Offshore and Coastal Renewable Energy:

Potential ecological benefits and impacts of large-scale offshore and coastal renewable energy projects

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Prepared by: Annie Linley (1), Karine Laffont (1), Ben Wilson (2), Mike Elliott (3), Rafael Perez-Dominguez (3) & Daryl Burdon (3).

Institutions: (1) PML Applications Ltd, (2) SAMS, (3) IECS

PML | Applications Ltd

SCOTTISH ASSOCIATION for MARINE SCIENCE

THE UNIVERSITY OF HULL
Institute of Estuarine & Coastal Studies (IECS)

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Acronyms

ADCP	Acoustic current Doppler profiler
AERO	Accompanying Ecological Research on Offshore Energy Development
ALSF	Aggregates Levy Sustainability Fund
BERR	Department for Business, Enterprise & Regulatory Reform
BODC	British Oceanographic Data Centre
BTO	British Trust for Ornithology
BWEA	British Wind Energy Association
CCW	Countryside Council for Wales
CE	Crown Estate
CEH	Centre for Ecology and Hydrology
CORE	Cornwall Ontario River Energy
COWRIE	Collaborative Offshore Wind Research Into The Environment
DECC	Department of Energy and Climate Change
DEFRA	Department for Environment, Food and Rural Affairs
DTI	Department of Trade and Industry, now BERR
EIA	Environmental Impact Assessment
EMEC	European Marine Energy Centre
EMF	Electromagnetic fields
EPSRC	Engineering and Physical Sciences Research Council
ERI	Environmental Research Institute
ERSEM	European Regional Seas Ecosystem Model
ESRC	Economic and Social Research Council
ETI	Energy Technologies Institute
FEPA	Food and Environment Protection Act 1985
FFHCA	Flora-Fauna Habitat Compatibility Assessment
FRS	Fisheries Research Services
HMSC	Hatfield Marine Science Center
ICIT	International Centre for Island Technology
ICL	Imperial College London
IECS	Institute of Estuarine and Coastal Studies
KT	Knowledge transfer
JNCC	Joint Nature Conservation Committee
MBA	Marine Biological Association
MCA	Maritime and Coastguard Agency
MCT	Marine Current Turbines Ltd
MDIP	Marine Data and Information Partnership
MFA	Marine and Fisheries Agency
MRED	Marine Renewable Energy Device
MS	Marine Scotland
MSP	Marine Spatial Planning
NE	Natural England
NOCS	National Oceanography Centre, Southampton
OA	Ocean Acidification
OREEF	Offshore Renewables Energy Environmental Forum
OSU	Oregon State University
OWF	Offshore wind farm
OWT	Offshore wind turbines
OWET	Oregon Wave Energy Trust
PML	Plymouth Marine Laboratory
POD	Acoustic Porpoise Detector

POL	Proudman Oceanographic Laboratory
PRIMaRE	Peninsular Research Institute for Marine renewable Energy
PSO	Public Service Obligation
QUB	Queen's University Belfast
RAG	Research Advisory Group
RCEP	Royal Commission on Environmental Pollution
ReDAPT	Reliable Data Acquisition Platform for Tidal
RITE	Roosevelt Island Tidal Energy
ROV	Remotely Operated Vehicles
SAHFOS	Sir Alister Hardy Foundation for Ocean Sciences
SAMS	Scottish Association for Marine Science
SEA	Strategic Environmental Assessment
SEPA	Scottish Environment Protection Agency
SIA	Seascape Impact Assessment
SNH	Scottish Natural Heritage
SMRU	Sea Mammal Research Unit
SWRDA	South West of England Regional Development Agency
SUNR	Sustainable Use of Natural Resources
SuperGen	Sustainable Power Generation and Supply Initiative
TADS	Thermal Animal Detection System
TSB	Technology Strategy Board
TSEC	Towards a Sustainable Energy Economy
UKERC	UK Energy Research Centre
WEC	Wave Energy Converter

Executive summary

The purpose of this report is to identify research needed to determine the impacts and benefits of large-scale marine renewable energy projects, and to allow NERC to develop detailed plans for research activities in the 2009 Theme Action Plans. The overarching research challenge is to demonstrate the benefits of including environmental thinking in energy technology development, and to raise the profile of environmentally focused, as opposed to technologically driven, science in the energy arena. Our review therefore focuses on: (i) identification of the key science challenges and research opportunities and (ii) indications of where NERC science can contribute most and institutions which should be involved.

