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# Offshore renewable energy and nature conservation: the case of marine tidal turbines in Northern Ireland

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**Abstract** The global demand for renewable energy continues to increase rapidly and with it the necessity to develop and test new technologies to deliver the power. Offshore renewable energy sources that harness wind, wave or tidal power are of major interest. Technological advances in these directions have not been matched by a clear understanding of the environmental impacts of the new devices, with most existing research concentrated on the impacts of offshore wind farms. Decisions often continue to be made without the support of a clear evidence base. Here we use an underwater tidal turbine, SeaGen, constructed and operated within the Strangford Lough marine protected area in Northern Ireland, as a case study to explore the potential impacts of the turbine as points of concern and argumentation in the decision-making processes. We use information obtained from official documents and one-to-one interviews with the main stakeholders. Our results demonstrate that during the construction and operation of the turbine the perceptions and views of different stakeholders sometimes disagreed but were often surprisingly similar in relation to both likelihood and intensity of the potential impacts of the turbine on marine

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biodiversity, ecosystem services and human well-being in general. The overall consensus of views was refined and evolved under an adaptive management approach over the 10 years of the discussions and decision-making processes. The results are discussed in relation to cumulative gains in knowledge, future arrays of many underwater turbines and multiple use of oceans within social ecological systems to maintain the conservation of marine biodiversity.

## Introduction

The global demand for renewable energy continues to increase rapidly (most recently accelerated by the United Nations 2015 Paris Agreement to combat climate change) and with it the necessity to develop and test new technologies to deliver renewable/clean power. Offshore renewable energy sources that harness wind, wave or tidal power are of major interest. Wind farms in the sea are now commonplace in many regions, but advances in wave and tidal power technology have also been rapid during their relatively short history (Lawrence et al. 2013). The Ocean Energy status Report of the EC for 2014 cites an estimate of 100 tidal energy companies worldwide, with more than half located within the EU and other strong representation in Canada, Australia, USA and eastern Asia. Most of these deployment activities are single devices or small, pre-commercial arrays (Magagna and Uihlein 2015). Unfortunately, the technological advances have not been matched by a clear understanding of the environmental impacts of the new machinery, and this remains a major concern and focus of research (Inger et al. 2009; Bailey et al. 2014). Most existing research has concentrated on the impacts of offshore wind farms on biodiversity (e.g., Bergström et al. 2014) and/or ecosystem service provision (e.g., Mangi 2013). However, even for wind farms, our overall knowledge is still very incomplete and the urgent call for more data and new research by Inger et al. (2009) remains valid, echoed by Bailey et al. (2014).

Further complications arise from the relatively recent recognition that biodiversity conservation in Europe and also globally, is embedded within complex, dynamic social-ecological systems that encompass the provision of ecosystem services, wider societal needs and human well-being, all with the need for appropriate and integrated sectoral policy and environmental management (Haslett et al. 2010; García-Llorente et al. 2015). In the context of marine environments, offshore renewable energy has already been noted as a new human activity entering the complexity of marine social-ecological systems (Burkhard and Gee 2012). How these systems respond has now begun to be directly addressed, but again the focus has been largely on wind farms (Busch et al. 2011; Burkhard and Gee 2012; Mangi 2013).

Marine tidal turbines that use tidal currents to turn large, submerged rotors have many parallels with wind turbines; indeed they function rather like "submerged windmills", but there are also many unique aspects of this still very young family of devices that can impact upon marine biodiversity and different components of social-ecological systems. These unique aspects arise mainly from the rotor blades moving under water rather than in the air above sea level, thus impacting on different types of organisms and parts of marine

social-ecological systems. The large gaps in knowledge that exist create uncertainties in decision-making processes concerning siting, construction, operation and eventual decommissioning of the turbine devices (Inger et al. 2009). This is true even at the level of testing full size operational prototype devices, including "SeaGen", the turbine that is the subject of this study.

SeaGen is "the world's first" commercial scale open stream underwater tidal turbine, constructed and operated in the strong tidal flow at the entrance to Strangford Lough on the east coast of County Down, Northern Ireland. Strangford Lough is a shallow, tidal sea lough about 30 km long and up to approximately 8 km wide. The Lough is almost land-locked, but is connected to the open sea by a narrow 8 km long channel known as the Strangford Narrows, where the SeaGen turbine is sited. The Lough supports a recognised wealth of marine and coastal biodiversity, and the entire area has many different designations of nature conservation status, at national and EU levels. These include Special Protection Area (SPA), Special Area of Conservation (SAC), Natura 2000 site and RAMSAR status and most recently Marine Conservation Zone under the Marine Act (Northern Ireland) 2013. Also, the area is important for its landscape, recreational use, some commercial fishing and a diversity of other ecosystem services (Strangford Lough and Lecale Partnership 2014).

This marine turbine project is important for the Northern Ireland and UK Governments' requirement to achieve renewable energy targets set by the EU (Department of the Environment, Northern Ireland 2009), but at the same time, the impacts throughout all stages of the turbine development were not well understood. The dual importance of the necessity to increase renewable energy output, with the associated extra benefits of hi-tech and industrial advances, while at the same time ensuring the continued essential role of the Protected Area for marine biodiversity conservation and the provision of a wide range of ecosystem services, created a spectrum of potential conflicts of stakeholder and policy interests that was new and complex.

Decision-making processes under these potentially antagonistic circumstances were guided by the adoption of an adaptive management approach, agreed by the stakeholders during the early stages of the negotiations. In the present context, adaptive management refers to an iterative process in which uncertainty surrounding the environmental effects of a human activity is reduced progressively by carefully managed, science-led monitoring of agreed indicators of environmental impacts. From the very beginning, an adaptive approach offers a middle way, so that risks and the needs of the different interest groups are continually re-assessed in the light of new information and balanced within an agreed management framework. This is clearly explained by Savidge et al. (2014), who also provide a useful general summary of adaptive management in the environmental context, with details of how these principles have been applied to the SeaGen situation. These authors also provide a primarily biological account of the environmental monitoring studies undertaken in Strangford Lough in relation to the turbine, including information on the findings, some of the resulting adaptations and also pointing out the lessons learned.

In the present paper we address the stakeholder argumentation and decision-making aspects of the turbine development, thus complementing more biological or technical perspectives. Particularly, we explore the use of the potential impacts of the turbine as points of concern and argumentation. We examine the levels of agreement between the main stakeholders involved and then follow the temporal dynamics of the discussions as the turbine development progressed. We differentiate between the negative impacts on both biodiversity itself and on humans—including ecosystem services, as well as the positive potential benefits on each of these. We also distinguish between the likelihood and

intensity of the impacts. The information obtained should aid future argumentation and decision-making to protect biodiversity in offshore renewable energy development and also in wider social-ecological system contexts.

## Methods

Information on the turbine development and its impacts was obtained from selected official written reports and from one-to-one meetings and interviews with a variety of the central stakeholders.

### Reports examined and timeline of events

The reports examined represent important strategic events along the timeline of the discussions and decision-making surrounding the turbine development, as depicted in Fig. 1. They were chosen as significant and clearly documented markers along the entire chain of events that conveniently bring the different relevant aspects of the study together. They were:

*Event 1* an initial Independent Environmental Statement, which was an impact assessment undertaken in the period April 2004–June 2005, before any construction work was undertaken (Royal Haskoning 2005). One of the general conclusions of this report was that the potential impact of the SeaGen marine current turbine on some of the designated features was uncertain. Because of this uncertainty of impact, an adaptive management approach to construction and deployment, with integrated mitigation and monitoring was proposed by the turbine company and was accepted by the Department of Environment, Northern Ireland and became the basis for progressing the project.

