances and are usually a bit further from the water’s edge. Species identification in the field was aided by the use of the ‘real’ camcorder image and by direct observation using binoculars. In addition, most groups of seals were photographed using a Canon 20D digital SLR camera with an image-stabilised 70-300mm zoom lens. Species identity and the number of seals in groups were later confirmed from reviewing both the digital thermal video and the still images.

To maximise the extent of coast surveyed during the four-hour tidal window, the standard survey route begins at the southern tip of Carlingford Lough and continues in an anticlockwise direction around the coast. The coast is surveyed up to the Strangford ferry slipway in Strangford Lough, crosses the Narrows to the slipway in Portaferry and continues along the Outer Ards coast, finishing between the Copeland Islands and Bangor town. After refuelling at Newtownards Airport, the survey continues around Strangford Lough as the time of low tide inside Strangford Lough is approximately one hour later than at Strangford Narrows.

2.3.5 Harbour seal telemetry

Thirty six seals were fitted with electronic tags during the environmental monitoring of SeaGen. These instruments were glued to the animals’ fur meaning that they detached during the annual moult. These instruments collect GPS (Global Positioning System) location data and information on animals’ diving and haulout behaviour, and relay these through mobile phones incorporated into each instrument. The 3 deployments took place in 2006 (April-July, pre-installation), 2008 (March – July, during installation and commissioning) and in 2010 (April-July, operation). The seals were captured at sites in Strangford Narrows and the southern islands in Strangford Lough. The three groups of animals tagged contained similar mixes of ages and sexes.

The GPS/GSM tags were programmed to obtain a GPS location every 20 minutes (10 minutes in 2010). The tags also recorded when animals were hauled out.

2.3.5.1 2009 analysis

An analysis carried out in 2009 after two deployments with the following objectives:

1) Describing the times at which seals are most susceptible to the impact of the turbine;

2) Detecting any changes in movement and haul out behaviour between the two years.

A band across the Narrows 300 metres on either side of the turbine site was defined as the turbine buffer zone. The presence of a track location within the buffer zone, given that the animal had left from a haulout site within the Narrows was modelled as a binary generalized additive mixed model[3]. The year, season, time of day and tidal phase were included as covariates.

To assess any changes beyond the buffer zone and their geographical extent, the distance of the hourly track locations to the turbine was also modelled.

Three behavioural measures were derived: Probability of hauling out, trip duration and extent.

Usage maps were constructed to describe the relative distribution of the population of harbour seals departing from the haulout sites in the Strangford Lough and the Narrows. The usage estimation method is based on a case-control development of Matthiopoulos et al.'s (2004) technique. The method constructs haulout-specific usage maps by averaging individual usage. The maps are then scaled by the number of individuals counted at each site and combined into an aggregate map of usage.

2.3.5.2 2010 analysis

In 2010 after a third deployment of tags while the turbine was fully operational, a further analysis was carried out to look at changes between years in terms of the transiting behaviour of seals.

2.3.5.3 Transit rate and location

A transit was defined as an individual seal tracking passing through the Narrows past the site of the turbine. Differences in two features of transit behaviour through time were investigated: the mean number of transits per day per seal and the distribution of these transits across the Narrows in terms of distance from the turbine. These were compared between years, between times when the turbine was operational or non-operational, between day and night, and in relation to tide and season.

There are three main issues that complicate testing for statistically significant differences between years. The first is the relatively small numbers of animals that were tagged and the high levels of variability in behaviour between individuals. Secondly, there are very

[3] GAMM, function gamm() within r library mgcv by Simon Wood

different amounts of data from individual animals. In particular, the tags used in 2010 were programmed to attempt to obtain locations every 10 minutes rather than every 20 minutes, as in previous years. The third limitation is that the different transits made by each individual cannot be treated as independent data points in comparisons of the overall behaviour of groups of animals.

The uncertainty in the mean transit rate (number of transits per day) for the population was estimated by non-parametric bootstraps of the data from individual seals. The significance of differences was assessed by comparing the resulting confidence intervals. The significance of differences between the overall transit rates in 2010 when the turbine was operating and when it was not operating was investigated with the Wilcoxon signed-rank test and also by bootstrapping with individual as the unit of resampling. The same approach was used for looking at differences in relation to tidal, diurnal and seasonal effects.

The Kolmogorov-Smirnov two sample test was used to compare the distributions of transit locations. This test was applied directly to the data from each pair of animals. Similar comparisons were carried out between the distributions of transit locations for individual seals when the turbine was on and off.

2.3.6 Active Sonar

An active Sonar monitoring and mitigation system has been in operation on SeaGen since the turbine was commissioned in 2008. This system provided real time sub-surface sonar imagery of large objects within 80m of the turbine whilst it is operating. This system was remotely monitored by operators in real time during all turbine operation and is used to detect potential marine mammal and other large vertebrate targets which may have been at risk of rotor strike whilst the turbine is operational.

The development of this system has been somewhat iterative and has gone through a number of stages since it was first installed in July 2008. Initially the effectiveness of the active sonar to detect marine mammals underwater in close proximity to the turbine was trialled alongside concurrent pile based visual observations in the early stages of SeaGen commissioning and operation. The trial had two objectives: 1) to determine whether the sonar could detect moving marine mammals in a tidally turbulent environment and provide an effective mitigation tool, and 2) to determine whether the sonar could be used as a behavioural monitoring tool to measure the behaviour of marine mammals around the turbine.

Two Tritech Super SeaKing DST sonar heads were mounted on the upstream and downstream sides of the SeaGen tidal turbine in Strangford Lough, NI. The Super SeaKing DST is a mechanically scanning imaging sonar with two individual sonar heads; a 300 kHz CHIRP (Compressed High Intensity Radar Pulse) sonar and a 670 kHz CHIRP sonar for high definition images. CHIRP technology is designed to provide relatively good range resolution compared to monotonic frequency sonars and is potentially good for detecting and discriminating between closely spaced targets. The sonar heads were attached to a mounting plate and secured to the hand rail of the ladder on the crossbeam of the turbine. The heads were electrolytically isolated from the turbine using rubber matting between the head and the mounting plate. The depth of each sonar head when the crossbeam was lowered was approximately 11.5m below MLWS. This was close to the middle of the water column (seabed = 23.9m below

MLWS). Data transmission from the sonar heads was incorporated into custom built cables within the turbines existing systems cabling.

Each sonar head provided approximately 120-180^{o} horizontal coverage x 40o vertical coverage around the turbine. This provided full water column coverage from at least 15 metres from the turbine out to approximately 80 metres. A laptop computer located in the turbine control room was used to record and image the sonar data. The Seanet Pro software was used to monitor the sonar signals in real time. As the sonar is a manually scanning system, with these settings, image update rates were around 6 seconds (for a 180^{o} scan).

2.3.6.1 Data collection

Sonar images were monitored by a user (located on top of the turbine control room) and times when targets were detected were noted. In addition, a visual observer located on the top of the turbine control room simultaneously monitored for marine mammals upstream of the turbine (on both the flood and ebb tides). A wire grid was erected in front of, and perpendicular to, the observers' field of view to divide the view of the study area into the 9 sub-areas on each side of the turbine (18 in total). The grid was constructed using two 2m long wooden poles inserted into aluminium sleeves on the hand rail at the edge of control room roof. Between the poles, lines of 1.5mm thick wire divided the view of the study area sub areas. To ensure that the grid maintained its position, its alignment was checked each day. Each time a marine mammal was sighted, the visual observer noted species, number of animals, sub area, and time of the sighting.

A total of 135 hours of real-time monitoring using a combination of visual and sonar techniques were carried out. Weather conditions during these periods were variable with sea states ranging from Beaufort 1 to 3 and wind speeds ranging from Beaufort 1 to 5.

2.3.6.2 Data analysis

To assess the efficacy of the sonar at detecting marine mammals, the timing and location of all visual observer sightings were compared to target detections made using the sonar. If a target detection made with the sonar occurred within approximately 30 seconds of a visual sighting and was spatially in a similar location to the sighting, the target was tentatively confirmed as a marine mammal. The data were summarised in terms of number of targets confirmed as marine mammals by spatial and temporal data from the visual observer, and number of 'other' targets (those detected using the sonar but not correlated with a visual sighting of a marine mammal). In this way, targets were also confirmed as 'bird' targets if a target detection made with the sonar occurred at the same time and similar location to a sighting of a bird by the visual observer.

To evaluate whether the target tracks detected on the sonar could be used to measure behaviour around the turbine, the tracks of all detected targets were plotted in X□Y coordinates around the turbine. The speed of marine mammals and unconfirmed targets were then compared. Two other metrics of the target track for marine mammals and unconfirmed targets were also compared; the mean angle of the track relative to the turbine and the standard deviation (SD) of the mean track angle relative to the turbine; these allowed an assessment of the variation in the track from a linear track along the predicted direction of the tide.

Target characteristics (speed, track trajectory and variation in track angle) were also examined in relation to turbine operation. Differences in these metrics between turbine on and turbine off condition were compared.

To determine whether there was any evidence of turbine avoidance, tracks were examined during periods where only one of the rotors was operating. These were investigated for any evidence of preferential transit past the turbine on the side of the non-operating rotor. The distance at which the tracks passed the centre of the turbine in relation to turbine operation was also calculated. Distance from the centre of the turbine was modelled as a response in a general linear model with rotor side and turbine operation as explanatory factors.

2.3.7 Noise

2.3.7.1 Construction noise

Underwater noise measurements were undertaken in Strangford Lough on 23th April 2008 between 09:00 and 21:00 during drilling operations on the North-West foot of the SeaGen base. Drilling was predominantly through bedrock material except for a small amount of overlying loose rocky material over some of the sockets. During measurements of the drilling operations the vessel was moved as close to the drilling rig as possible. The ships engines and all electrical equipment on board were turned off and the vessel was then allowed to drift away from the noise source. This method allowed measurements to be taken at ranges between 23m and 2130m from the drilling operation. The hydrophone was at a depth of 10m below the water surface for most of the measurements.

Background underwater noise measurements were also carried out during periods when no drilling was taking place in order to determine the pre-existing noise levels in the Strangford Lough region. The potential effects on fish and marine mammals were predicted by Subacoustech Ltd using the dBht metric (measure of the perceived level above the species hearing threshold).

2.3.7.2 Operational noise

Noise measurements of SeaGen during operation were carried out with high-precision instruments from a drifting boat. Underwater sound propagation models were used to predict how the noise levels would vary with distance from SeaGen. Within one kilometre of SeaGen, simple transmission loss models fit the data relatively well; however, received levels were found to increase at distances of more than 3km.

The potential effects on marine mammals of underwater noise from SeaGen were predicted by SMRU Ltd using current information on hearing abilities and observed responses from previous studies, and are presented as a series of influence zones around SeaGen. The zones of influence calculated were: the zone of audibility, the zone of potential auditory injury, the zone of behavioural response, and the zone of potential masking.

2.4 Results

2.4.1 Shore-based Marine Mammals Surveys

Data source:
- SMRU Ltd (2011, unpublished). Detecting changes in relative animal abundance using Strangford Narrows visual observations. Report prepared by DMP Statistical Solutions.

2.4.1.1 Model results

Harbour seal results

The analysis of the shore based survey data revealed marked relationships between harbour seal sighting rates and the state of tide, year, time of day and time of year.

There were monthly fluctuations in average relative abundance across the year. Relative numbers were highest in June and July with similar numbers seen across the rest of the year.

There were also annual fluctuations in relative abundance. The absolute number of sightings was highest in 2005 but this was statistically indistinguishable from those in 2006 (2nd year of baseline) and 2009 (first year of operation). Numbers in 2007, 2008 and 2010 were all lower than 2005/2006 numbers but numbers in 2007 (3rd year of baseline) were indistinguishable from either 2008 (installation), 2009 or 2010 (operation), indicating that changes were a result of natural variability rather than anything related to SeaGen. This result highlights the importance of collecting baseline data over a sufficiently long period to fully characterise natural variability in sightings rates.

Substantially higher sightings rates occurred during flood tides and at high and low water compared to during the ebb tide. Specifically about 2.5 times the numbers of seals were seen during flood tides compared to ebb tides. Sightings rates during slack water were intermediate between flood and ebb tides.