Environmental research in relation to marine renewable energy is progressing against a background of a complex funding and research landscape with a wide diversity of organisations involved, with research being undertaken on behalf of regulatory bodies, policy makers and developers. The main focus to date has been the DECC / COWRIE Research Programme overseen by a multi agency Research Advisory Group. This group has prioritised and commissioned research to support deployment and licensing of arrays of wind turbines, and is now focussing mainly on the needs of the wave and tidal energy sector. All Oceans 2025 partners have been involved in delivering some of this research, which has included development of appropriate methods and novel technologies for studying organisms in hostile environments, studies focused on individual species and communities and their interactions with renewable energy technologies, as well as exploring the nature of potential ecosystem and economic benefits.

We have synthesised the key science challenges and research opportunities associated with biodiversity and ecosystems which have emerged from the scoping study, into the major science areas as shown in the table below:

Research priorities	**Feeder projects**	**Main elements/nature of research**	**Impact / utility***
(I) Whole system			
Development and expansion of ecosystem modelling capability to allow assessment of regional scale impacts of energy extraction : - potential impact of multiple arrays on whole range of ecosystem services e.g. nutrient regeneration, CO_2 sequestration to food production, - potential of MREDs (plus cumulative impacts of extractive activities.) to cause major system changes / tipping point given context of CC and OA; - ecosystem functioning changes in relation to the resilience of the system and the ability to naturally or anthropogenically mitigate or compensate effects.	TSEC UKERC phase 2 MARBEF	(1) desktop data collation to set up scenarios (spatial and range of values from literature for services), (2) modelling development to allow simulation of potential impact at MRED array scale (1nm resolution now possible) (3) test different combinations MRED /footprints at regional scale (4) Field observations / experimentation to fill gaps (see (VI) below) (5) Run models for whole range of scenarios (6) If significant, then KT to policy development process	NERC UKERC DEFRA DECC
Effects of multiple systems as	As above	(1) Field monitoring, field	

interference for natural processes at the physical and biological level (latter at individual, population and community levels): - degradation and recovery trajectories; - response by alien species and resulting community effects; - determinations of cumulative effects and relationship with mitigation / compensation.		experimentation and mesocosm effects; (2) Coupled physical and biological models.	
(II) Mammals			
Development of research method to allow quantification / assessment of collision risk	Equimar WP6	(1) Observational studies to determine the probability of encounters, avoidance behaviours, population consequences, monitoring technologies and mitigation options (particularly relative risks for different design concepts within device families). (2) Locate at different sites e.g. Strangford Lough, Ramsay Sound, Wave Hub.	NE / SNH DEFRA
Consequences of large scale displacement of predators and prey from arrays or spatial bottlenecks / movement corridors. Displacement due to physical presence, noise, habitat changes, EMF etc.	As above	(1).Observational studies (e.g., Blackcraig / Falls of Warness / Ramsay Sound / Wave Hub (2) Comparative studies for tools development : surveys, telemetry, remote sensing, modelling (3) Existing remote sensing data – identify where needs extending inshore for predicting displacement / feeding hotspots. (4) Field studies across discontinuities near MREDs	NE / SNH / CCW DEFRA
(III) Birds			
Behavioural and functioning studies Better impact prediction models with uncertainty/risk modelling Site-specific to generic assessments – linked to mitigation and compensation issues; Carrying capacity determination of offshore areas for large and mobile predators. Cumulative impacts on populations	Ongoing BTO	(1) Collision issues in poor visibility and darkness; (2) Generic aspects of data gathering with distance offshore (development of remote techniques and ground-truthing of radar and thermal imaging); (3) Effects on energetic and population viability as well as risk and vulnerability; (4) Cumulative/in-combination assessment methods	NE / SNH / CCW DEFRA
(IV) Fish			
Sub-lethal and behavioural effects and linked population effects - interference with migration routes at open sea scales; - feeding Quantifying carrying capacity and its	Oceans 2025 Cefas EMPA FISH	(1) Audiograms on hearing specialist and development of noise exposure criteria based on behavioural effects (2) Modelling of sublethal responses at ecologically	NE / SNH/ CCW DEFRA MFA