*Event 2* EU Habitats Directive Article 6 Report, covering the period 15 December 2005–2 February 2008 (Department of the Environment (Northern Ireland) 2008). To enable the turbine to be constructed and allowed to operate, a government Marine Licence was required. For this, particularly in relation to modifications (variations) to the conditions of the Licence and Natura 2000 site requirements, an assessment was necessary under Article 6 of the EU Habitats Directive. A Stage One Screening Assessment was undertaken. The report was favourable to granting the Licence and indicated that a Stage two Assessment was not required.
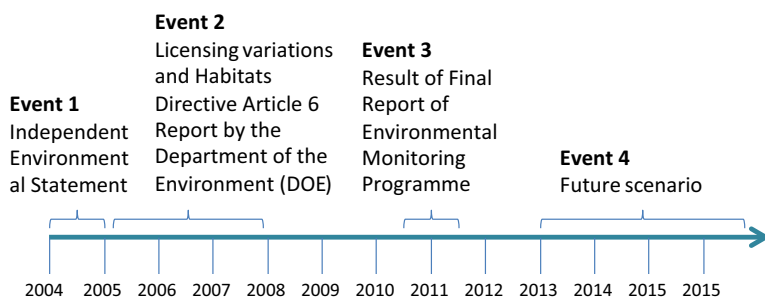


**Event 2**
Licensing variations and Habitats Directive Article 6 Report by the Department of the Environment (DOE)

**Event 1**
Independent Environmental Statement

**Event 3**
Result of Final Report of Environmental Monitoring Programme

**Event 4**
Future scenario

2004  2005  2006  2007  2008  2009  2010  2011  2012  2013  2014  2015  2015

**Fig. 1** Timeline and the four events identified

*Event 3* Environmental Monitoring Programme Final Report (Royal Haskoning 2011). As a condition of the Marine Licence and following from the 2005 Environmental Impact Assessment report, it was required that a detailed Environmental Monitoring Programme and associated suite of mitigation measures be established, covering the entire duration of the turbine development. Monitoring data collection began pre-installation in 2005 and a final report was delivered in January 2011.

*Event 4* a future scenario of multiple turbines (arrays) developed at other sites, considered during the stakeholder interviews. (See "Methods" section on data gathering from target stakeholders below).

## Target stakeholders

The central stakeholders that were consulted for the present study were identified from information gained from a number of preliminary stakeholder scoping meetings with governmental and NGO contacts, conducted in the years 2012 and 2013. These preliminary discussions revealed that over 50 interested parties, covering a wide spectrum of stakeholder types were included in the dialogue of discussion and consultation during the 10 years and more of the turbine project. However, many of the individuals only contributed for a portion of the proceedings due to changes in job situation or political changes or discontinuities, while others were not actively involved. To provide continuity within the present study and to ensure the highest possible degree of consistency over the full time period, we chose to focus on a small, central group of individuals who had been active and closely aware of all developments and discussions throughout the entire time of the turbine project. Each of the five persons consequently interviewed represents a major stakeholder group and each has been involved in the process from its beginning in 2004 to the end of the present investigation (end 2013). The stakeholders were:

(A) Government (Environment)
(B) Government (Agri-Food)
(C) Consortium of conservation NGOs in Northern Ireland
(D) Academic research
(E) Local residents and cultural heritage NGO

It may be noted that the industrial company responsible for the turbine development initiative relied upon the information provided by the other stakeholders in the decision-making processes and so was not included in the design of the present study.

## Data gathering from target stakeholders

In a first round of one-to-one discussion interviews with the above-listed key stakeholders, the interviewees were asked to comment generally on their perspective of the potential impacts of the turbine and the relative importance of these to the decision-making processes surrounding the turbine development. From these discussions, in combination with the information available in the official reports examined, a total of 21 potential negative impacts of the turbine on biodiversity, ecosystem services or directly affecting humans were clearly identified relevant to the aims of the present study. Each impact was a possible point of argument to be considered during the negotiations and their usage could be followed over the turbine development. In addition, direct questioning during the

discussions with the interviewees identified 10 possible positive impacts of the turbine. However, these did not appear in the documentation and did not form any part of the official discussions and decision-making process. All impacts identified, both negative and positive, are listed in Table 1.

A further round of interviews with the stakeholders centred on a "questionnaire" in which each of the interviewees was asked to populate a simple table reflecting their perceived importance attached to the impacts of the turbine. The table questionnaire was presented in two parts, covering first the negative impacts and then the positive impacts as listed in Table 1. Both parts had the same structure, so that for each impact listed, two aspects of importance, "likelihood to occur" and "intensity of impact" were scored using a Likert-style scale of 1–5, defined respectively as 1 = very unlikely/very weak; 2 = unlikely/weak; 3 = neutral/medium; 4 = likely/strong; 5 = very likely/very strong. This Likert scale is similar to that used by Jones and Eiser (2010) to investigate wind farm impacts. The interviewees were required to provide separately scored assessments for each of the events defined along the timeline. Note that the table consisted of only a list with parallel blank cells and did not include any statements, sentences or other text. As all of the interviewees had been actively involved with the turbine throughout its history, this provided a strong temporal continuity and provides a valuable insight into the role of cumulative gains in knowledge in the discussion process. All selected interviewees had clear recall of the sequence of events and had no difficulties in differentiating along the timeline.

In addition to the three historical events, a fourth "event" of a future scenario (2013 and beyond, see the timeline of Fig. 1) was defined for similar scoring within the questionnaire. This required the interviewed stakeholders to extend their views on the listed potential impacts of the single turbine to the consideration of future large arrays of many turbines at other coastal locations. Previous discussions with the stakeholders had revealed that such arrays were already being planned. It is most important to note that this future scenario referred only to arrays at other sites and did not include any reference to the future of the existing turbine. The interviews with the selected stakeholders were all conducted during the year 2013. The views expressed by all selected interviewees were based on their professional experience and judgements, though possible influences of personal views cannot be completely excluded.

The information obtained from the questionnaires was visualised in polar (radial) diagrams and analysed using simple descriptive statistical techniques to provide information on similarities and differences between stakeholders and also along the temporal axis. The Kappa statistic (or coefficient) was calculated as a measure of the level of agreement between different individuals, taking into account that agreement (or disagreement) can occur by chance (Viera and Garrett 2005).

# Results

## Differences and similarities in stakeholder perspectives

The likelihood and intensity of occurrence scores were averaged across the four events on the timeline and analysed separately for each stakeholder (Figs. 2, 3). The results show considerable variation in stakeholder views on both likelihood and intensity of both negative and positive impacts of the turbine.

**Table 1** Broad classification of the potential environmental impacts of the marine turbine that are considered in the case study, as identified from the reports examined and consultations with stakeholders

**Potential negative impacts on biodiversity**

Protected habitats (general)

Protected species (general)

Birds

Marine mammals

Sharks/other elasmobranchs

Teleost fish

Shellfish (molluscs, crustaceans)

Benthic communities

Plankton communities

Cabling to land—electric fields, abrasion

Noise/vibration marine animals

**Potential negative impacts on humans, including ecosystem services**

*Regulating*

Nutrient cycling/food web dynamics

Water quality (sediment, waste remediation)

*Cultural*

Nature watching

Recreational boating/fishing

Landscape/seascape quality

Boating navigation/access

*Provisioning*

Commercial fishing—teleosts

Commercial fishing (pot fishing)

*Human well-being*

Noise/vibration humans

Tidal hydrodynamics

**Potential positive impacts**

*Regulating*

New marine habitat

Improved biodiversity protection from access and fishing prevention

Water quality

Air quality (reduction in $CO_2$, etc.)