There was evidence for a redistribution of harbour seals in relation to turbine operation – some grid cells increased in relative abundance when the turbine was operating, others decreased. However, there was no statistical evidence for an average change in harbour seal numbers overall while the turbine was operating or on days when the turbine was not operating. Although sightings rates were significantly different between years, there was no evidence for a change associated with the installation or operation of the turbine.

Grey seal results

The grey seal data were analysed separately from the other species and, two sets of grey seal results were obtained: one set of results concerned confirmed sightings of grey seals and one set of results concerned both the confirmed grey seals data and the data from unidentified seals. The analysis revealed marked relationships between grey seal sighting rates and the state of the tide, year, time of day, time of year and spatial location.

There was no statistically significant change in the relative numbers of grey seals seen, or in their distribution during turbine operation. There was also no evidence for an underlying change in seal numbers or distribution on days when the turbine was operating.

Grey seal numbers in 2006—2010 were significantly lower than average numbers seen in 2005. However, there was considerable overlap in the best/worst case scenarios (based on the 95% confidence intervals) exhibited in recent years. Relative grey seal numbers in 2009--2010 were just 20% of the numbers seen in 2005. Seal numbers varied from month to month across the survey period, with highest numbers in April. Specifically, after accounting for other sources of variation approximately twice the numbers of seals were seen in April than in January, while all other months were statistically indistinguishable from January levels.

There were many more animals seen close to, and in front of, the observation point. Specifically, up to 5 times the numbers of animals were seen in the grid cells closest to the observation point (first 200m) compared to those cells farthest from the observation point (up to 800m away). This could be entirely due to the detection process and the fact that animals far from the observer are more difficult to see.

Refitting the model for grey seals including the unidentified seals resulted in very similar results for all covariate terms.

Harbour porpoise results

The analysis revealed marked relationships between relative porpoise numbers and time of day, time of year, year, state of the tide and spatial location. There was no evidence of any effect of turbine operation on sightings rates.

Porpoise numbers in 2007—2010 were significantly lower than average numbers seen in 2005. However, there was considerable overlap in the 95% confidence intervals exhibited in these last four years. Relative numbers in 2007-2010 were just a fraction (20%) of the size of the numbers seen in 2005.

Porpoise numbers varied from month to month across the survey period, with highest numbers in September-November. Specifically, (all other factors held constant) approximately twice the numbers of animals were seen in November than in February to April.

2.4.1.2 Power analyses

Since a significant effect of the turbine on distribution was detected for harbour seals, no power analyses were run for this species.

Grey seals

There were two sets of results, one including only positive grey seal sightings, the other including all unidentified seals as grey seals. This generated two sets of results which could be viewed as providing best and worst case scenarios for each combination of effect size and additional monitoring.

The power to detect an underlying change naturally increases with the effect size. However, small effects (<10%) had very similar low probabilities of detection (6-8% depending on which dataset is used; power of around 80% is usually considered reasonable). The extra monitoring between 3 and 6 months made little difference to the power to detect an effect.

Power to detect change was generally low for all effect sizes regardless of additional monitoring duration or addition of the extra (unidentified) seals to the sample size. Maximum power was 59% to detect a 20% change in numbers after 6 months of monitoring post impact and making the (unlikely) assumption that all unidentified seals were grey seals. Using only grey seals sightings the power to detect a 20% change in relative abundance after 3 and 6 months was only 12-15%.

All effects considered here had very low probabilities of detection. The extra monitoring between 3 and 6 months for all effects <20% made little difference to the power to detect an effect.

2.4.1.3 Conclusions

There will always be a number of animals within the survey area undetected by the observer due to two causes: 1) because marine mammals spend a large proportion of their time underwater and therefore unavailable for detection, and 2) because detection probability declines with increasing distance from the observation point. Information on the extent of these two issues is currently unavailable and so the models presented here are not informed by detection or availability information. However, this does not necessarily preclude detection of relative changes through time under a consistent monitoring scheme. It does mean that all abundance estimations are under-estimates to an unknown degree – hence they are interpreted as *relative* average animal abundances.

Turbine-related changes in relative animal abundance

There were no detected turbine-related changes in relative abundance over time for harbour seals, grey seals or porpoises. However, there was evidence of redistribution for harbour seals in the survey area during turbine operation. This redistribution was relatively small scale (a few hundred metres) and is probably of little biological significance.

Power of the monitoring scheme and analysis

The power of the monitoring regime and subsequent analyses to detect base changes in the porpoise and grey seal abundances was relatively low. Even large effects, say a reduction in the average abundance of 20%, had a probability of detection of only 0.28 after 6 months monitoring for porpoises. This probability of detecting an effect was even smaller for grey seals – a 20% decline in the number of animals seen would only be detected with probability of approximately 0.12. This is indicative of the naturally large variability of the system under study and this variability necessarily requires extended monitoring to detect systematic changes in underlying abundances. For example, weeks can elapse without sighting any porpoises – hence even large shifts in average porpoise habitat usage cannot be detected on a fine scale temporal resolution. This highlights the possibility that a significant effect could remain undetected at this spatial scale. However, the wide ranging nature of these species means that a change in relative abundance at this spatial scale is unlikely to be biologically significant.

Table 2.1: Marine mammal EMP questions answered by shore based survey

Key Question	**Phase**	**Answer**	**Statistical Significant change from baseline detected with current data?**	**Data confidence**
Is marine mammal density and behaviour in Strangford Narrows significantly (biologically) modified by the SeaGen turbine?	Installation	No	No	Harbour seals = medium; Porpoise and grey seals = low
	Commissioning/ initial operation	No	No	Med/Low
	Operation	No	No	Med/Low
Are harbour seals significantly (biologically) excluded from Strangford Narrows as a result of the SeaGen turbine?	Installation	No	No	Med
	Commissioning/ initial operation	No	No	Med
	Operation	No	No	Med
Does operation of the SeaGen turbine have a significant (biological) effect on marine mammal sightings within the immediate waters of the turbine?	Installation	No	No	Med
	Commissioning/ initial operation	No	No	Med
	Operation	No	No	Med

2.4.2 Passive Acoustic Monitoring (T-PODs)

Data source:

- SMRU Ltd. 2011. Booth, C.G., Mackay, A.I., Northridge, S. and Sparling, C.E. Acoustic Monitoring of Harbour Porpoise *(Phocoena phocoena*) in Strangford Lough. *Report SMRUL-MCT-2011-16 to Marine Current Turbines. July, 2011* (unpublished).

TPODs deployed in Strangford Lough between 2006 and 2011 have recorded a summed total of over 350,000 hours of data.

The results from this study highlighted a number of important features relating to porpoise activity in Strangford Lough and Narrows. Porpoises were detected on 86% of days in the study area indicating that porpoises were generally present in the region throughout the study period. This is slightly lower than other studies from elsewhere that have used a porpoise positive days (PPD) as a metric (Verfuss, et al. 2007; Simon, et al. 2010). In both these studies, PPD were close to 100%. Detection rates (DPH) in the region were generally low, with most sites having porpoise detections in <10% of recording hours and mean Detection Positive Minutes per hour of <1.

To begin investigating the influence of SeaGen on the presence of harbour porpoise in Strangford Lough, a model was constructed using all data and available covariates with data from all sites pooled. Overall, porpoise activity varied with month, with activity lowest in the summer months and two peaks of similar magnitude in spring and autumn before declining slightly in the winter. A great deal of variability in the detections was observed across the TPODs used in this study. These differences may be explained by different sensitivities of the TPODs or by genuine variations in the availability of porpoises to be detected. The TPOD's sensitivities were tested in 2010 and it was determined that their sensitivity changed during the deployment. It was not possible to incorporate the individual TPOD sensitivity measurements as a covariate in the model as there are only two measurements for a limited number of TPODs. Furthermore, the rate of deterioration in sensitivity is unknown and interpolation between measurements was not possible.

Porpoise activity was highest during the pre-installation phase. It then declined rapidly during the installation period before recovering to close to pre-installation levels in the post-installation phase. A cyclical pattern in porpoise activity was identified with respect to day and night. Detections were lowest in the middle of the day, increased as sunset approaches, and were highest during the middle of the night before decreasing as the following sunrise approached. Phase of tide also appeared to impact porpoise activity. Peaks in detections occurred on the flood and ebb tide before and after high water before dropping strongly as low water approached and then increasing again on the flood tide.

The full model highlighted that there were differences in porpoise activity between the Inner Lough and the Narrows regions. Consequently, two sub models were constructed using subsets of the full dataset; one using data from the 'Inner Lough only' and another using 'Narrows only' data.

Inner Lough model

Porpoise activity varied similarly to the full model with month and TPOD ID and time of day. In contrast to the full model, porpoise activity was similar during all three installation phases in the Inner Lough. Detections increased very slightly over the study period, post-installation detection rate significantly higher than pre-installation.

Whether the turbine rotors were active or not was significant and porpoise activity was slightly lower in the Inner Lough when the turbine was active than when inactive. However, the difference was small and the variable had low predictive power in this model. The pattern of porpoise activity with respect to tide differed from the full model. In the Inner Lough model, there was a clear pattern with detections highest around and during high slack water and lowest around low slack water.

Narrows model

The model constructed using the data just from the Narrows revealed some similar patterns as the Inner Lough model. The monthly pattern of detections was very similar, with lowest detection rates in summer compared with the rest of the year. There were also significant variations between TPODs. In the Narrows, a significant decline in detections was observed during the installation phase, similar to that generated from the main model. East/West was also selected in this model, indicating a slightly lower probably of detection at the eastern sites (2) than in the western sites (1) of the Narrows. However, the predictive power of East/West was the lowest in the model. A similar pattern of porpoise activity was observed as in the other models, with peaks in detections during the night and lulls during the day. In contrast to the Inner Lough models, peaks in porpoise activity occurred during mid-flood and mid-ebb tides. Detections were slightly lower during high slack water and lowest during low slack water.

The covariate representing the active turbine was not retained in the best model indicating there was no significant difference in the probability of detection between active and inactive turbine periods in the Narrows.

2.4.2.1 Conclusions

Although TPOD data cannot be used to estimate abundance or density these results suggest that Strangford Lough and the Narrows did not represent important habitat for harbour porpoises relative to the rest of the Irish Sea. An analysis of data from the Joint Cetacean Protocol Database estimated densities of harbour porpoises across the Irish Sea and this suggested that the highest densities occurred further to the west and south of the Irish Sea (Paxton and Thomas, 2010).

There was a similar degree of occurrence in the Narrows and Lough, but higher detection rates in the Inner Lough. The modelling approach employed in this study allowed an evaluation of the different factors affecting porpoise activity in the Lough and Narrows and allowed us to assess the relative importance of each factor in explaining the observed variations in porpoise activity, in particular an evaluation of the importance of any turbine related effects.

The biggest turbine related effect was observed during the short installation phase in 2008, with a large and rapid decline in activity. This effect was only seen in the Narrows; activity in the Inner Lough remained unaffected by installation. Harbour porpoises are generally considered to be shy of boats and it may have been the increased levels of boat and human activity which resulted in the large decline in porpoise activity in the Narrows during this period. There was also the possibility that porpoises may have been avoiding noise produced as a result of the construction activities, although a report commissioned by COWRIE suggested that harbour porpoises would be unlikely to hear the drilling noise at ranges beyond a few metres because of the high levels of background noise in the Narrows (Nedwell and Brooker 2008). Levels of porpoise activity in the Narrows recovered immediately after the installation phase but remained very slightly lower than the baseline level. Levels of activity in the inner Lough increased very slightly above the baseline level post installation so this may represent a small change in distribution of porpoises post-installation. Harbour porpoises have continued to frequent the Narrows and the Lough throughout the operational phase indicating that neither the presence nor operation of the turbine has created a barrier effect.

The magnitude of turbine related effects were very small relative to the variation in detections explained by the other covariates.