modification at sites, between sites: - input to models at differing scales; - quantifying use of differential habitats; Socio-economic and environmental benefits of creating no-take zones in relation to fisheries.		relevant endpoints (3) Assessment with non invasive techniques (i.e. acoustic, video tracking). Sensitivity analysis (4) Control exposure experiments in the field (5) Displacement of species and cascade effects on community structure	
(V) Benthos			
Development of research methods for studying benthos in tidal rapids : - routine characterisation of communities (biodiversity) - to measure productivity (functional significance) - input to ecosystem models at device array and multiple array scale. - Determination of functional response of benthic organisms to energy changes through substratum modifications. - Habitat creation/modification/ enhancement potential - Biogeochemical repercussions of *in situ* deployment and substratum modifications and knock-on effects for nutrient dynamics/fluxes and exchange.	Wave Hub EMEC MCT	(1) Statistical and predictive modelling approaches on system change; (2) Policy-oriented research on level of data required to understand the system. (3) Testing ecological theory regarding the trajectories of change and resilience/hysteresis in the system	NE / SNH/ CCW
(VI) Water column			
Characterisation / functioning of plankton communities (to input to several research questions above) - environmental impact of energy extraction on core ecosystem processes (info for (I) above) - role of fronts/discontinuities in driving locations of biodiversity/ feeding hotspots for birds/cetaceans - to provide key information for interpretation of benthic /pelagic processes and testing models in (I) above - assess risk of locating in areas susceptible to HABs etc - economic valuation of ecosystem goods and services	ReDAPT Supergen UKERC FP6 'Cost impact'	(1) Theoretical desk top study focused on spatial and temporal variability and statistical considerations in experimental design (2) Field studies of pre and post deployment water column processes, focusing on ecosystem functions (e.g.. Wave Hub in parallel with CTD / hydrodynamics studies.) (3) Influence of multiple structures on upwelling and downwelling systems and large circulation patterns	NERC UKERC DEFRA MFA
(VII) Acoustics			
Development and testing of new technology (T-pods and surface sensors)	Equimar WP6	Field testing at existing demonstrator sites initially then acquisiton of further information from development sites elsewhere	DECC DEFRA Develop-ers
Assessment of sensitivity of individual species to noise and consequences for behaviour, survival etc.	Ditto	(1)Population & ecosystem consequences of auditory damage Development of alternatives and mitigation. (2)Operational noise studies wrt	DEFRA NE /SNH/ CCW

		background levels to assess noise pollution vs necessary acoustic warning	
(VIII) EMFs			
Outstanding issues for fish possibly (cross refer DECC RAG programme for further details).	University of Cranfield		DEFRA NE / SNH
(IX) Technology and model development			
Resource assessment and measurement - tidal and wave Develop methodologies to identify areas of high population significance that are not indicated by absolute abundance e.g. migration corridors	RASCAL POL/PML ERSEM	(1) review technology and modelling gaps and future needs (2) national capability assessment to include computing	NERC EPSRC TSB
(X) Significance			
Where impacts can be demonstrated or predicted, a second level of assessment is required – ecological significance. Extend and apply existing tools (such as PVA) to allow regulators to quantitatively assess projected impacts alongside other human activities & measures of uncertainty, climate change scenarios etc to assess if impacts are within acceptable ecological bounds. Objective needs to be a better set of decision tools than currently available including better ways to detect signals in noisy marine datasets. Will allow better use of pre-installation monitoring programmes and the identification of true effects	See IEEM review	(1) A theoretical research study to define what is significant in ecological and spatial/temporal terms for all ecosystem components i.e. mammals, birds, fish, benthos, water column, (seasonal, decadal, random - signal to noise); (2) review status of all biodiversity components – at gene, species, population level (3) Define what field observations need to be undertaken. (4) Development of decision tools with regulators.	DEFRA NE / SNH / CCW
(XI) Impacts of scaling up			
Device, array and multiple array scale research and monitoring will all contribute, in the longer term, to a body of knowledge which will inevitably converge to inform adaptive management - individual devices will need to be assessed for their environmental impacts and arrays of devices will invariably have a different set of impacts. There may need to be trade offs between devices with different energy extraction and environmental impact characteristics	EMEC ReDAPT PRIMaRE	(1) This is likely to continue to be opportunistic for a number of years as devices are licensed and deployed. We should take every opportunity to undertake environmental assessment in parallel with performance measurements i.e. observational / field studies of mammal and bird interactions where they feed into the need for understanding about individual species or groups. (2) Long term support for monitoring at demonstrator sites to provide basis for research and investigation.	Developers DEFRA DECC
(XII) Opportunities for improved site sustainability			
Opportunities for improved site sustainability by enhancement of ecological and socio-economic benefits: - quantify potential socio-economic	DECC 'reef effects' UKERC	(1) Desk top data mining from existing sites / proxies plus gap analysis (2) Field observations (Loch Linnhe	NERC ESRC UKERC DEFRA