*Cultural*

New biological research initiatives

Educational value

Cultural heritage addition

Tourist attraction

*Human well-being*

Power economic value

Local employment

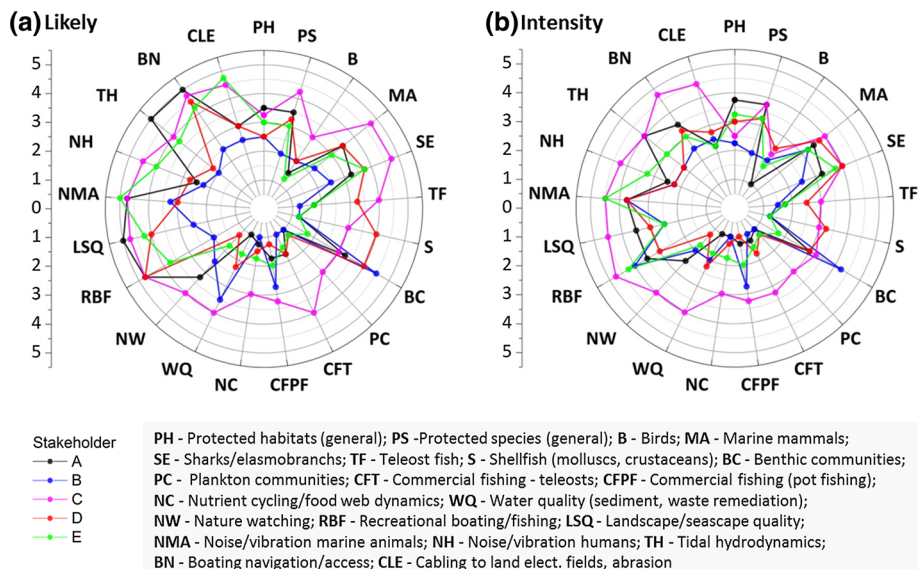Note that some of the categories can overlap

Fig. 2 Polar diagrams showing the differences between stakeholder groups of the scores for likelihood (a) and intensity (b) of occurrence of negative impacts, averaged across all four events
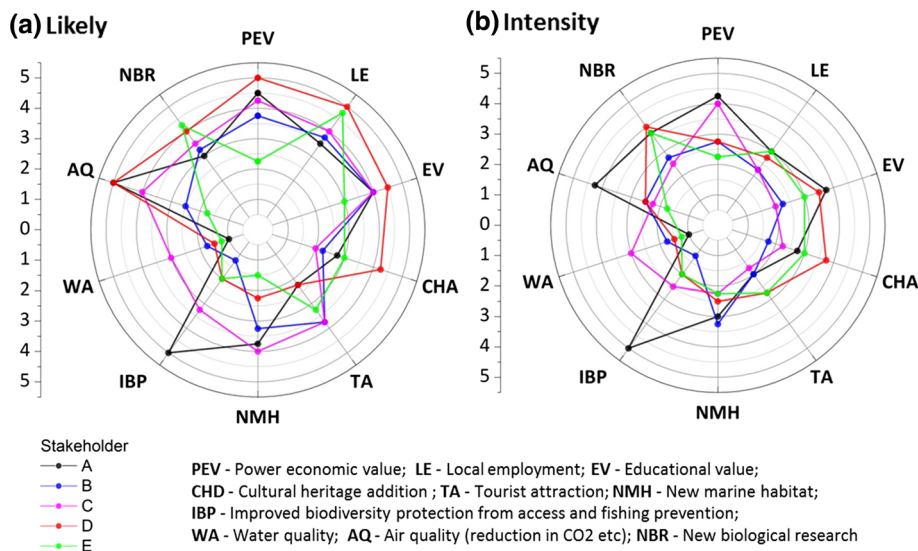


Fig. 3 Polar diagrams showing the differences between stakeholder groups of the scores for likelihood (a) and intensity (b) of occurrence of positive impacts, averaged across all four events

Particularly Stakeholder C, the conservation NGO consortium, tended to give higher ratings for likelihood and intensity of negative impacts than the other stakeholders. Ratings by this stakeholder of positive impacts were less extreme. The difference is borne out by calculation of Kappa coefficients to measure the degree of agreement of each stakeholder with the others, for all four events combined (Table 2). Again, stakeholder C is shown to

**Table 2** The degree of agreement/disagreement between stakeholders' scores of likelihood and intensity of impacts as measured by Kappa coefficients

| | Stakeholder B (Government) | Stakeholder C (NGO) | Stakeholder D (Academic research) | Stakeholder E (NGO) |
|---|---|---|---|---|
| Likelihood | | | | |
| Stakeholder A (Government) | 0.111 | **0.250** | **0.352** | **0.372** |
| Stakeholder B (Government) | | *0.038* | 0.152 | 0.114 |
| Stakeholder C (NGO) | | | 0.140 | **0.214** |
| Stakeholder D (Academic research) | | | | **0.229** |
| Intensity | | | | |
| Stakeholder A (Government) | **0.208** | **0.210** | **0.295** | **0.403** |
| Stakeholder B (Government) | | 0.145 | 0.144 | 0.198 |
| Stakeholder C (NGO) | | | *0.065* | 0.126 |
| Stakeholder D (Academic research) | | | | **0.34** |

Data from four different events were combined together. Likelihood/intensity values were categorised as: low (1); medium (2–3); high (4–5). Kappa Interpretation: <0 poor agreement; 0.0–0.20 slight agreement; 0.21–0.40 fair agreement; 0.41–0.60 moderate agreement; 0.61–0.80 substantial agreement; 0.81–1.00 almost perfect agreement. Highlighted in the table are kappa >0.2 in bold representing a certain degree of agreement and kappa <0.1 in italics representing more disagreement between stakeholders

disagree most with the other stakeholders for both the likelihood and intensity of impact occurrence. The Kappa coefficients also highlight that there are various instances of at least fair agreement between stakeholders, indicating that some general trends do occur at the level of the entire time span covered by this study.

In Figs. 2 and 3, these areas of general agreement may be seen where the coloured lines representing the different stakeholders follow similar patterns. For example, the negative impacts on sharks and other elasmobranch fish, marine mammals, birds, protected species and protected habitats are rated similarly in relative terms by the stakeholders for both likelihood and intensity, although the values assigned by each stakeholder may be different. Those impacts that were scored most highly (the "top three") by each stakeholder for likelihood and intensity of occurrence also reveal general similarities. For instance, the likelihood of negative impacts on landscape/seascape quality, boating navigation and access, and the impacts of noise/vibrations on marine animals were scored highly by 3 of the 5 stakeholders, while the intensity of the effects of noise on marine animals was also considered to be high by 3 of the stakeholders, and intensity of impact on recreational boating/fishing was scored highly by 4 of the 5 stakeholders.

Equivalent patterns can be seen for positive impacts, but these are not so clear. For example, the similarity in the patterns for cultural heritage, educational value and local employment, and the high scores given by 4 of the 5 stakeholders to the likelihood of positive impacts from power economic value and to local employment. Also, for intensity,

higher scores for the benefits through educational value and the creation of new biological research were given by 3 of the 5 stakeholders.