Table 2.2: Marine mammal EMP questions answered by TPOD data

Key Question	**Phase**	**Answer**	**Statistical significant change from baseline detected with current data?**	**Data confidence**
Does the SeaGen turbine displace harbour porpoises from the Strangford Lough?	Installation	Yes	Yes	High
	Commissioning	No	No	High
	Operation	No	No	High
Does the SeaGen turbine present a biologically significant barrier effect to the free passage of harbour porpoises through the Strangford Narrows?	Installation	Yes	Yes	High
	Commissioning	No	No	High
	Operation	No	No	High

2.4.3 Marine mammal carcass monitoring

Data source: Pers. comm. NIEA 2008, 2009, 2010, and 2011

All marine mammal carcasses which have been found in the area have had a post mortem carried out by a vet pathologist. These post mortems have shown no evidence of any connection with the SeaGen turbine in the mortality.

Table 2.3: Marine mammal EMP questions answered by carcass monitoring

Key Question	Phase	Answer	Statistical Significant change from baseline detected with current data?	Data confidence
For all recorded stranding events, have any marine mammal mortalities occurred as a consequence of physical interaction with the SeaGen turbine?	Installation	NA	NA	NA
	Commissioning	No	N/A[4]	High
	Operation	No	N/A	High

2.4.4 Aerial survey

Data source:
- SMRU Ltd (2010, unpublished).Seals in Northern Ireland: Helicopter surveys 2010.
- Duck, C.D. (2002). Results of the thermal image survey of seals around the coast of Northern Ireland, August (2002). Sea Mammal Research Unit. Unpublished report to Environment and Heritage Service, Northern Ireland.

2.4.4.1 Moult surveys – harbour seals

Moult survey counts represent the minimum number of seals within each area. At the time of the survey, a proportion of the local population will have been at sea (or at least in the water) and therefore not counted (although surveying during the moult maximises the number of seals hauled out). Harbour seal counts have been made in five annual moult surveys carried out to date, in the Augusts of 2002, 2006, 2007, 2008 and 2010. Counts have generally declined since 2002 in all areas surveyed. 124 seals were counted in Strangford Lough and Narrows in 2002, compared to a count of only 38 in 2010. Total counts for the whole coast were 597 in 2002 and 126 in 2010. These counts represent a snapshot of one day in one year, and although every effort is made to standardise conditions numbers can fluctuate from day to day. Unpublished historical data from surveys carried out in July by EHS (Environment and Heritage Service of Northern Ireland) and the National Trust show that in the late 1970s, there were just under 300 harbour seals in Strangford Lough. Numbers increased, reaching a peak of just over 600 in the mid 1980s, and subsequently declined to approximately 200 by the mid 1990s (Montgomery-Watson, 1999).

[4] No pre-installation surveys are available to provide a baseline for comparison with post-installation dataset.

2.4.4.2 Breeding surveys – harbour seals

Four surveys have been carried out during the harbour seal breeding season. Regionally total numbers of adults were highest in 2006 (597) and lowest in 2010 (391). Total pup numbers were highest in 2009 (224) and lowest in 2010 (126). After the 2009 breeding season survey, the date of the survey was not considered to have had a major influence on the numbers of harbour seal adult and pups seen. The 2010 survey was only four days later than the 2009 survey and it is unlikely, though possible, that this short delay might account for the lower count. The biggest reductions were in Carlingford Lough and from Portaferry to Donaghadee. In Strangford Lough and Narrows numbers of adults were highest in 2008 (168), an increase from 124 in 2006. Adult numbers were at their lowest (89) in 2010. Pup numbers followed a similar pattern but were highest in 2008 (76), an increase from 66 in 2007 and 45 in 2006. Pup numbers were at their lowest (38) in 2010. Pup numbers in Strangford Lough and Narrows were approximately 30-40% of total surveyed pup numbers across the region.

2.4.4.3 Grey seals

Numbers of grey seals onshore can vary widely from day to day during the summer months and counts are unlikely to accurately represent the size of the local grey seal population.

Overall, grey seals were considerably less abundant than harbour seals and were found mainly on the Outer Ards coast and the Copeland Islands. Small numbers of grey seals breed within Strangford Lough with approximately 40 pups born annually (NIEA/NT boat survey data). Small numbers of pups are also born on the small skerries off the Outer Ards coast (up to 30 on North Rocks) and on the two smaller Copeland Islands (between 10 and 20 Lighthouse and Mews Islands). These pups were counted on SMRU aerial surveys, carried out for EHS, in October and November 2003 and 2005. Interestingly, the two areas differ in birth date, with pups inside Strangford Lough born approximately 10 to 14 days earlier than pups outside.

2.4.4.4 Conclusions

There has been a decreasing trend in the numbers of harbour seals counted during surveys across the whole region since surveys began in 2002.

This trend has been observed in both moult and breeding season counts. No major changes have been observed in the distribution of haul out and breeding sites. Numbers in Strangford Lough and the Narrows follow this region-wide trend but to be clear, the start of the decline predates the installation and operation of SeaGen, and there was no evidence an acceleration in the decline after installation. This decline reflects declines in other harbour seal populations elsewhere in the UK. Analysis of the monthly boat based counts made in the Lough and Narrows by NIEA and the National Trust demonstrate a similar pattern of counts declining annually (Lonergan *et al* 2009).

Counts of grey seals were much more variable from year to year at the time that the surveys were carried out and were unlikely to provide a reliable index of population size.

Table 2.4: Marine mammal EMP questions answered by aerial survey data

Key Question	Phase	Answer	Significant change from baseline detected with current data?	Data confidence
Has the number of harbour seal adults and pups decreased significantly within the Strangford Lough SAC?	Installation	Yes*	No	Med
	Commissioning	Yes*	No	Med
	Operation	Yes*	No	Med
Has there been a biologically significant change in the use of harbour seal haul out sites within the Strangford Lough SAC?	Installation	No	No	Med
	Commissioning	No	No	Med
	Operation	No	No	Med

*** NB: Section 2.3.4.4 outlines that the declining trend in harbour seal numbers in Strangford Lough predated SeaGen installation and also follows the region wide trend in declining numbers**

2.4.5 Harbour seal telemetry

Data source:
SMRU Ltd (2009, unpublished) Seal Tagging: Strangford Lough.
SMRU Ltd (2010, unpublished) Using telemetry to investigate the effect of SeaGen on harbour seal behaviour and movement at Strangford Lough, Northern Ireland.

The telemetry work generated 2772 seal-days of track data. Mean track durations were similar between 2006 and 2008 but were longer in 2010 (2006 71 days, 2008 68 days, 2010 92 days). n

The major features of the tracks were broadly consistent between years - a high degree of variability between seals, but a high degree of consistency within seals. Some seals spent their entire time within Strangford Lough, others never entered the Lough at all and some seals spent the entire time transiting up and down the Narrows. Some individuals travelled to distant haul out sites in the Irish Sea, indicating that seals in Strangford Lough/Narrows are not ecologically isolated from the remaining Northern Ireland population.

2.4.5.1 2009 analysis – 2006 (baseline) and 2008 (during installation and early operation) tag deployments

The presence of seals was modelled within a 300m buffer zone in either side of the turbine across the Narrows. There was strong evidence for a reduction in the buffer zone usage between 2006 and 2008. The seals were more likely to spend time within the buffer zone at night and earlier in the season (April - May). There was no overall change in how far animals travelled to forage, but there was a significant reduction in trip duration between 2006 and 2008.

Scaling individual movement by haulout counts to get relative population movement demonstrated that usage was concentrated in the Narrows and South of the Lough. There was no evidence for a change in overall usage patterns between 2006 and 2008. High variability in movements between individuals reduced our ability to detect change.

2.4.5.2 2010 analysis – 2006, 2008 and 2010 (full scale operation) tag deployments

Transit rates were highly variable between individuals. There was no significant difference in overall mean daily transit rate between the years but transit rates were highly variable between individuals. The differences in the behaviour of the individual seals also led to broad confidence intervals around the estimated transit rates for when the turbine was on and off in 2010. There was therefore no significant difference in transit rates over all seals when the turbine was on relative to when it was off in 2010.

In 2010, calculating the ratio of the transit rates for each seal when the turbine was operating to transit rates when it was not operating (corrected for tidal state), gave a mean ratio of 0.8, indicating on average 20% fewer transits when the turbine was on relative to when it was off. This mean had a 95% confidence interval of 0.51-0.90. This confidence interval does not include 1, suggesting that this reduction was significant.

Visual inspection of the distributions of transit locations suggested that transit locations differed between years. In 2006 the majority of the transits occurred in the middle of the channel, in 2008, the peak in locations occurred on the east side of the channel whereas in 2010 there was a distinct bimodal distribution showing two peaks in transits occurring at approximately 250m either side of the turbine location. However, there was considerable variation between the individuals within each year, and the grouped test shows no significant difference between 2006 and 2010 ($p>0.1$). This is effectively a result of the limited data available. There were only eight animals in each year that provide sufficient data on which to carry out the statistical tests, and this effectively means the comparisons were between sets of eight disparate data points.

2.4.5.3 Conclusions

The environmental monitoring of SeaGen has produced a telemetry dataset with precision and intensity of observation that is unrivalled in any other study of seal behaviour worldwide and has answered a number of fundamental questions about the effects of SeaGen on the harbour seals in the vicinity. Harbour seals travelled through the Narrows, and frequently transited past the line of the turbine site. Several haulout sites occurred in the Narrows and seals were still using them even after turbine installation and the start of operation. Some of the transits were movements between the Inner Lough and the Irish Sea whilst others represented local movements within the Narrows. The rate of transits varied greatly between animals. This individual variation lessens our power to detect statistically significant changes in the true transit rate of the local population. This means that there is the possibility of making a type II error here and falsely rejecting the null hypothesis of no change in transit rate. Nevertheless, there was clear evidence that the presence of an operating tidal turbine was not acting as a barrier to seals transiting the Narrows and moving in and out of the Strangford Lough SAC.

Despite a high degree of individual variability in seal behaviour, there appears to be some degree of local avoidance of the turbine – the spatial distribution of the transit locations changed visibly between 2006, 2008 and 2010. A different sample of animals was tagged in each year, therefore individual responses to the installation of the turbine could not be tracked and the assumption is that a representative sample of animals was tagged in each year. In 2010 when the turbine was fully operational, relatively few transits of the tagged seals occurred close to the turbine, and the distribution of transits suggest that a degree of avoidance was evident up to a distance of approximately 250m either side of the turbine. This pattern of avoidance was similar regardless of whether the turbine was operating or not operating, suggesting that it was not a direct result of noise produced by the operating turbine, nor necessarily related to moving turbine rotors. It may be simply due to the presence of the structure, or a learned “habit” of avoidance.

The seals which regularly transit the Narrows appeared to transit less frequently when the turbine was operating relative to when it was not operating. However, assessing the biological significance of this possible effect is difficult. Combining data from all three years showed that seals transited at a relatively higher rate during periods of slack tide. This may have implications for the level of collision risk if seals preferentially transit during periods when the turbine will not be operating.

Table 2.5: Marine mammal EMP questions answered by telemetry data

Key Question	Phase	Answer	Statistical Significant change from baseline detected with current data?	Data confidence
Does SeaGen present a biologically significant barrier effect to the free passage of seals through the Strangford Narrows?	Installation	No	No	Medium
	Commissioning	No	No	Medium
	Operation	No	No	Medium
Does SeaGen operation have a	Installation	No	No	Medium

Key Question	Phase	Answer	Statistical Significant change from baseline detected with current data?	Data confidence
biologically significant effect on harbour seal movements through the Narrows?				
	Commissioning	No	No	Medium
	Operation	No[5]	No[6]	Medium

2.4.6 Active sonar

Data source:

- Monthly active sonar field reports by SMRU Ltd
- SMRU Ltd (2011, unpublished). Using active sonar to detect and measure fine-scale behaviour of marine mammals around SeaGen.
- SMRU Ltd (2009, unpublished). Preliminary report on fine-scale behaviour of marine mammals around SeaGen using active sonar
- SMRU Ltd (2010, unpublished). Summary report on the variation in sonar target detections between night and day.

2.4.6.1 Ability of active sonar to detect marine mammals in vicinity of the turbine

During an initial period where active sonar observations and visual observations were carried out concurrently, the ability of the sonar to detect marine mammals was evaluated. A total of 72 marine mammals were visually sighted within the sub areas closest to the turbine. This compares to a total of 159 moving targets that were detected using the active sonar. Comparison of the sonar targets to the spatial and temporal information on sightings made by the visual observer information suggested that a number of the detected sonar targets (22 targets; 16% of all sonar targets) were marine mammals. This included harbour seals, harbour porpoises, and grey seals.