benefits of alternative uses of OWF footprints - opportunities include : ecosystem restoration, no-take MPAs, food production – eg. mussels / algal culture, recreational use etc. - do benefits of resultant no-fish zones spill-over to surrounds and what impacts do displaced fisheries have at their destinations ? - test effects of climate change / OA and cumulative impacts of marine space use – does this result in overall greater socio-economic benefit ?	EMPA-FISH MARBEF	artificial reef, aquaculture test site AWI, City University HK - aqua culture / artificial reef remediation sites etc.) (3) insert into POL-PML ERSEM 3D model to test different scenarios (4) utilize economic valuation of ecosystem goods and services to assess pros and cons of options (5) KT to regulators / policy makers and operators plus KT to wave and tidal sectors	MFA NE / SNH / CCW

*(*Priorities to be inserted after consultation with DECC RAG)*

During the NERC workshop and in subsequent written responses, meetings and telephone follow-up conversations, it became clear that *the majority of scientists want NERC to take a leading role* in environmental research associated with development of offshore renewables. Whilst for most, this involvement is long overdue, there is still the opportunity for NERC science to make a significant impact and particularly to address concerns about sustainable use of natural resources, and biodiversity and ecosystem integrity and function through interaction with development of marine renewables. It is also clear that because of the requirement to demonstrate knowledge transfer and the economic impact of its science, NERC needs to engage directly with the end user / stakeholder community. In the case of the marine renewable energy sector, this community already exists, and it is just a question of NERC situating itself for optimum benefit. One outcome of our analysis was recognition of the common research agenda between NERC and the DECC RAG. There is clear evidence that the DECC RAG programme is burdened by too many projects and too little resource, and consequently our recommendation is that high level discussions are initiated between NERC and DECC to consider joint resourcing of this research programme, with NERC providing input to reviewing, commissioning and QA of research projects *where there is commonality between NERC strategic and DECC objectives.* This would contribute new momentum and drive to the programme and above all, contribute much needed resource to deal with the most pressing problems faced by the wave and tidal sectors.

Although it is tempting to suggest that NERC sets up its own RAG and stakeholder network, it would be much more efficient and cost effective to build on what exists already. Again the DECC based OREEF and the stakeholder community evolving around UKERC phase 2, together with the EMEC RAG and emerging Wave Hub RAG all need drawing together in a coherent structure, which ensures the most effective engagement at all levels and across organisations. Consequently, and to avoid duplication of effort, we recommend careful consideration and consultation before new structures are developed. Given appropriate representation, *existing structures could evolve around a new managed programme (for eg. 5yrs) defined by NERC strategic requirements.* This would undoubtedly be the most cost effective and efficient way of delivering the necessary research, which has the potential to make a major impact on the current levels of understanding and confidence that the present rate of development and deployment is sustainable. It would also allow NERC to test directly the economic impact and commercial benefits of its research as an integral component of the programme.

Given more time and resource, this research area would benefit from closer scrutiny regarding the potential economic impact of the science. However, our view is that in

the short term (<3yrs) support for research on mammals and birds, and issues surrounding noise interference in the marine environment are a high priority for all stakeholders, whereas investment in physical and ecosystem modelling combined with development of methods for economic valuation of ecosystem goods and services will, in the longer term (3 to 5yrs) yield significant benefits to the end user community – particularly regarding the potential positive socio-economic benefits of developing offshore energy. Moreover, investment in these areas will enable NERC to deliver on its strategic science objectives, through investigating the impacts and potential benefits of large scale offshore renewable energy projects, both in the UK and further afield.