To examine more closely where areas of greatest and least differences of stakeholder opinion occur in relation to the different impacts considered, standard deviations of the means of "likelihood" and "intensity" values were calculated for each impact, pooled over all four events on the timeline (Fig. 4). Larger standard deviations indicate greater differences in stakeholder rating values. The ranking order for the negative impacts clearly indicates that opinions on ecosystem services and other human impacts are the most strongly divided. Conversely, the ratings given to impacts on particular aspects of



**(a) Negative impacts**
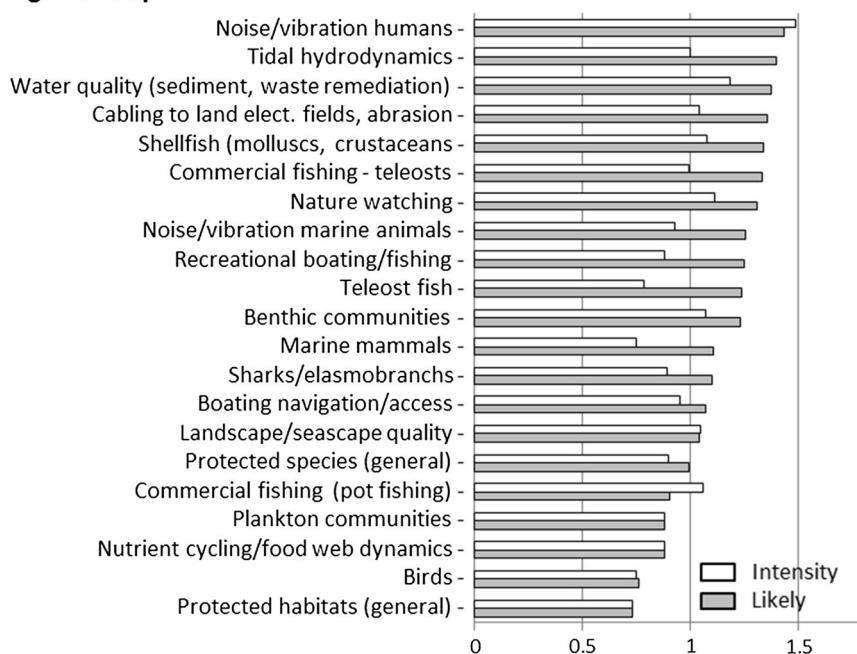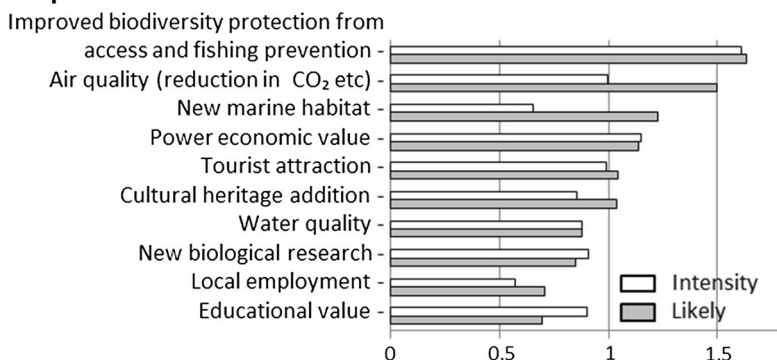
**(b) Positive impacts**

Fig. 4 Levels of disagreement between stakeholder ratings of negative (a) and positive (b) impacts using standard deviations of the means from all stakeholders over all four events and ranked by likelihood of impact (grey bars)

biodiversity and conservation issues are much more consistent between stakeholders—they share similar opinion values. For the positive impacts there is no such clear interpretation. Opinions on the turbine being a source of providing improved biodiversity protection, or benefitting air quality or creating new marine habitat are the most variable, but there is more general consensus on the other positive impacts, particularly in providing local employment and the education value.

## Temporal dynamics: constancy and change in perceived impacts along the timeline

Examination of the impacts information separately for each of the four events along the timeline, but with stakeholder views combined, identifies some general patterns in likelihood and intensity of the influences of the turbine on both biodiversity and ecosystem services/human well-being.

Amongst the negative impacts (Fig. 5), those acting on parts of biodiversity, including benthic communities, sharks, marine mammals and protected species and habitats in general, and also impacts from cabling to land and from noise/vibration effects on animals, are all classified as having medium to strong intensities, as well as being relatively likely to occur within all or most of the events. Thus these may be regarded as, in the stakeholders' combined consensus, the greatest threats to biodiversity, taken over the entire time period. This is in contrast to the negative impacts on, for example, birds, teleost fish, shellfish, plankton commercial fishing and nature watching, all of which are considered to be rather unlikely to occur, and when they do, rather weak in their intensity across most of the events. These are still considered by the stakeholders to represent potential threats to biodiversity and ecosystem services, but at lower levels. Note that there appears to be a
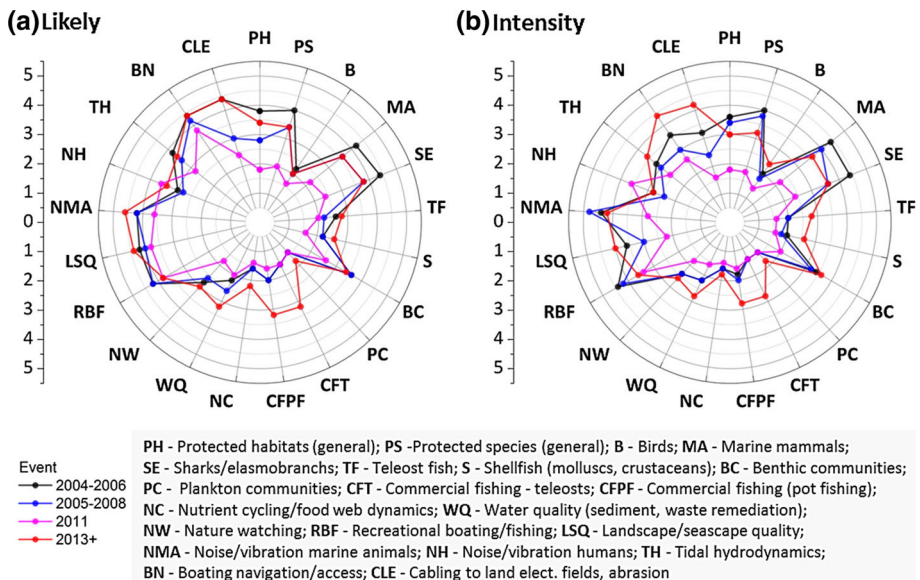


Fig. 5 Polar diagrams showing the differences between stakeholder groups of the scores for likelihood (a) and intensity (b) of occurrence of negative impacts, averaged across all stakeholders

general positive correlation between likelihood and intensity of impacts, reflected in the overall similarities of the shapes of the diagrams Fig. 5a, b).

For the positive impacts (Fig. 6), although a number of these were considered likely to occur within the time periods of most or all of the events, such as educational value, local employment, power economic value and new biological research, only the last of these, new research, was considered to be of strong intensity. Again, as noted with the negative impacts, the results for the positive impacts also appear to exhibit an overall correlation between likelihood and intensity (Fig. 6a, b).

The similarities in the patterns of likelihood and intensity of impacts are supported by examining the mean intensity values in the different likelihood categories (1–5), for both negative and positive impacts. These show that mean intensity generally increases as likelihood increases (Table 3). These results also show that overall, stakeholders seem more cautious in rating intensity, especially when they rated likelihood with high scores. In other words, an impact may be expected to occur, but its impact intensity may not be as strong as its likelihood. This is also to be seen in both Figs. 5 and 6, where the plots of intensity tend to show lower scores (closer to the centre of the circles) than the likelihood scores. This is particularly pronounced among the positive impacts (Fig. 6).