Within those areas where marine mammals would be expected to come within relatively close proximity of the turbine (up to 100m directly upstream), the percentage of visual sightings that were also detected with the sonar was 46.7%. The distances that marine mammals were first detected on the sonar ranged between 17 and 67m (median = 32.7m).

These data suggest that a number of marine mammals sighted at the surface, were not detected by the sonar (just over half). Only a small proportion (16%) of the sonar targets detected were confirmed as marine mammals by the visual observer.

A proportion of animals seen at the surface by the visual observer may not be detected by the sonar due to acoustic clutter and scattering making objects at the surface hard to detect. Similarly a number of moving targets detected on the sonar screen likely to be

[5] Some individual seals show a small decrease in transit rate during SeaGen operation. The biological significance of this can not be determined at this time.
[6] No significant change in harbour seal transit rates from baseline.

non-marine mammal targets (e.g. diving birds, debris, weed etc.) so it is unsurprising that not all targets detected were confirmed as being marine mammals. Also some marine mammal targets detected by the sonar may have continued to be under water until out of sight of the observer and therefore undetected at the surface visually. Despite these, it is possible that the sonar did not detect 100% of marine mammals within close proximity of the turbine. Detection ranges were within the limits of turbine shutdown.

2.4.6.2 Precautionary shutdowns

Between July 2008, when SeaGen was first commissioned, and July 2011, a total of 1948 targets were detected by the active sonar during operation. These resulted in a total of 342 precautionary shutdowns during this same time.

The rate of shutdowns varied throughout the year, being highest around July and August, coinciding with peaks in seal abundance during breeding and moult seasons. Average shutdown rates ranged from around three per 24 hours of operation at the highest point in the year to less than one per 24hr in some months, some months had no shut downs at all. Generally shutdowns were more frequent on the ebb tide than the flood tide which was in contrast to the shore based visual sightings data which demonstrated higher sightings rates during the flood tide.

2.4.6.3 Target tracking

Initial results (SMRU Ltd 2009) on a small sample of sonar target tracks suggested that confirmed marine mammal targets may be able to be distinguished from non-marine mammal targets by the target track characteristics – confirmed marine mammal tracks were significantly faster and more direct than non-marine mammal tracks. However, a more recent analysis incorporating a larger dataset (SMRU Ltd 2011) demonstrated much less obvious differences between marine mammal and other types of targets, suggesting that the ability to distinguish targets based on characteristics is not as straightforward as previously thought. The low resolution of the sonar system is likely to contribute to this problem – the swathe refreshed the screen every six seconds and some resolution of fine scale movement was lost as a result. There was clearly some error in track characterisation as a small proportion of tracks had implausible travel speeds after correcting for current speed (up to 8 $m.s^{-1}$,which is much higher than the maximum swim speeds of seals or harbour porpoise). This suggests that there was a degree of misinterpretation in the identification of subsequent targets as being part of the same track by the sonar operators.

Analysis of sonar data did not demonstrate any differences in track characteristics in relation to turbine operation which could be confidently attributed to any degree of behavioural response by animals around operating turbines. However, such an analysis was clearly confounded by the limited ability for reliably distinguishing marine mammal targets from other types, as well as the ongoing requirement for precautionary shutdown.

2.4.6.4 Night time sonar operation

An analysis of sonar operation at night found that relatively fewer targets were detected on the sonar at night in contrast to telemetry data which suggested that seals were more likely to be in the water at night compared to day and that proportion of time spent in a buffer zone around SeaGen is higher at night than during the day. However, it is important to note that only a proportion of the targets detected on the sonar will be marine mammals and patterns in seal behaviour may be masked by differences in occurrence or behaviour of other targets (e.g. diving birds).

However, there was no difference in the detectability of targets different between day and night so the sonar remains effective mitigation equally between night and day.

2.4.6.5 Conclusions

There is no doubt that the active sonar detected marine mammals underwater in proximity of the turbine and provided an effective monitoring solution for the current shut down mitigation requirement. The sonar had limited use as a behavioural monitoring tool for tracking individual animal movements around the turbine. Low resolution and a slow update rate limited the tracking and identification abilities required for such an application. SMRU Ltd has been trialling a new multibeam sonar on SeaGen (as part of an ongoing DECC funded project, separate from the SeaGen EMP) and results have been encouraging in terms of marine mammal tracking and identification ability. The sonar manufacturer Tritech has also been developing automatic identification and tracking software for this application. Results of these trials are currently being written up in a report to DECC and should be available in Spring 2012.

Table 2.6: Marine mammal EMP questions answered by active sonar

Key Question	Phase	Answer	Statistical Significant change from non-operational periods detected with current data?	Data confidence
Can the active sonar system detect marine mammals within 50m of the turbine?	Installation	NA	NA	NA
	Commissioning	Yes	NA	High
	Operation	Yes	NA	High
Can the turbine stop before the travel path of a detected marine mammal brings it into a zone of possible injury?	Installation	NA	NA	NA
	Commissioning	Yes	NA	High

Key Question	Phase	Answer	Statistical Significant change from non-operational periods detected with current data?	Data confidence
	Operation	Yes[7]	NA	High

2.4.7 Noise

Data source:
- Nedwell J R and Brooker A G (2008). Measurement and assessment of background underwater noise and its comparison with noise from pin pile drilling operations during installation of the SeaGen tidal turbine device, Strangford Lough. *Subacoustech Report No. 724R0120 to COWRIE Ltd.* ISBN: 978-0-9557501-9-9.
- Kongsberg (2010, unpublished). Operational Underwater Noise, SeaGen Unit. *For Marine Current Turbines Ltd*
- SMRU Ltd (2011, unpublished). The impact of SeaGen operational noise on marine mammals and fish at Strangford Lough, Northern Ireland

2.4.7.1 During construction

The measurements at a range of 28 m from the drilling operation indicate mean Sound Pressure Levels of 136 dB re. 1 µPa. The data indicate that the noise decreases with range from the drilling to mean Sound Pressure Levels of 110 dB re. 1 µPa. at a range of 2130 m.
The data indicates that at ranges between 28 m and 2130 m, the dB_{ht} levels for the seal vary from 59 to 30 dB_{ht}. At ranges of approximately 300 m from the drilling operation, the perceived level falls below the minimum background levels. At ranges greater than 300 m, therefore the overall perceived levels of noise are dominated by background noise.

2.4.7.2 During operation of SeaGen

The evaluation of the risk of physical injury occurring in marine mammals showed that short-term exposure to SeaGen noise is very unlikely to cause non-auditory tissue damage. It was predicted that temporary damage to the auditory system of seals could occur if animals remain within 85, 372, or 720m of SeaGen for periods of 1, 8, or 24 hours respectively. For porpoises, temporary damage was predicted at ranges of 4, 14,

[7] During remote operation of the active sonar the turbine can be stopped rapidly by the Active Sonar Operator (ASO) in approximately 3 seconds.

or 27m for the same periods. It is unlikely that seals and porpoises will maintain such close positions for such extended periods.

It was predicted that permanent damage to the auditory system of seals could occur if animals remain within 14 and 27m of SeaGen for periods of 8 and 24 hours respectively. For porpoises, only temporary damage was predicted at ranges of 2 and 4m for the same periods. Residence times of these durations in such proximity are highly unlikely.

A more precautionary approach to assessing permanent hearing damage was also carried out using recent data for porpoises. This predicted ranges of 72, 317, and 617m for periods of 1, 8, and 24 hours respectively. However, the experimental study that was used to predict these impact zones was based on test signals (brief pulses) that are much more likely to cause hearing damage than the SeaGen noise. Furthermore such residence times at the stated proximity are highly unlikely.

Throughout normal SeaGen operation, SeaGen is likely to be audible to marine mammals up to about 1.4km.

There is potential for SeaGen noise to mask seal underwater communication calls; although lack of information on the source level of calls makes it difficult to predict the extent of this effect, using source levels of calls produced by the closely related harp seal, it was predicted that masking of harbour seal breeding calls and grey seal underwater communication calls could occur up to at least 900m - 1.5km.

Two models were developed to evaluate the potential behavioural effects of the different components of the noise (tonal peaks and broadband) on marine mammals. It was predicted that noise from SeaGen has the potential to elicit behavioural avoidance responses in porpoise and both seal species. The initial model suggested that behavioural responses could be predicted from the frequency band containing the tonal peaks up to 77m from SeaGen for porpoise and up to 150m for seals. The second model based on broadband noise levels predicted much larger behavioural response zones; porpoises and seals were predicted to show behavioural responses during peak tidal flow (highest ambient noise and highest levels of operational noise) at approximately 1.0 km and 610m from SeaGen respectively. Without detailed data describing how both ambient noise levels and SeaGen noise vary over the tidal cycle it is difficult to conclude what these distances might be at other states of the tide.

2.4.7.3 Conclusions

Construction noise

Drilling noise during the installation of SeaGen was unlikely to have resulted in any disturbance to marine mammals given the very short ranges of predicted audibility and predicted behavioural response.

Operational noise

Instantaneous levels of noise from an operating SeaGen are below levels expected to cause auditory injury. When considering cumulative noise exposure, the zones predicted for potential auditory injury are small and residence times within these would need to be high for any marine mammals to be at risk from injury. Data from the land based observations, the seal telemetry study and the acoustic monitoring of harbour porpoises suggest that neither seals nor porpoises are remaining close enough to SeaGen for the length of time required to receive a noise dose high enough to cause any damage.

SeaGen noise was above thresholds predicted to elicit behavioural responses in seals and porpoises up to several hundred metres from the turbine. However, the predictions of behavioural response must be viewed in the context of the observed behaviour of marine mammals around the turbine. Land-based observations, telemetry derived data on seal movements and TPOD detections of harbour porpoise echolocation all indicate that seals and porpoises are regularly occurring within the distances within which they were predicted to display behavioural avoidance responses.

3 BENTHIC ECOLOGY

3.1 Introduction

This report provides a description of subtidal colonisation of the SeaGen tidal turbine following its installation in Strangford Lough in April 2008.

3.1.1 The site

SeaGen is situated within the Narrows of Strangford Lough. Strangford Lough is a Special Area of Conservation (SAC) and the subtidal reef is an Annex 1 (Habitats Directive) feature which is a primary reason for site selection.

The Joint Nature Conservation Committee (JNCC) describes tide swept bedrock and boulders within the Narrows providing an important habitat with rock surfaces primarily colonised by suspension-feeding species, including the soft coral *Alcyonium digitatum*; sponges including *Pachymatisma johnstonia*, the rock-boring *Cliona celata* and encrusting sponge *Myxilla* spp; ascidians including *Dendrodoa grossularia* and *Corella parallelogramma*; hydroids, especially *Tubularia indivisa;* and sea-anemones. Coarse sand scours rock surfaces at the sides and either end of the Narrows. Here the characteristic species is the bryozoan *Flustra foliacea*. [8]

Pre-installation benthic surveys were undertaken within the Narrows, in support of the Environmental Impact Assessment (EIA) for the SeaGen project. These surveys included diver, acoustic and drop down video surveys, to provide detailed baseline characterisation information on the seabed communities within the Narrows to allow potential impacts of SeaGen's installation and operation to be assessed.

The dominant biotope was found to be *Balanus crenatus* and *Tubularia indivisa* on extremely tide-swept circalittoral rock, CR.HCR.FaT.BalTub (Connor *et al*., 2004). This biotope was also found to represent the benthic community around where the device was later installed.

Figure 3.1 shows a biotope map established by acoustic surveys which were ground truthed using data from drop down video and diver surveys. Table 3.1 provides definitions of the biotopes identified in Figure 1. The biotopes identified are the 'best fit' under the UK wide 2004 classification (Connor *et al*., 2004), and it is common that some communities may not fit the biotope classification as well as others.

[8] http://www.jncc.gov.uk/protectedsites/sacselection/sac.asp?EUcode=UK0016618

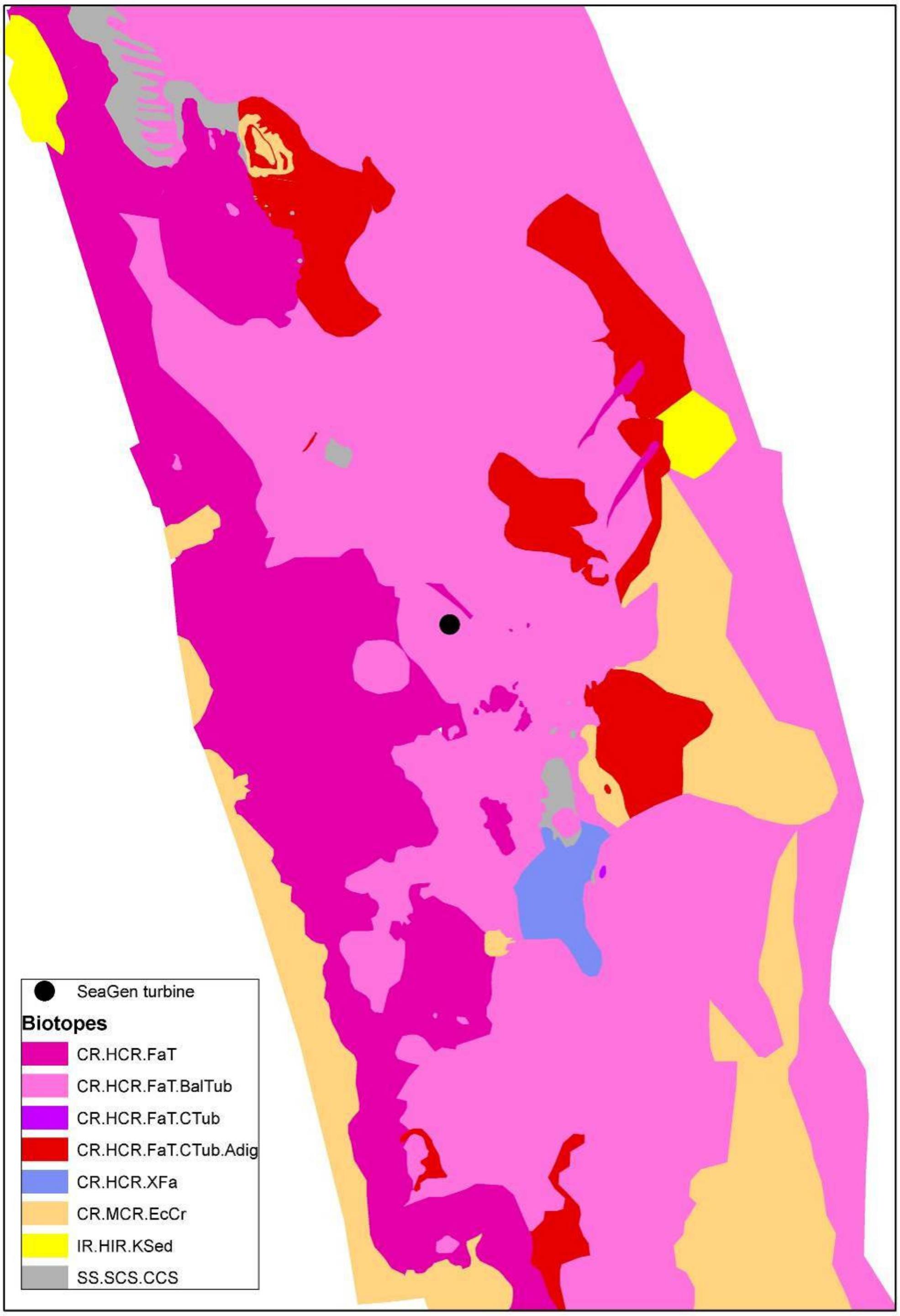

Figure 3.1: Pre-installation biotope mapping by acoustic surveys with drop video ground truthing

Table 3.1: Biotopes identified during acoustic and drop down video survey

Biotope Code	Biotope Description
CR.HCR.FaT	Very tide-swept faunal communities
CR.HCR.FaT.BalTub	*Balanus crenatus* and *Tubularia indivisa* on extremely tide-swept circalittoral rock
CR.HCR.FaT.CTub	*Tubularia indivisa* on tide-swept circalittoral rock

Biotope Code	Biotope Description
CR.HCR.FaT.CTub.Adig	*Alcyonium digitatum* with dense *Tubularia indivisa* and anemones on strongly tide-swept circalittoral rock
CR.HCR.XFa	Mixed faunal turf communities
CR.MCR.EcCr	Echinoderms and crustose communities
IR.HIR.KSed	Sediment-affected or disturbed kelp and seaweed communities
SS.SCS.CCS	Circalittoral coarse sediment

3.2 Main Findings

Some changes were observed in the benthic community as can be expected in a high energy environment such as Strangford Lough. All of the data support a conclusion that the observed changes are a result of a combination of normal seasonal variation and a natural process of species competition and succession. Changes in the vicinity of SeaGen are consistent with changes at the reference station. There appears to be no deleterious effect of the installation of the marine current turbine.

3.3 Methodology

3.3.1 Change over time – diver survey

Diver video was collected by Irish Diving and Marine Contractors Ltd.

Four relocatable sample stations were established by installing Ultra Short Baseline (USBL) transceivers. Three stations were placed in line with the rotational axis of the east turbine at 20m, 150m and 300m down/upstream to the south-east (approx.) of the turbine installation (Figure 3.2). A further single reference station was installed approximately 50m to the ENE of the turbine structure.

Water depth at the stations was 25-27m.

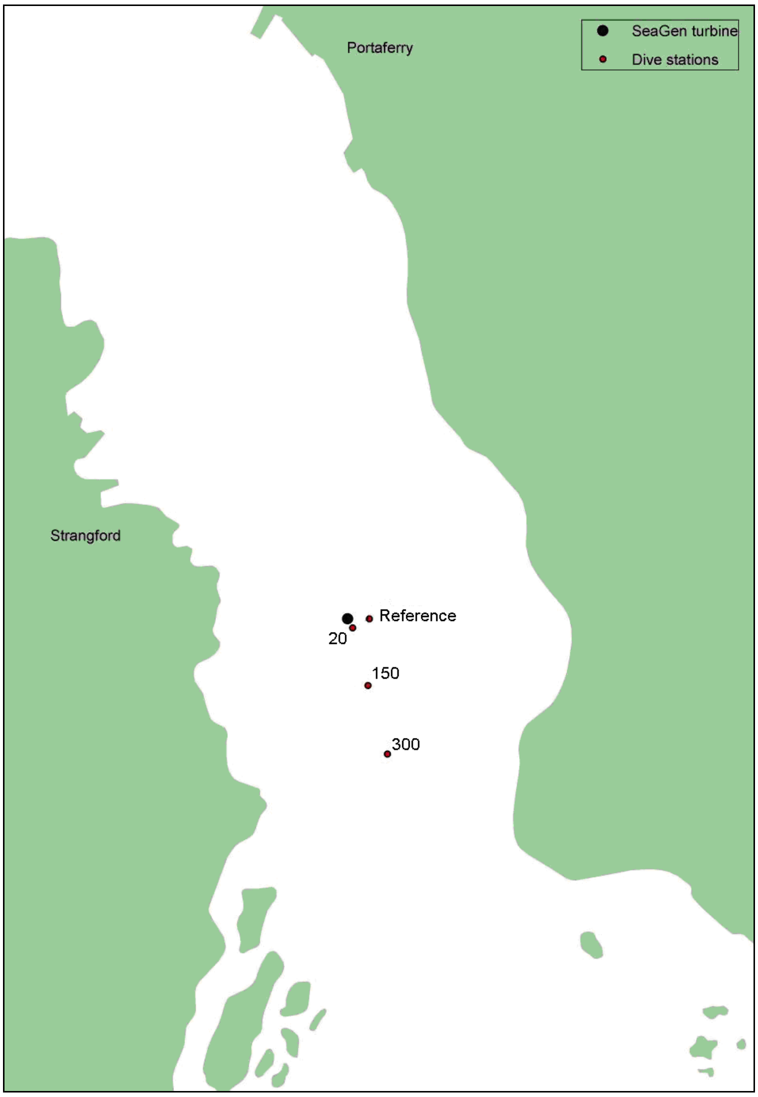

Figure 3.2: Location of the sampling stations in Strangford Narrows. MCT = marine current turbine, Ref = reference station (50m east of MCT), 150m = 150m south southeast of the MCT, 300m = 300m SSE of the SE MCT. A further station 20m SSE of the MCT is not shown.

At each of the four stations five adjacent video quadrats were sampled using a 0.5m x 0.5m quadrat, which was in turn divided into 25 10cm x 10cm cells. Each cell was filmed in close up using a digital video camera. The digital footage was burned to DVD and sent to Atlantic RMS for analysis.

The following diver surveys were completed:

- Pre-installation survey in March 2008;
- The first post installation survey in July 2008;
- The second post installation survey was carried out in March 2009;
- The third post installation survey was performed in July 2009; and
- The fourth post installation survey was carried out in April 2010

3.3.1.1 Image Analysis

Still images and video of each cell in the quadrats were assessed for percentage cover of epifauna by visual estimation. The percentage cover of each species per 0.01m2 cell in a quadrat was averaged to derive a value for the entire quadrat.

3.3.1.2 Data Analysis

The habitat at each station was classified in accordance with Connor et al. (2004). The percentage cover data was transformed to the MNCR SACFOR abundance scale. SIMPER analyses were performed to determine characterising species for each station.

The March 2008, July 2008, March 2009 and July 2009 data were combined in a single species by station matrix. Multidimensional scaling (MDS; Kruskal and Wish 1978, cited in Kennedy, 2010) was used to determine whether stations are statistically different from each other and which samples are more or less similar.

Analysis of similarities (Anosim; Clarke and Green (1993), cited in Kennedy, 2010) was also used to test for differences in similarity between predefined groups.

3.3.1.3 Colonisation study

Further to the detailed video of quadrats, general inspection footage of the turbine foundations was recorded during each survey. Diver video collected in April 2010 provides the latest view of the turbine, showing colonisation two years after installation

The video data collected does not have a scale and therefore it is not possible to do quantitative assessment of the abundance of each species recorded. However an estimated semi quantitative abundance rating has been derived, using the SACFOR[9] scale, and assigned to each species recorded, based on the approximate percentage cover of the structure shown in the diver video. The SACFOR[9] scale allows classification of each species under the following abundance categories:

- Superabundant
- Abundant
- Frequent
- Common
- Occasional
- Rare

[9] http://www.jncc.gov.uk/page-2684

3.4 Results

3.4.1 Change over time

Data source: Kennedy, Dr R. (2010, unpublished). Benthic Monitoring at Strangford Lough Narrows in relation to the installation of the SeaGen Wave Turbine: Baseline survey and first to fourth post installation surveys

The high quality of the diver-collected video data has provided a detailed record of the biological communities at each of the four re-locatable sample stations, with over 60 species identified. There is, however, a high degree of natural species dominance, by a small number of species, notably the hydroids *Sertularia cupressina*, and *Tubularia* spp. and the sponges *Halichondria* sp. and *Esperiopsis fucorum*.

The Reference and 20m stations underwent a slight increase in mixed faunal turf (mainly bryozoans) with the appearance of amphipod tubes on *Sertularia*. In the 150m and 300m stations there has been a similar increase in bryozoan cover, but with increased encrusting red algal cover. A divergence between the samples taken adjacent to SeaGen (20m) and those more distant (150m, 300m) in July 2008 reflected a temporary establishment of opportunistic species characteristic of summer events in these habitats. The changes across all stations are broadly similar in nature and the dominant species (hydroids and sponges) continued to dominate throughout the period surveyed.

In general, the benthic communities present at each sampling time and at all stations were detectably different from the communities recorded at the previous sampling times, but the changes were largely due to subtle abundance adjustment.

The community changes across all stations within the downstream influence of the SeaGen turbine are broadly similar over time and are largely mirrored in the reference station.

Sampling times have been found to be the most significant factor regarding differences in benthic communities. Changes observed represent random spatial variation that encompasses disturbance, competition and succession. In general, all of the stations sampled have shifted in community structure in a manner that matches the reference station.