The patterns described so far have referred to general trends exhibited by the events along the timeline considered overall. However, the results also permit changes in the importance of the different impacts to be followed more specifically as the turbine project evolved along the timeline of events, as well as consideration of the future scenario of arrays of turbines.

In considering the results below, it should be remembered that of the four events defined in the timeline of Fig. 1, the first three refer to the documented history of the turbine project and to a single construction in Strangford Lough, while the fourth event refers to a scenario situation with arrays of many turbines at other locations along the coast of Northern Ireland, that are already being planned. Thus the future scenario event 4 must be interpreted rather differently to the other three events.
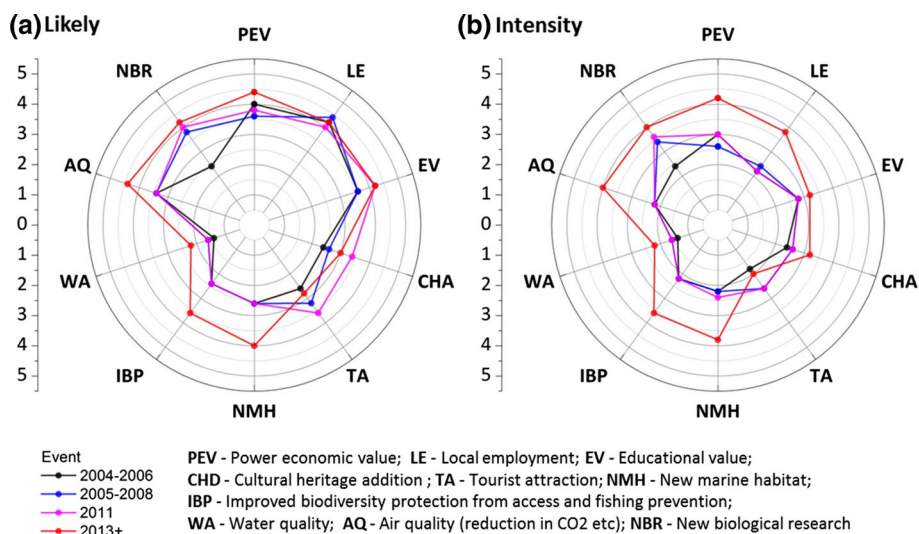


Fig. 6 Polar diagrams showing the differences between stakeholder groups of the scores for likelihood (a) and intensity (b) of occurrence of positive impacts, averaged across all stakeholders

**Table 3** Relationship between likelihood and intensity of impacts

| Impacts | Mean intensity value (SD) | | | | |
|---|---|---|---|---|---|
| | Likely = 1 | Likely = 2 | Likely = 3 | Likely = 4 | Likely = 5 |
| Intensity of negative impacts | 1.06 (0.28) | 2.09 (0.63) | 2.95 (0.57) | 3.53 (0.88) | 4.18 (0.98) |
| Intensity of positive impacts | 1.13 (0.34) | 2.07 (0.36) | 2.89 (0.81) | 2.91 (0.85) | 3.70 (1.22) |

Mean intensity values (standard deviation in parenthesis) within different likelihood score categories (1–5) for both negative and positive impacts

Throughout the consecutive events 1 to 3, there is a clear, strong trend that the negative impacts were perceived in the early stages (the initial Environmental Statement, event 1) as more likely to occur and with noticeable intensity, but the assessment of the importance of the same impacts decreases with time up to and including event 3, when the Environmental Monitoring Report was completed in 2011. This is indicated by the progressive inward retreat of the concentric patterns in the polar diagrams of Fig. 5, so that the results from event 3 are mostly depicted as tighter, inner rings. Impacts that conform to this pattern include most of the impacts on both biodiversity and ecosystem services/human well-being. The only (sometimes only partial) exceptions are influences on plankton communities, teleost fish, commercial fishing for teleosts and impacts of noise/vibration on humans. Intensity and likelihood patterns are very similar, but not identical.

In the future scenario of event 4, the scores then show a distinct and strong reverse trend, with values of intensity and likelihood increasing again, usually very strongly, to attain levels above those of event 3 (the only exception is the impact of noise/vibration on humans, where a strong negative impact was reported on a house during the operation of the turbine). This strong reverse trend reflects the differences between the single turbine situation where there has been concentrated effort to mitigate the negative effects, and the consideration of arrays of many turbines together, where environmental risks may be amplified and are not yet understood.

The temporal dynamics of the positive impacts are rather different. Indeed, in many instances the trend is the opposite to that of the negative impacts—there is often an increase in likelihood and intensity ratings from event 1 to event 3, and this trend of increase usually extends to encompass the future scenario event 4 (Fig. 6). Although the changes in score values between events are generally not as marked as in the negative impacts, there is still clear indication that the stakeholders give more credence to the potential positive impacts of the turbine, or even arrays of turbines, as the turbine project progressed.

These relative changes over time are described qualitatively with reference to the polar diagrams. A supporting quantitative analysis is provided in Table 4, in which differences in mean score values between consecutive events are used to quantify the relative changes between events. These statistics verify the conclusions drawn from the polar diagrams. For example, the negative impacts are seen initially as more likely to occur and with higher intensities but the assessments often decline with time over the events 1–3 (highlighted in italics in Table 4) and for the scenario event 4 the values of likelihood and intensity increase again (results highlighted in bold in Table 4). Also, the positive impacts often exhibit a trend for likelihood and intensity ratings to increase over time from events 1 to 3 and this may extend to include the scenario event 4 (highlighted in bold in Table 4).

**Table 4** Differences in mean score values of each impact, compared between consecutive events

| | Intensity | | | | Likely | | | |
|---|---|---|---|---|---|---|---|---|
| | P0 | PA | PB | PC | P0 | PA | PB | PC |
| **Negative impacts on biodiversity** | | | | | | | | |
| Protected habitats (general) | 3.6 | *−1* | *−1* | **1.6** | 3.8 | *−0.2* | *−1.6* | **1.2** |
| Protected species (general) | 4 | *−0.6* | *−1.4* | **1.4** | 4 | *−0.2* | *−2* | **1.4** |
| Birds | 2 | *−0.2* | *−0.4* | **0.4** | 2.2 | *−0.2* | *−0.4* | **1** |
| Marine mammals | 4.4 | *−0.6* | *−1.4* | **1.4** | 4.2 | *−0.4* | *−1.8* | **1.4** |
| Sharks/other elasmobranchs | 4.4 | *−0.6* | *−1.4* | **1.4** | 4.4 | *−0.8* | *−1.2* | **1.2** |
| Teleost fish | 2 | *−0.4* | *−0.2* | **0.8** | 2.6 | 0 | *−0.4* | **1.2** |
| Shellfish (molluscs, crustaceans) | 2 | 0 | *−0.6* | **1** | 2.2 | *−0.2* | *−0.2* | **1** |
| Benthic communities | 3.4 | 0 | *−1* | **0.8** | 3.6 | *−0.2* | *−1.2* | **1.6** |
| Plankton communities | 1.4 | 0 | 0 | **0.4** | 1.4 | 0 | 0 | **0.4** |
| Cabling to land—electric fields, abrasion | 3.2 | *−1.4* | *−0.6* | **2** | 4.4 | *−0.8* | *−0.8* | **2.6** |
| Noise/vibration marine animals | 4.4 | 0 | *−0.6* | **1** | 4.2 | **0.4** | *−2* | **1.4** |
| **Negative impacts on humans (including ecosystem services)** | | | | | | | | |
| Nutrient cycling/food web dynamics | 1.6 | 0 | *−0.2* | **0.8** | 1.6 | 0 | *−0.2* | **0.4** |
| Water quality (sediment, waste remediation) | 2.2 | **0.4** | *−0.6* | **1.2** | 2.2 | 0 | *−0.6* | **1.2** |
| Nature watching | 2.4 | *−0.2* | *−0.8* | **1.2** | 2.8 | 0 | *−0.6* | **0.8** |
| Recreational boating/fishing | 4.4 | 0 | *−0.4* | 0 | 4.2 | *−0.2* | *−0.8* | **0.2** |
| Landscape/seascape quality | 3.6 | *−0.2* | *−0.2* | **0.6** | 4.2 | *−0.6* | *−0.8* | **1.8** |
| Noise/vibration humans | 2.8 | *−0.2* | **0.8** | *−0.2* | 3 | *−0.4* | **1.2** | *−0.8* |
| Tidal hydrodynamics | 3.2 | *−0.4* | *−0.6* | **0.8** | 3.8 | *−0.2* | *−0.4* | **1** |
| Boating navigation/access | 3.6 | *−0.2* | *−0.4* | **0.6** | 4.4 | *−0.6* | *−0.4* | **1.8** |
| Commercial fishing—teleosts | 1.4 | 0 | 0 | **1.6** | 1.6 | 0 | 0 | **1.4** |
| Commercial fishing (pot fishing) | 1.8 | 0 | *−0.4* | **1.6** | 2 | **0.2** | *−0.4* | **1.2** |
| **Positive impacts** | | | | | | | | |
| Power economic value | 3 | *−0.4* | **0.2** | **0.6** | 4 | *−0.4* | **0.4** | **1.2** |
| Local employment | 2.2 | **0.2** | *−0.4* | **0.2** | 4.2 | **0.2** | *−0.2* | **1.6** |
| Educational value | 2.8 | 0 | **0.6** | 0 | 3.6 | 0 | 0 | **0.4** |
| Cultural heritage addition | 2.4 | **0.2** | **0.8** | *−0.4* | 2.4 | **0.2** | 0 | **0.6** |
| Tourist attraction | 1.8 | **0.6** | **0.4** | *−0.8* | 2.6 | **0.8** | 0 | *−0.6* |
| New marine habitat | 2.2 | 0 | 0 | **1.4** | 2.6 | 0 | **0.2** | **1.4** |
| Improved biodiversity protection from access and fishing prevention | 2.2 | 0 | 0 | **1.2** | 2.4 | 0 | 0 | **1.4** |
| Water quality | 1.4 | **0.2** | 0 | **0.6** | 1.4 | 0.2 | 0 | **0.6** |
| Air quality (reduction in $CO_2$ etc.) | 2.2 | 0 | 0 | **1** | 3.4 | 0 | 0 | **1.8** |
| New biological research | 2.4 | **1.4** | **0.2** | **0.2** | 2.4 | **1** | **0.2** | **0.4** |

*P0* averaged values in "2004–2006"; *PA* averaged values in "2005–2008" minus averaged values in "2004–2006", *PB* averaged values in "2011" minus averaged values in "2005–2008"; *PC* averaged values in "2013+" minus averaged values in "2011". Highlighted in the table values are relative changes >0 in bold and relative changes <0 in italics

# Discussion

This study has demonstrated that during the construction and operation of the marine tidal turbine in Strangford Lough, the perceptions and views of different stakeholders sometimes disagreed but were often surprisingly similar in relation to both likelihood and intensity of the potential impacts of the turbine on marine biodiversity, ecosystem services and human well-being in general. While stakeholders maintained their own profiles in having differences in opinion on the overall degree of importance of the impacts (some being more conservative in their judgements than others), there was a general consensus of views that was honed/refined and evolved over the entire timeline of the discussions and decision-making processes. This underlines the paramount importance of establishing and maintaining effective stakeholder engagement throughout the negotiations, as has been previously stressed most recently in regard to marine protected area policy in Scotland (Hopkins et al. 2016a) and also in regard to the development of marine renewable energy (Inger et al. 2009).

Such evolution of stakeholders perspectives, specifically their assessments of the negative impacts, is particularly relevant to understanding the full dynamics of this case study. This is because the progressive changes observed between events 1, 2 and 3 on the timeline can be understood as reflecting stakeholders increased knowledge, particularly the cumulative gain in scientific information that was obtained from the continuous monitoring programme and associated academic research (Savidge et al. 2014). This cumulative gain in knowledge also informed on potential points for consideration in the argumentation processes relating to future arrays of turbines at other sites, as referenced by the scenario of event 4.

It is interesting that all the different stakeholders displayed an overall appreciation of the many gains in scientific knowledge as the monitoring results became available. Thus no large differences were observed between the responses of stakeholder D, representing academic biological research and the other stakeholders, as might have been otherwise expected had the new scientific knowledge been appreciated only by this stakeholder group (Figs. 2, 3). The clearly higher ratings of likelihood and intensity of negative impacts assigned by stakeholder C, representing the consortium of conservation NGOs, is most likely to be a reflection of a slightly stronger tendency towards application of the precautionary principle by this stakeholder. These findings conform with the results of Berry et al. (2016, this issue) who showed that different stakeholder groups share some common views on biodiversity and its conservation, particularly in relation to moral, intrinsic and ecological values.

There are clear patterns in the temporal dynamics of the use and perceived importance and effectiveness of arguments based on the individual negative impacts during the negotiations and decision-making process surrounding the turbine development. Most of the listed negative impacts were used as arguments which were repeated in the events over the entire time course of the turbine development. Some of these exhibited increased and broadening use along the timeline of events. Particularly, the arguments of risks to marine mammals, notably seal populations with some focus on the EU Habitats Directive protected species status of the harbour seal, and the risks of any type of large animal collisions with the turbine increased their status as centres of attention during the course of the case (Savidge et al. 2014). However, arguments centred on Protected Area status, including benthic and Habitats Directive listed habitats, and acoustic/vibration disturbance to animals also maintained higher profiles. Arguments of negative impacts on cetaceans (dolphins and

whales), sharks and other elasmobranchs (cartilaginous fish), including risks from electromagnetic fields and cables scraping the seabed, showed lost impetus over the timeline. Risks to birds maintained a low profile throughout the study. All of these temporal patterns of argumentation using particular impacts are also the same as, or very similar to, those reflected in the official report documents examined. From the very broad spectrum of concerns and uncertainties initially identified in the early Environmental Impact statement (Royal Haskoning 2005), focus on the different specific impacts was progressively narrowed and concentrated through the Habitats Directive Article 6 Report (Department of the Environment (Northern Ireland) 2008) and the Final Report of the monitoring programme (Royal Haskoning 2011), in the manner reported above.