The objective of this monitoring program is to detect significant change that lies outside the range of natural variability of this habitat. It is clear that the monitoring is sufficient to detect change in these communities and that the changes observed appear to be gradual and in consistent with the reference station. There therefore appears to be no deleterious effect of the installation of SeaGen. The two years of sampling in 2008 and 2009 while the current turbine was operating at a very low level has provided a very robust baseline against which to assess future change once the turbine becomes fully operational.

The latest (fourth post installation) survey was carried out in April 2010. A video quadrat survey was undertaken at four stations: a reference station 50m east of the turbine and stations 20m, 150m and 300m south southeast of the turbine along the axis of the Narrows. The epifaunal communities of Strangford Narrows where classified as the CR.HCR.FaT biotope, very tide-swept faunal communities.

The objective of this monitoring program is to detect significant change that lies outside the range of natural variability of this habitat. The monitoring is sufficient to detect change in these communities and data analyses support the view that observed change is gradual and natural. In general, the changes observed are consistent between the reference station and the impact stations. There appears to be no deleterious effect of the installation of the marine current turbine.

All of the data to date support a conclusion that the observed changes over the three sample times are relatively minor and are a result of a combination of normal seasonal variation and a natural process of species competition and succession and therefore are not predicted to be a result of SeaGen.

3.4.1.1 EMP Questions

Table 3.2 presents the findings in relation to the EMP questions relevant to the benthic ecology.

Table 3.2: Benthic EMP Questions

Key Question	Phase	Answer	Significant[10] change from baseline detected with current data?	Data confidence
Is there a biologically significant change in the benthic community structure that can be attributed to the turbine presence?	Installation	No	No	High
	Commissioning	No	No	High
	Operation	No	No	High
Is there a significant change in abundance of dominant or characterising benthic species on the seabed that can be attributed to the turbine presence?	Installation	No	No	High
	Commissioning	No	No	High
	Operation	No	No	High

[10] Significance in this case is considered to be biological significance beyond natural variation.

3.4.2 Colonisation

Data source: Video provided by Irish Diving and Marine Contractors Ltd, analysed by Royal Haskoning.

Analysis of the diver video collected on the 25th April 2010 found that the device appears to have provided two different types of circalittoral[11] 'habitat', each with an associated biota. The habitats area:

- The cylindrical structures, i.e. legs, struts and lower[12] tower (see Figure 1.2) situated in the water column; and
- The shoes (see Figure 1.2) situated on the seabed.

3.4.3 Species and biotopes on the cylindrical structures

Table 3.3 outlines the species observed during analysis of the diver footage of the cylindrical structures. The table provides the semi-quantitative SACFOR rating assigned and the common name for each species.

Table 3.3: Species present on the cylindrical structures

Species name	Common name	SACFOR
Mytilus edulis	common mussel	C
Balanus crenatus	acorn barnacle	C
Sertularia argentea	hydroid	R
Tubularia indivisa	hydroid	R
Bryozoan indet branched	bryozoan	R
Hydrozoa indet turf	hydroid	O
Indet Patellidae	limpet	R
Ophiothrix fragilis	common brittlestar	R

The cylindrical structures are colonised predominantly by the barnacle *Balanus crenatus* and mussel *Mytilus edulis*. Very dense patches of *M. edulis* were observed, which are generally surrounded by *B. crenatus.* Within the dense *M. edulis* patches a small number of *Ophiothrix fragilis* were also observed.

Some parts of the device remained bare at the time of the survey.

The UK biotope (Connor *et al* 2004[13]) which most closely represents the community which has colonised the cylindrical structures is *M. edulis* beds with hydroids and ascidians on tide-swept exposed to moderately wave-exposed circalittoral rock, CR.MCR.CMus.CMyt. However, no hydroids and ascidians were recorded and the substrate is, of course, artificial (steel) rather than rock. Coverage of this biotope on the

[11] The infralittoral and intertidal zones on the device were not recorded
[12] Video was collected to just above the cross beam.
[13] http://www.jncc.gov.uk/page-1584

lower tower, struts and legs shown by the diver footage is estimated to be approximately 50%.

Figure 3.3 shows dense patches of *M. edulis* surrounded by *B. crenatus.* Large bare patches which have not been colonised can also be seen.

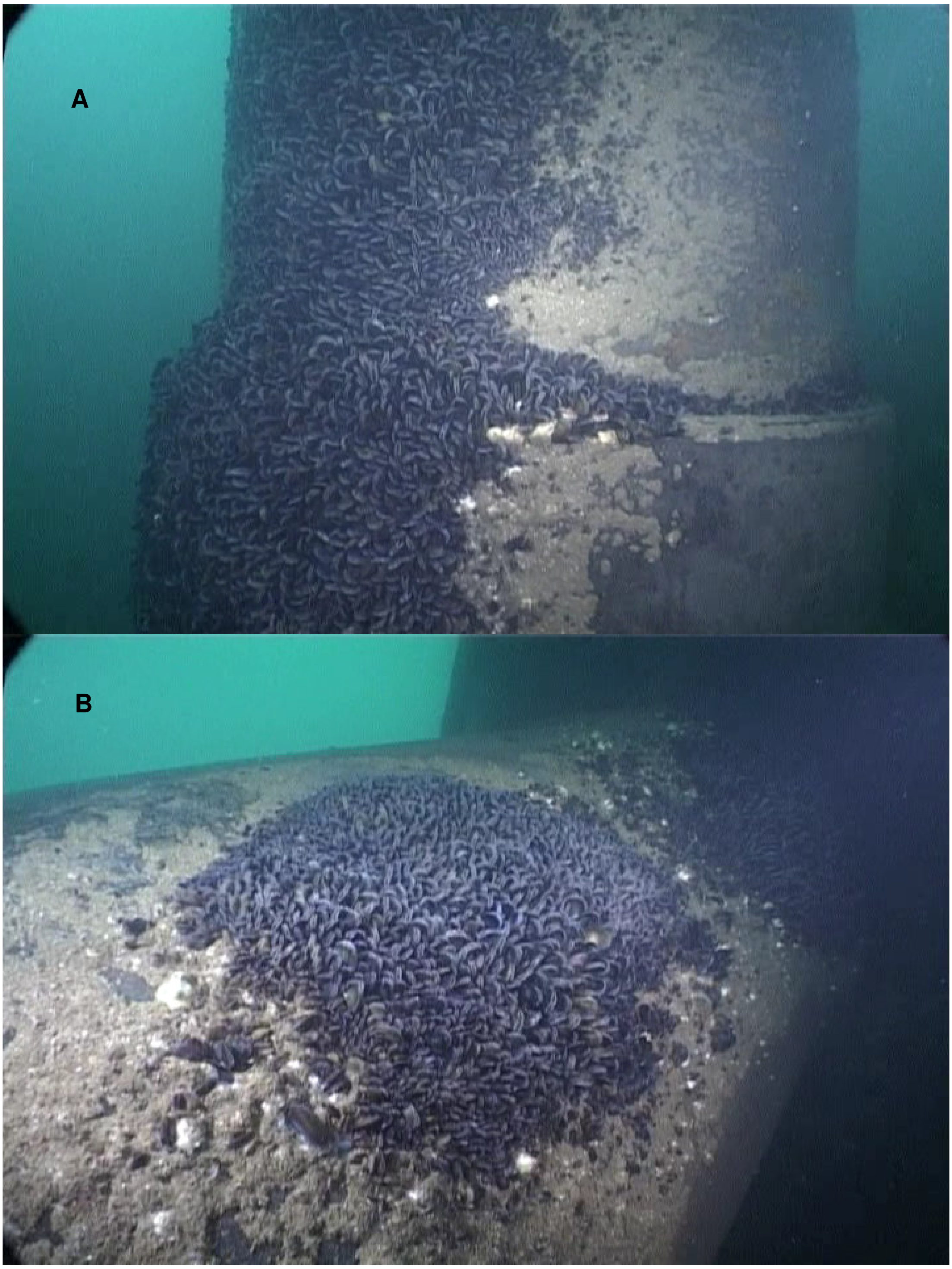

Figure 3.3: Colonisation on the cylindrical structures

3.4.3.1 Species and biotopes on the shoes

Table 3.4 outlines the species observed during analysis of the diver footage of the cylindrical structures. The table provides the approximate semi quantitative SACFOR rating and the common name for each species.

Table 3.4: Species present on the shoes

Species name	Common name	SACFOR
Balanus crenatus	acorn barnacle	F
Sertularia argentea	hydroid	R
Tubularia indivisa	hydroid	F
Hydrozoa indet turf	hydroid	A
Necora puber	velvet swimming crab	R
Cancer pagurus	edible crab	R

The shoes are colonised by *B. crenatus* and *Tubularia indivisa* along with other hydroids such as *Sertularia argentea*. These structures also attract the crabs *Necora puber* and *Cancer pagurus.*

The biotope on the shoe structures can be classified as *B. crenatus* and *T. indivisa* on extremely tide swept circalittoral rock, CR.HCR.FaT.BalTub, although the substrate is artificial rather than rock. Coverage of this biotope on the shoes, shown by the diver footage, is estimated to be approximately 30%; however, a number of the species associated with this biotope are very small and would be difficult to see and identify using the videography provided for this study. The shoes also have an inside edge which was not videoed by the divers and there is potential that the inside edge of the shoes has also been colonised by CR.HCR.FaT.BalTub. However, given the likelihood of different environmental conditions, e.g. current speed, in comparison with the outside edge this can not be assumed.

Figure 3.4 shows colonisation on the shoes of the SeaGen quadropod. Figure 3.5A shows *B. crenatus, T. indivisa* and *N. puber*. Figure 3.5B shows *B. crenatus* and *C. pagurus*.

Figure 3.4: Colonisation on the shoes

3.5 Conclusions

3.5.1 Change over time

The objective of the EMP is to detect significant change that lies outside the range of natural variability of this habitat. The data collection and analysis are robust in determining that the changes observed appear to be gradual and in general, consistent between the reference station and the impact stations. There appears to be no deleterious effect of the installation of the marine current turbine.

The environment is subject to high levels of physical disturbance due to the very fast tidal currents and as such a high level of natural variation can be expected of the benthic community. Boulders may be moved by the strong currents which will disturb patches of the benthos, keeping the communities of the Narrows boulder field in a constant state of succession.

The epifaunal communities of the tide swept boulders of the Strangford Narrows are highly diverse. They correspond well to the level 4 EUNIS biotopes encompassed by CR.HCR.FaT Very tide-swept faunal communities. They do not correspond well to the associated level 5 biotopes and the combination of *Sertularia argentea* and *Tubularia indivisa* may make these communities a unique biotope.

3.5.2 Colonisation

The pre-installation acoustic surveys, with ground truthing, provided a biotope map as shown in Figure 3.1. The estimated area of each biotope within the Narrows prior to installation of the SeaGen device is shown in Table 3.5. CR.HCR.FaT.BalTub was the dominant biotope in the Narrows in 2006 and was also the biotope recorded within the footprint of SeaGen, pre-installation.

Table 3.5: Pre-installation biotope surface areas within the Narrows

Biotope	Surface area (m2)
CR.HCR.FaT	130113.62
CR.HCR.FaT.BalTub	372817.47
CR.HCR.FaT.CTub	53.1909
CR.HCR.FaT.CTub.Adig	43837.35
CR.HCR.XFa	6065.7
CR.MCR.EcCr	86655.05
IR.HIR.KSed	7866.96
SS.SCS.CCS	9140.42

The footprint of the quadropile structure is 3.1m^2, however the four pins were drilled at a diameter of 1.7m, giving a total installation footprint of 36.3m^2. This habitat take represents 0.0097% of the estimated CR.HCR.FaT.BalTub within Strangford Narrows prior to installation. The three dimensional nature of the four shoe structures which have become colonised by the biotope CR.HCR.FaT.BalTub provides a surface area of 75.2m^2. Analysis of the video collected in April 2010 showed that approximately 50% of this surface area had been colonised giving a replacement of 37.6m^2, compared to the 36.3m^2 removed during installation. This calculation only considers the surface area of the outer edge of the shoe structures, which is visible on the diver video and it is important to note that there is likely to be some further colonisation on the inside edge of these structures, however as previously discussed this can not be, and has not been, assumed.