One important point here is that the above examples and the present results overall clearly show that concerns and discussions along the timeline of the decision-making processes were very strongly oriented to impacts that centred on aspects of biodiversity or included aspects of biodiversity as a component. The negative impacts of the turbine on ecosystem services and human well-being are noticeably absent from active argumentation. All stakeholders were aware of the full spectrum of impacts, including those affecting ecosystem services and human well-being, and they provided judgements on these in the questionnaire used. Equally, the human-directed influences were identified and considered within the formal Environmental Impact Assessment (event 1) in the early stages of the turbine project (Royal Haskoning 2005). However, after this assessment, the primary documentation up to and including the Monitoring Programme Report of event 3 (Royal Haskoning 2011), is mainly focussed on the potential threats to biodiversity and biodiversity protection policy affecting the Protected Area. Other impacts appear to have been regarded as much more peripheral, even though there can be direct positive links between biodiversity and ecosystem service provision. For example, in the review of biodiversity and ecosystem service relationships by Harrison et al. (2014), positive relations were found to be frequently reported between commercial fishing and the attributes of biodiversity of species richness, abundance and size of individuals. Also, species-based recreation was shown to have a positive relation with both abundance and size of the species present.

Concerns about negative impacts on the seal populations in the Lough maintained a particularly high profile throughout the timeline of the project. Seals may appear simply as charismatic species capable of attracting public attention. However, and most importantly, in addition to their strong aesthetic appeal, the seals are the subjects of a more complex set of arguments involving the logistics of combining environmental policy with changing levels of scientific knowledge. Particularly, the risks of collisions with the rotating blades of the turbine, together with the fact that the harbour seal is listed in the Annexes of the EU Habitats Directive, so that protection of the species is legally obligatory. This is in contrast to all the other organisms present: no other species or community or habitat type offered such a strong combination of arguments (sometimes referred to as "bundles" of arguments). For example, it might have been expected that the bird fauna and bird habitats, which have a strong public profile and are commonly used in argumentation in biodiversity conservation matters, would play a pivotal role in discussions of the turbine development. However, despite the EU Habitats and Birds Directives listings of a few species and recognition that diving bird species potentially could be at risk of colliding with the turbine rotors whilst in operation, arguments involving birds remained at a low profile, becoming less important as the project progressed. This is because, as research and monitoring continued and the associated levels of scientific knowledge increased, it became clear that apart from some early concerns about disturbances to birds caused by the construction of the turbine (mitigated by undertaking the work outside the overwintering and breeding

seasons), birds and bird habitats were at negligible risk from the turbine project (Department of the Environment, Northern Ireland 2008).

The potential positive impacts of the turbine on biodiversity and human well-being, beyond the provision of renewable energy (including both the economic value of the power and the inferred improvement of air quality), were not included in the argumentation and decision-making processes. The positive impacts listed in Table 1 were identified and obtained from discussions during meetings with the stakeholders for this study and were not included in the official reports or other documentation. However, a number of these potential positive impacts have been recently widely discussed in the literature in relation to offshore wind farms. Two of the more obvious examples that are particularly pertinent to the present study may be expanded upon here.

First, there is the recognition of the creation of new habitat provided by the anchoring structures of the turbine (often referred to as "foundations") on the seabed. The advantages of such new, artificial substrate have been well advertised in the wind farm literature as being available for colonisation by benthic organisms, to form new reef communities (Inger et al. 2009; Busch et al. 2011; Lacroix and Pioch 2011; Mangi 2013; Bergström et al. 2014; Hammar et al. 2016) and also as structures that may encourage the aggregation of fish (Bergström et al. 2014; Gilbert et al. 2015; Hammar et al. 2016). Taking the idea a step further, it has been suggested that new designs of the underwater portions of wind turbines could incorporate structural features specifically intended to enhance colonisation and shelter opportunities for marine organisms and even to accommodate aquaculture needs. Thus offshore wind farms could become an element in the creation of a green infrastructure in marine environments (Lacroix and Pioch 2011).

Second, boating navigation and fishing restriction/exclusion zones designated around offshore wind farms for reasons of safety and damage to fishing tackle can provide protection for biodiversity. In this context, offshore wind farms have been widely suggested as capable of fulfilling functions very similar to those of marine protected areas (Inger et al. 2009; Mangi 2013; Hammar et al. 2016). In addition, protection could extend to boosting commercial fish stocks, with spillover of populations that could be harvested in adjacent fishing grounds (Busch et al. 2011; Mangi 2013). But all these issues are complex, not always observable and relationships are still not well understood (Bergström et al. 2014; Vandendriessche et al. 2014).

The extent to which these and other recognised potential positive influences could apply to the rather different situation of tidal turbines with their submerged rotors impacting on the underwater environment remains unclear.

Both of the above examples serve to highlight the importance of considering possibilities for trade-offs between different impacts that may affect biodiversity protection, provision of various ecosystem services and human well-being, involving different sectors and stakeholder interests, all within the framework of entire marine social-ecological systems. Such trade-offs were not addressed or attempted during the tidal turbine negotiations of the present study, even though the potential clearly exists. But with the focus on a single turbine in the Strangford Lough Protected Area, all such trade-offs are small and of only minor importance. Throughout the turbine development as documented by events 1–3, the central concerns of all the major stakeholders were clearly the maintenance of marine and coastal biodiversity protection, including the integrity of the protected area and local cultural landscape, so no major trade-off situations arose. However, when considered in the light of the future scenario of event 4, large arrays of turbines at other locations (with the parallels to wind farms), the potential importance of various trade-offs between the different impacts begins to take on a new and much greater significance.

Indeed, from the social-ecological system perspective, such arrays will be a major new addition to multi-sectoral ocean use and will further stimulate trade-offs already documented as being partly catalysed by wind farms. For example, trade-offs identified among offshore wind energy, commercial fishing and whale watching as explored by White et al. (2012) in Massachusetts coastal waters. This type of thinking has led to a new recognition of the importance of considering how we use and divide ocean space and the need for marine spatial planning that must also keep the maintenance of marine environmental quality and conservation at the forefront (White et al. 2012; Gilbert et al. 2015; Hammar et al. 2016; Hopkins et al. 2016a).

Of course the confinement of the present study to a single working prototype turbine within a marine protected area is also a limitation to the generality of the results—the findings cannot be used to directly extrapolate to situations of arrays of turbines as envisaged at other coastal sites. Such extrapolation would be potentially extremely dangerous where much larger areas of seabed are involved. Such need for caution is clearly reflected by the results of the stakeholders' responses to the questionnaire presented here and future understanding will require continued new research effort with an emphasis on marine spatial planning that includes biodiversity protection as discussed above. Also, some may argue that the restriction of the study to only five stakeholders limits the amount of data obtained and the ensuing analyses. However, focusing on a small number of reliable experts that had key roles throughout the entire duration of the project ensured that the information captured was of a consistent and high quality, avoiding the need for more complicated statistical analysis of a highly patchy albeit larger dataset.

One potential bureaucratic complication to this study is that Northern Ireland has experienced a complex set of governmental changes over the years. Issues of environmental policy and its governance within Northern Ireland have been the responsibility of a variety of governmental entities, mainly associated with the Department of the Environment, but under a variety of different names, during the time course of the SeaGen turbine project. This includes some periods when the local Government, the Northern Ireland Assembly, was suspended, during which times responsibility was at the national level, handled directly from the UK Government in London. However, such internal changes do not appear to have interfered with the decision-making processes related to the development of the turbine project and indeed reflects the reality of politically unstable situations that could arise in any country.

Undoubtedly, the innovative "adaptive management approach" to the turbine development as reported here and described by Savidge et al. (2014) with integrated mitigation and monitoring, adopted from the early stages, has played a crucial role in the success of the entire turbine project. Adaptive management has been acknowledged as a useful approach in other studies involving marine protected areas in various contexts, including management for the provision of ecosystem services (Rees et al. 2012) or for resilience to climate change (Hopkins et al. 2016b). However, even though there is a general perception of the need for processes to be adaptive, the reality is that currently, adaptive management has rarely been demonstrated, nor the legal or scientific capability to carry it out (Hopkins et al. 2016b). The present study joins the work of Savidge et al. (2014) as one of the first to provide such evidence. The present study has clearly demonstrated the importance of establishing and maintaining effective stakeholder engagement and that the flexibility created among the engaged stakeholders permitted a strong adherence to the precautionary principle of biodiversity protection throughout. It may be hoped that continued high levels of stakeholder engagement and agreement will allow such an approach to be maintained when arrays of underwater turbines are developed in the near future.

# References

Bailey H, Brookes KL, Thompson PM (2014) Assessing environmental impacts of offshore wind farms: lessons learned and recommendations for the future. Aquat Biosyst 10:8. http://www.aquaticbiosystems.org/content/10/1/8

Bergström L, Kautsky L, Malm T, Rosenberg R, Wahlberg M, Capetillo NA, Wilhelmsson D (2014) Effects of offshore windfarms on marine wildlife—a generalised impact assessmen. Environ Res Lett 9:034012. doi:10.1088/1748-9326/9/3/034012

Berry PM, Fabók V, Blicharska M, Bredin YK, Garcia-Llorente M, Kovács E, Geamana N, Stanciu A, Termansen M, Jääskejäinen T, Haslett JR, Harrison PA (2016) Why conserve biodiversity? A multi-national exploration of stakeholders´ views on the arguments for biodiversity conservation. Biodivers Conserv. doi:10.1007/s10531-016-1173-z

Burkhard B, Gee K (2012) Establishing the resilience of a coastal-marine social-ecological system to the installation of offshore wind farms. Ecol Soc 17(4):32. doi:10.5751/ES-05207-170432

Busch M, Gee K, Burkhard B, Lange M, Stelljes N (2011) Conceptualizing the link between marine ecosystem services and human well-being: the case of offshore wind farming. Int J Biodivers Sci Ecosyst Serv Manag 7:190–203

Department of the Environment (Northern Ireland) (2008) Marine Current Turbine (MCT) Article 6 Assessment, Stage One Screening. Environment and Heritage Service, Northern Ireland, February 2008. Unpublished report

Department of the Environment (Northern Ireland) (2009) Planning Policy Statement 18 "Renewable Energy". Planning and Environmental Policy Group. http://www.planningni.gov.uk/index/policy/planning_statements_and_supplementary_planning_guidance/planning_policy_statement_18__renewable_energy.pdf

García-Llorente M, Iniesta-Arandia I, Willaarts B, Harrison PA, Berry P, del Mar Bayo M, Castro A, Montes C, Martín-López B (2015) Biophysical and sociocultural factors underlying spatial trade-offs of ecosystem services in semiarid watersheds. Ecol Soc 20(3):39. doi:10.5751/ES-07785-200339

Gilbert AJ, Alexander K, Sardá R, Brazinskaite R, Fischer C, Gee K, Jessopp M, Kershaw P, Los HJ, Morla DM, ÓMahony C, Pihlajamäki M, Rees S, Varjopuro R (2015) Marine spatial planning and good environmental status: a perspective on spatial and temporal dimensions. Ecol Soc 20(1):64. doi:10.5751/ES-06979-200164

Hammar L, Perry D, Gullström M (2016) Offshore wind power for marine conservation. Open J Mar Sci 6:66–78. doi:10.4236/ojms.2016.61007

Harrison PA, Berry PM, Simpson G, Haslett JR, Blicharska M, Bucur M, Dunford R, Egoh B, Garcia-Llorente M, Geamana N, Geertsema W, Lommelen E, Meiresonne L, Turkelboom F (2014) Linkages between biodiversity attributes and ecosystem services: a systematic review. Ecosyst Serv 9:191–203. doi:10.1016/j.ecoser.2014.05.006

Haslett JR, Berry PA, Bela G, Jongman RHG, Pataki G, Samways MJ, Zobel M (2010) Changing conservation strategies in Europe: a framework integrating ecosystem services and dynamics. Biodivers Conserv 19:2963–2977

Hopkins CR, Bailey DM, Potts T (2016a) Scotlands Marine Protected Area network: reviewing progress towards achieving commitments for marine conservation. Mar Policy 71:44–53

Hopkins CR, Bailey DM, Potts T (2016b) Perceptions of practitioners: managing marine protectred areas for climate change resilience. Ocean Coast Manag 128:18–28

Inger R, Attrill MJ, Bearhop S, Broderick AC, Grecian WJ, Hodgson DJ, Mills C, Sheenan E, Votier SC, Witt MJ, Godley B (2009) Marine renewable energy: potential benefits to biodiversity? An urgent call for research. J Appl Ecol 46:1145–1153

Jones CR, Eiser JR (2010) Understanding 'local' opposition to wind development in the UK: how big is abackyard? Energy Policy 38:3106–3117

Lacroix D, Pioch S (2011) The multi-use in wind farm projects: more conflicts or a win-win opportunity? Aquat Living Resour 24:129–135

Lawrence J, Sedgwick J, Jeffrey H, Bryden I (2013) An overview of the UK marine energy sector. Proc IEEE 101:876–889

Magagna D, Uihlein A (2015) 2014 JRC Ocean Energy Status Report: Technology, market and economic aspects of ocean energy in Europe. JRC Science and Policy Reports, Joint Research Centre—Institute for Energy and Transport. European Commission. Luxembourg Publications Office of the European Union.

Mangi SI (2013) The impact of offshore windfarms on marine ecosystems: a review taking an ecosystem services perspective. Proc IEEE 101:999–1009

Rees SE, Austen MC, Attrill MJ, Rodwell LD (2012) incorporating indirect ecosystem services into marine protected area planning and management. Int J Biodivers Sci Ecosyst Serv Manag 8:273–285

Royal Haskoning(2005) Strangford Lough Marine Current Turbine: Environmental Statement. Final Environment Impact Assessment. Report produced for Marine Current Turbines Ltd. Royal Haskoning, Edinburgh, June 2005. Unpublished report

Royal Haskoning (2011) SeaGen Environmental Monitoring Programme. Final Report produced for Marine Current Turbines Ltd. Royal Haskoning, Edinburgh, January 2011. Unpublished report

Savidge G, Ainsworth D, Bearhop S, Christen N, Elsaesser B, Fortune F, Inger R, Kennedy R, McRobert A, Plummer KE, Prichard DE, Sparling CE, Whittaker JT (2014) Strangford Lough and the SeaGen Tidal Turbine. In: Whittaker MA, Payne AIL (eds) Marine renewable energy technology and environmental interactions. Springer, New York, pp 153–172

Strangford Lough and Lecale Partnership (2014) Strangford Lough European Marine Site http://www.strangfordlough.org/strangford-lough-european-marine-site.html. Accessed 12 June 2016

Vandendriessche S, Derweduwen J, Hostens K (2014) Equivocal effects of offshore wind farms in Belgium on soft substrate epibenthos and fish assemblages. Hydrobiologia 756:19. doi:10.1007/s10750-014-1997-z

Viera AJ, Garrett JM (2005) Understanding Interobserver Agreement: the Kappa Statistic. Fam Med 37(5):360–363

White C, Halpern BS, Kappel CV (2012) Ecosystem service tradeoff analysis reveals the value of marine spatial planning for multiple ocean uses. Proc Natl Acad Sci USA 109:4696–4701