In addition the mussel biotope, CR.MCR.CMus.CMyt, was not recorded in the Narrows during previous surveys. The CR.MCR.CMus.CMyt biotope, including the mussel eggs is believed to provide a food source for some fish species, echinoderms and crustaceans (Kautsky, 1981, cited on the MarLIN website[14]) and its addition to the Narrows is considered to be positive.

The parts of the SeaGen device which most closely represent a seabed type habitat, i.e. the shoe structures, have become colonised by the biotope CR.HCR.FaT.BalTub, which was found to be dominant prior to installation of SeaGen.

Further monitoring will be undertaken during decommissioning, to determine the impact of decommissioning work on the benthic community. Given the level of colonisation of the device within 2 years of installation it is anticipated that after decommissioning the benthic community will recover rapidly to a state similar to baseline condition.

[14] http://www.marlin.ac.uk/habitatecology.php?habitatid=208&code=2004

4 TIDAL FLOW REGIME

4.1 Introduction

The SeaGen Environmental Monitoring Programme (EMP) includes a requirement to evaluate the impact of the turbine on the water flow regime within the Narrows of Strangford Lough. Queen's University Belfast (QUB) was contracted to undertake this work between 2007 and 2011. This section of the Final EMP report provides a summary of the methodology and results of the Acoustic Doppler Current Profiling (ADCP) survey.

The SeaGen turbine is a single, isolated machine, operating in a large area of tidal flow. It was expected that the downstream velocity field would recover very rapidly, and any adverse flow disturbance introduced by the turbine would therefore have a minimal footprint. The intention of the ADCP study was to confirm this and quantify the extent of the disturbance.

The key receptors identified as being potentially sensitive to disturbance caused by the operating machine are:

Seabed ecosystem
A change in the rate of flow may potentially have an adverse effect. A faster flow may affect feeding patterns, while a slower flow may lead to sediments coming out of suspension and smothering the seabed ecosystem. The monitoring of changes to the benthic community was included in the EMP and the results of this are presented in the benthic section of the final EMP report.

Commercial vessels, ferries and recreational users
A change in the rate of flow, particularly if occurring at the surface, may have safety implications for vessels.

The potential impacts upon these receptors identified and subsequently investigated by the monitoring programme were:

- The impact of turbine operation on velocity at or near the seabed;
- The impact of turbine operation on velocity at or near the surface;
- The effect of the turbine downstream of the turbine; and
- Identify any large scale variations (far-field flow regime) in water flow patterns.

4.2 Main Findings

The data showed no evidence of significant deviation of the ambient velocity or flow direction within the Lough, subsequent to the installation of the turbine.

The absence of increased velocity or turbulence 2.5 m below the water surface and close to the seabed, correlates with the benthic survey findings, where any changes in benthic community were in line with natural variation.

4.3 Methodology

4.3.1 Field survey

The field monitoring programme was conducted from April 2004 to June 2011. A vessel mounted with an ADCP and ancillary equipment was used to perform the surveys.

The study was conducted in two phases: the pre-deployment phase (prior to SeaGen installation) and post-deployment phase (following the SeaGen installation), which produced two datasets. This allowed any change in the state of water flow to be detected. During the post-deployment phase, suitable tides (weather window permitting and conditional on turbine operational status) were selected for the surveys to closely match the tidal heights as surveyed during the pre-deployment phase.

The study included periods of the two extreme tidal states (neap and spring) and consider both ebb and flood tidal movements. These were considered to give a reasonable overview of the data extremes and a conservative illustration of the wake effects, as generally, greatest wake generation occurs naturally at periods of highest flow. Corresponding tidal times (relative to high water) of the pre-deployment and post-deployment phases were compared where possible.

For each phase the water velocity and direction over the full water column at pre-determined locations and at pre-determined intervals, was recorded. This was conducted through a far field survey (measurement of wake in the wider Narrows survey area, see Figure 4.1) and a near field survey (measurement of flow which is still connected to the device, in the immediate vicinity, up to around 30m).

Far-field survey: 10 transects (denoted as one full survey area traverse) across the Lough at 200m spacing (approximately equidistant and centred about the turbine). These began at the most south-westerly point opposite Isle O'Valla. The traverses were repeated at hourly intervals over a full 13 hour tidal cycle for neap, mid and spring tides (see Figure 4.1). Each survey run up the Lough took approximately 1 hour including transit time required to return to the starting position This transect pattern was selected to coincide with the naturally occurring "control zone" within the Lough just south of Rue Point to just north of Church Point, a survey area of approximately 2000m x 600m.

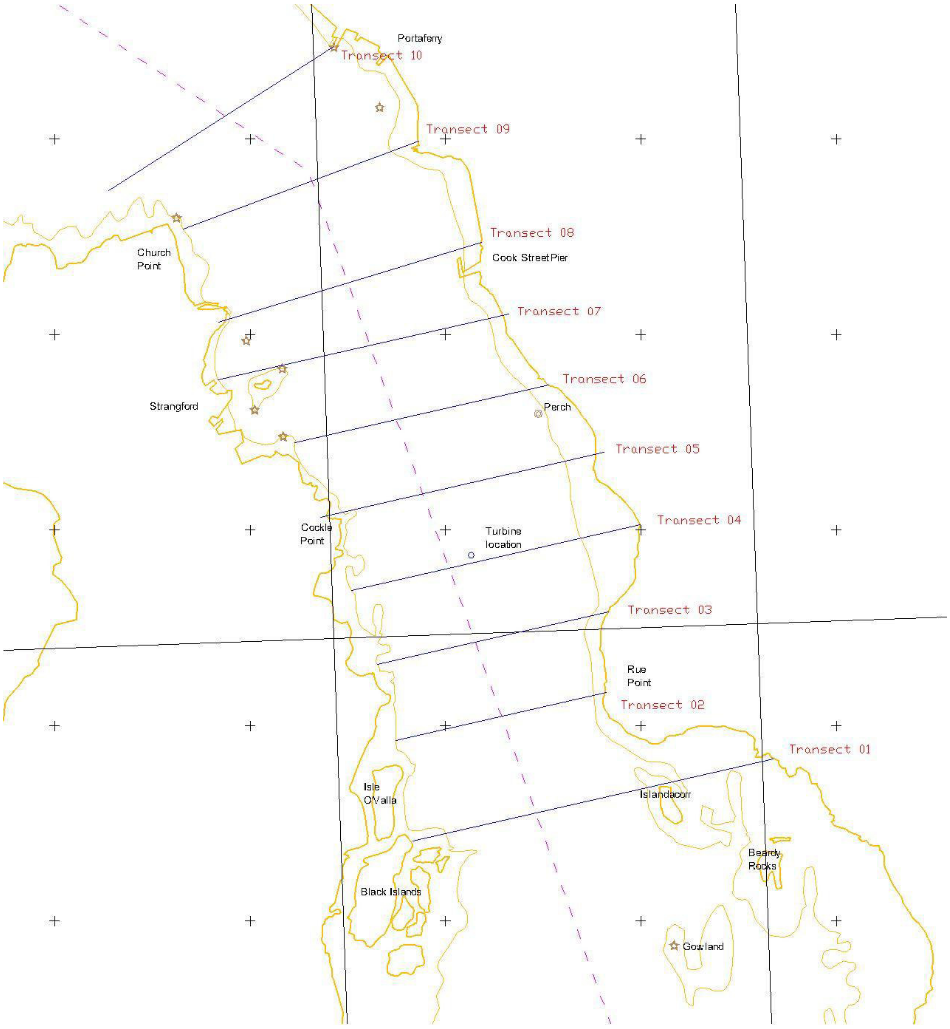

Figure 4.1: Far-field Vessel Transects within Strangford Lough

Near-field survey: 6 transects across the Lough at 100m spacing and hourly intervals over a full 13 hour tidal cycle for neap and tides.

During periods when the turbine was not operational on the day of survey it was possible to collect data in relation to the effect of the physical presence of the device without the effects of the moving rotors upon wake generation.

Key parameters measured during the surveys were:

- Bottom tracking reference;
- Earth velocity magnitude;
- Earth velocity direction;
- Earth up velocity;
- Average backscatter; and
- Correlation.

Survey constraints:
The surveys were subject to the following constraints:

- Suitable weather windows;
- Vessel or surveyor availability; and

- Turbine operational status (the post-deployment phase required a fully operational turbine over a full 13 hour cycle).

All data sets were downloaded from the data acquisition computer to a secure file server at QUB for backup and subsequent data analysis processing.

4.3.2 Data analysis

The following software was used to analyse the ADCP data:
- TRDI WinRiver data acquisition software;
- WinRiver;
- Seazone Geotemporal Editor; and
- Custom Matlab Software.

4.4 Results

Data source:
QUB (2011, unpublished) SeaGen Wake Survey, ADCP Current Monitoring Campaign.

4.4.1 Ambient velocity

The ambient velocity field beyond the near-field wake does not deviate noticeably when comparing the pre-deployment and post-deployment data sets (Table 4.1).

The largest deviation in average velocity occurs for the ebb neap tide data set with an increase of average velocity of 16.2% (Table 4.1). This difference could possibly be attributed to the limitations of the survey (being impossible to collect all measurements at the exact same state of tide) or some other external factor such as a storm surge.

The average current direction varied by a maximum of 3.8% between all pre-deployment and post-deployment data sets (Table 4.1). This was considered to be within the bounds of experimental accuracy.

The data shows that, with regards to the average ambient velocity of the flow within the Lough survey area there is no evidence of any significant deviation after the turbine was installed. The results can be considered to be within the bounds of experimental uncertainty associated with the instruments and the methodology.

Table 4.1: Average current speeds and direction pre and post development (source; QUB, 2011 unpublished)

	Flood neap	Ebb neap	Flood spring	Ebb spring
Average current speed (m/s)				
Pre-deployment	1.26	1.30	1.65	1.78
Post-deployment	1.24	1.09	1.89	1.65

% change	1.587%	16.154%	14.545%	7.303%
Average direction (degrees)				
Pre-deployment	336.97	167.15	338.42	167.64
Post-deployment	338.18	160.77	339.72	161.20
% change	0.4%	3.8%	0.4%	3.8%

4.4.2 Wake extent far-field

The data from this element of the study showed that a discernible wake is only apparent a maximum of 300m downstream of the installation, which is caused largely by the tower. Beyond 300m, there is little or no evidence of wake sub-surface. No evidence was found of a downstream wake generated by the turbine rotors.

Areas of high turbulence were recorded, which are not associated with the turbine, in particular at the Routen Wheel, a well known whirlpool-type feature present in the south of the survey area.

The area between Strangford town and Portaferry does not appear to be subjected to any increase in flow turbulence generated by the installation.

4.4.3 Wake extent: near-field

Comparison of the data from the pre and post deployment data collection shows that outside the near-field zone there are few discernible differences in the ambient flow field at respective depths. Specifically, the measurements closest to the sea bed do not indicate increased velocities or turbulence. A similar conclusion is reached for the data measured 2.5m beneath the surface. These results show that the observed surface disturbance wake which has been seen from the air is not propagated into the water column.

4.4.4 EMP Questions

Table 4.2 presents the findings in relation to the EMP questions relevant to current flow dynamics.

Table 4.2: ADCP EMP Questions

Key Question	Phase	Answer	Statistical Significant change from baseline detected with current data?	Data confidence
Has the SeaGen turbine modified the flow dynamics, scour patterns or turbulence character of the Strangford Narrows in such a way to have caused a change in benthic community structure?	Installation	NA	NA	NA
	Commissioning	NA	NA	NA
	Operation	No	No	High

If changes in the flow dynamics, scour patterns or turbulence do occur, have they caused a change in benthic community structure and function?		NA	NA	NA
	Commissioning	NA	NA	NA
	Operation	No	No	High

4.5 Conclusions

In general, the current magnitudes and principal directions recorded are considered to be sufficiently representative of the flow field within Strangford Lough.

One limitation of the monitoring programme was the amount of data gathered over a large area and time period. The inherent difficulty of analysing such data sets is that there is reduced opportunity for extracting statistically based indicators of flow characteristics. This is especially true in Strangford Lough where the high current speeds and highly variable bathymetry along the Lough are highly likely to create localised flow characteristics that may mask any perceived influence of the turbine on the flow field. However, the methodology and equipment used to undertake the surveys was considered to generate results of a sufficient quality for the purpose of addressing the questions posed.

From the data from the pre and post deployment phases which were gathered, it was possible to draw the following conclusions.

The data showed no evidence of significant deviation of the ambient velocity or flow direction within the Lough, subsequent to the installation of the turbine.

The absence of increased velocity or turbulence 2.5 m below the water surface and close to the seabed, correlates with the benthic survey findings, where any changes in benthic community were in line with natural variation.

5 ORNITHOLOGY

5.1 Introduction

Strangford Lough is designated as both an SPA and a Ramsar site for a number of bird species which exploit its rich food supply and sheltered conditions.

The SeaGen Environmental Statement (ES) identified the following species that use various methods of diving to feed as being considered as the most important group of birds in relation to the sub-surface activity of tidal turbines (Royal Haskoning, June 2005):

- terns (sandwich, common and Arctic);
- gannet;
- cormorant;
- shag;
- red-breasted merganser;
- black guillemot;
- razorbill; and
- guillemot

Strangford Lough supports nationally and internationally important breeding populations of sandwich, common and arctic terns over the summer months and anecdotal evidence suggested that they are the main species feeding in the Narrows.

Terns are plunge divers, feeding on small fish such as sand eels within depths normally of 1-3m (Cramp, 1985). Observational data suggests that, when plunge diving in the Narrows, terns usually dive to a depth of between 10 and 20cm below the surface. As a result terns are highly unlikely to encounter any moving parts of the tidal turbine with the rotor tips reaching a minimum of 3 m below the surface during Lowest Astronomical Tidal (LAT).

Gannet were identified as being known to dive to up to 15m depth (Cramp, 1985) and therefore having potential to encounter the rotors of SeaGen. However the majority of gannet feeding activity was found closer to Killard Point, at the mouth of Strangford Lough. The ES identified that it is possible that they feed further up the Narrows, especially in poor weather, although it was considered unlikely that this would be in significant numbers (RSPB pers. com., cited in Royal Haskoning 2007).

Cormorant and shag were regularly seen passing through the Narrows. These species can dive to depths of between 3 and 9m (Cramp, 1985).

Given the unlikelihood of significant numbers of birds encountering moving parts of the SeaGen device birds were originally discounted from the EMP. However to address wider concerns including potential disturbance effects bird data was collected in combination with the shore based marine mammal data.

5.2 Main Findings

Statistical analysis of the bird observation data showed evidence of a possible shift in bird distribution away from the point of turbine installation, for some bird species.

However there was no evidence of any overall decrease in the abundance of each bird group within Strangford Narrows. Therefore the displacement which has detected by statistical analysis is deemed to be on a very small scale which is of no biological significance.

Tern sightings have been generally increasing within the survey region over the years of the study.

There is statistical evidence that the tern sightings are lower for days that the turbine was in operation. The majority of the operational days recorded were prior to August 2009 when the turbine was operated on site. As a result the findings could be a factor of increased human activity, including vessels to and from the device and people on the device.

5.3 Methodology

5.3.1 Data collection

A monitoring programme was devised to establish the number, distribution and activity of the relevant bird species combined with marine mammal observations.

Watches have been undertaken by the QUB since April 2005 encompassing pre-installation (baseline), construction and post-construction (including periods of operation and non-operation). In line with the FEPA license conditions shore based monitoring ceased in March 2011.

To optimise consistency in data collection, the same observer carried out the surveys between 2005 and 2010 from a single vantage point on the east coast of the Lough. Holiday cover for the observer was provided following a thorough training / calibration period.

A voice recorder was used to collect data in the field to minimise loss of observations while writing. No observations were recorded in sea state 5 or above to reduce visual error caused by poor visibility and other adverse weather conditions.

Positions of birds recorded were determined using laser range finding binoculars and bearing. The zone of interest falls between the two hatched lines in Figure 5.1 below, dependent on visibility and weather conditions.

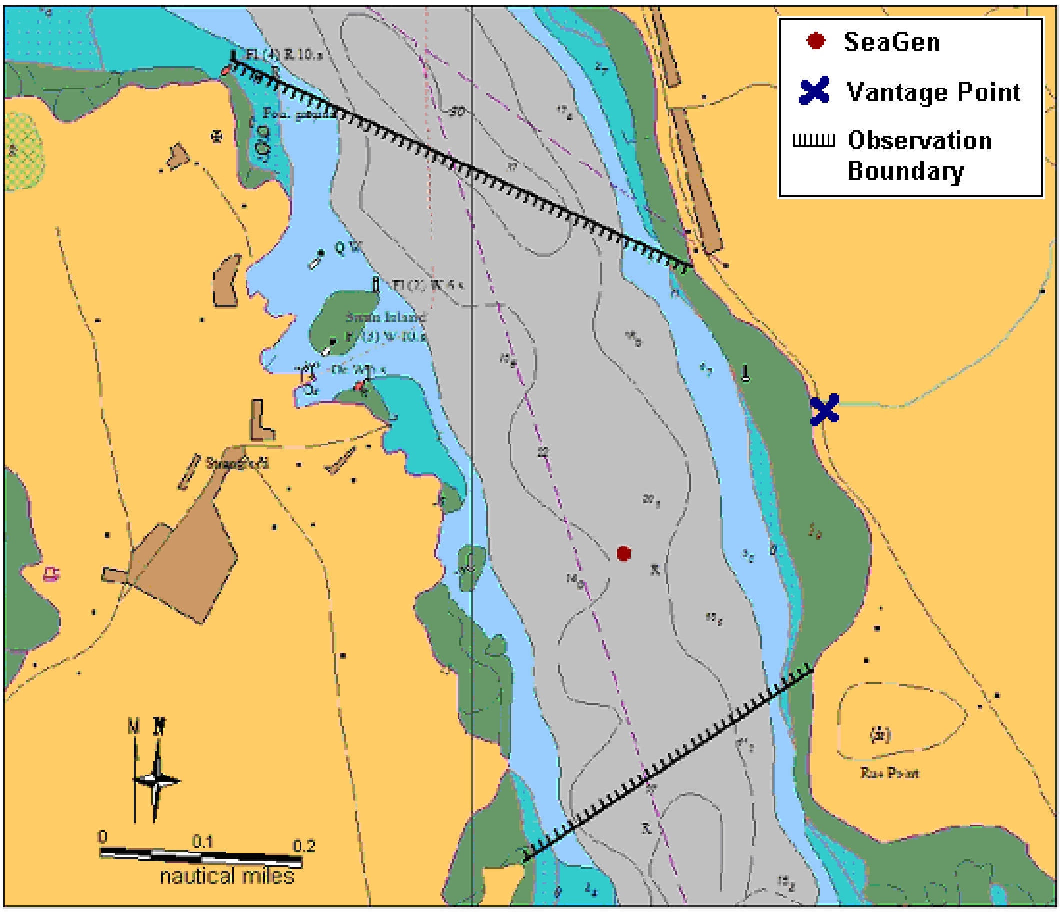

Figure 5.1: Zone of observation from vantage point

5.3.2 Data analysis

The data collected by QUB was provided in spreadsheet format to SMRU Ltd for analysis, with DMP solutions undertaking statistical analysis of the data. One set of analyses was completed exclusively for terns, and another for the remaining bird species combined. All statistical modelling and data manipulations were performed in the statistical package R (R core Development Team, 2006). The packages geepack (Højsgaard et al, 2005, cited in DMP, 2010), car (Fox, 2006, cited in DMP, 2010) and mvtnorm (Gentz & Bretz, 2007, cited in DMP, 2010) were also used for these analyses. The methodologies used were suitable for addressing nonlinear model relationships, and correlated and/or overdispersed observations across time and/or space which are key features of the Strangford data.

In addition to the SMRU Ltd analysis commissioned by MCT, QUB commissioned parallel analysis of the same data by University of Exeter. Analyses were carried out using general linear mixed effects models (GLMMs) using maximum likelihood estimation in the R statistical and computing environment.

5.4 Results

Data source:
DMP Solutions (2010, unpublished). Detecting changes in relative bird abundances using Strangford Narrows visual observations. *Prepared for SMRU Ltd, 08 October 2010*

University of Exeter (2010). The impacts of the SeaGen tidal turbine on the avian community of the Strangford Lough Narrows.

Records of position and activity of diving birds (in conjunction with marine mammal and basking shark surveys) were collected each month from May 2005, however as survey methods were still being refined in 2005, data for that year were omitted from analysis. DMP Statistical Solutions (2010) carried out analysis of the data, initially separating terns from all other birds, providing two groups of data for analysis and then carrying out further analysis on cormorants, brent geese, black guillemots and guillemots.

The main findings from the two sets of the analysis of tern data were:

- Tern sightings were highest during the flood and ebb tidal phases and lowest at high water slack. A factor of this effect may be the attraction of terns to the wake of SeaGen when the tide is moving at speed. Additional food source may be brought to the surface by the high levels of water turbulence.
- Tern sightings were lowest during SeaGen operation. However, the data analysed were collected during a period of on-site commissioning and operation of the device and therefore human activity on the pile may have contributed considerably to this disturbance.
- Tern sightings are highest during summer months with a marked decline in November. The relative tern abundances have been generally increasing throughout the survey period, with 2009 being significantly greater than preceding years.
- There is evidence that the south zone displays significantly lower tern sightings during SeaGen operation (by approximately 50%).

Whilst these findings suggest slight variations in tern abundance in relation to season, tidal state and SeaGen operation, tern abundance has increased significantly overall within the survey region throughout the course of the study.

The data for other bird species were also analysed. It is important to note that the volume of operational data available at the time of analysis was relatively low and so the confidence in the trends observed is medium (see Table 5.1).

Few records used in either analysis came from the operational phase and so potential changes might not be fully apparent. In addition the data were collected during a period of on-site commissioning and operation of the device and therefore human activity on the pile may have contributed considerably to this disturbance. The device is now being operated remotely.

The key findings for all other birds were:

- Bird sighting rates were found to be generally lower during the summer months.

- Tidal cycle was found to be a significant factor in the number of bird sightings with relatively few birds seen during the ebb tidal phase

- The numbers of birds observed during turbine operation were significantly (statistically) lower on average than numbers observed when the turbine was still. However this is not thought to be biologically significant as the numbers observed on days when the turbine was operating appeared to re-distribute across the area rather than increase or decrease overall. In addition, while there is evidence of redistribution, it is also possible that changes in relative numbers could be attributed to sampling variation alone.

- There was a decline by around 25% in the average numbers of cormorant sightings while the rotors were turning in comparison to periods of non-operation. There was also some re-distribution across the survey area for days with turbine operation.

- No significant effect related to SeaGen was detected for Brent geese; trends in relation to spatial distribution or turbine operation could not be determined due to low numbers of this species recorded.

- The evidence showed no overall average change in black guillemot observations on days during turbine operation, however there was some re-distribution across the survey area.

- No significant effect related to SeaGen was detected for guillemots; trends in relation to spatial distribution or turbine operation could not be determined due to low numbers of this species recorded.

The analysis undertaken by the University of Exeter (2010) indicates some minor statistically significant changes with regards to the distribution of certain species. However, there does not appear to be any biological significance to the changes observed.

5.4.1 EMP Questions

Table 5.1 presents the findings in relation to the EMP questions relevant to ornithology.

Table 5.1: Ornithology EMP Questions

Key Question	Phase	Answer	Statistical Significant change from baseline detected with current data?	Data confidence
Does the SeaGen turbine have a biologically significant impact on	Installation	No	No	Medium

seabird activities in the Strangford Narrows?	Commissioning/ Operation	No	Yes[15]	Medium
Does SeaGen displace foraging diving birds from important areas within Strangford Narrows?	Installation	No	No	Medium
	Commissioning/ Operation	No	Yes[15]	High

5.5 Conclusions

Statistical analysis of the bird observation data showed evidence of a possible shift in bird distribution away from the point of turbine installation, for some bird species. However there was no evidence of any overall decrease in the abundance of each bird group within Strangford Narrows. Therefore the displacement which has detected by statistical analysis is deemed to be on a very small scale which is of no biological significance.

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