1 Introduction

The expansion of society's footprint into the marine environment and constant pressure to develop and use marine space, means that UK coastal waters are already heavily used by extractive activities and marine space users. The carrying capacity of the natural environment, and the extent to which deployment of marine renewables devices exacerbates the cumulative impacts of all these activities on surrounding ecosystems has yet to be determined. This also includes the detection of local natural and anthropogenic changes against the moving baselines of global changes due to ocean acidification and climate change. It is imperative that we identify areas of deficient knowledge to ensure protection of the natural resource base, as well as to provide regulators and industry with well-defined environmentally-focused guidelines for the renewable energy sector.

The current study was commissioned to review existing biodiversity and ecosystems research effort in relation to marine renewable energy generation, and to identify critical research gaps in the current programme. This is to establish the extent to which implementation of marine renewable energy production is compatible with sustainable use of natural resources, and to provide additional depth and confidence to research-led evidence to ensure an energy extraction process which is environmentally acceptable. In particular, it is emphasised that environmental policy and management should be informed by the best science and that science should be fit-for-purpose.

In addition, NERC has recognised the need for a research programme which acknowledges the opportunities presented by energy technology deployments to enhance ecosystem recovery/restoration and maintain the health of existing ecosystems. This will help to ensure that renewable marine energy development optimises opportunities to build in resilience and responsiveness of the marine system to climate change, not only with respect to biodiversity and ecosystems, but in terms of socio-economic benefits as well. This concept goes beyond mitigation and compensation at the site scale – but considers the potential offered by energy production sites holistically in a regional seas context.

Consequently NERC commissioned a workshop involving research scientists and others from the principal universities and organisations involved in marine renewable energy research in the UK. The outcomes of the workshop provided the initial evidence for this review.

The main research themes which emerged from the workshop as relevant for future NERC programmes included:

- understanding the significance of energy extraction for physical processes (scoping study 1) biodiversity and ecosystem functioning (scoping study 2);
- emphasising that an understanding of the latter could not be achieved without a better understanding of the former;
- predicting the pace of ecological change at different scales (device to array to multiple array) using improved models;
- developing innovative solutions for building ecosystem resilience into management and planning of marine space use at increasing spatial and temporal scales.

This report collates data from a variety of sources together with the responses to consultation undertaken after the workshop, to identify the main gaps and opportunities in the current research programmes which meet the strategic goals of NERC science under the SUNR and Biodiversity themes.

2 Current status of marine renewable energy and associated environmental research

2.1 Review of offshore wind energy in Europe

This section provides a brief summary of published literature on offshore wind energy by the different European countries and funding bodies.

2.1.1 Research at offshore windfarm sites

Köller *et al.* (2006)[1] reviewed current environmental research associated with offshore wind energy in Europe and although they focussed on Germany, they included approaches undertaken by other European countries where research activities were more comprehensive than required by EU Directives or national licensing requirements for individual projects (see Bruns & Steinhauer, 2006[2]). The review clearly showed that different countries chose different research approaches to investigate the marine effects of offshore facilities. The research activities (and funding bodies) related to offshore wind energy in each country are briefly summarised below.

Germany (funded by the German Government under the AERO programme)

- Impact of sound emissions and vibrations of offshore wind turbines (OWT) on marine mammals and fish;
- Abundance and habitat patterns of marine mammals in the North and Baltic Seas related to the ecological relevance of potential areas for offshore windfarms or protected areas respectively;
- Bird migration and possible influence on migration paths in the North and Baltic Seas related to potential offshore windfarm areas;
- Bird collisions with OWTs;
- Time and area related dynamics of sea bird resting and reaction of resting birds to anthropogenic influence related to potential offshore windfarm areas;
- Impact of electromagnetic fields emitted by sea cables on marine organisms;
- Strategic Environmental Assessment (SEA), Environmental Impact Assessment (EIA, and Flora-Fauna Habitat Compatibility Assessment (FFH Assessment).

Denmark (funded as a Public Service Obligation (PSO) for Horns Rev and Nysted demonstration projects)

- Monitoring of the number and distribution of staging, moulting and wintering birds in the windfarm areas;
- Visual and radar observations to investigate changes in bird migration routes;

[1] Köller, J., Köppel, J. & Peters, W. (Eds.), 2006. *Offshore wind energy: research on environmental impacts*. Springer-Verlag, Berlin.

[2] Bruns, E. & Steinhauer, I., 2006. European review of environmental research on offshore wind energy. In: Köller, J., Köppel, J. & Peters, W. (Eds.). *Offshore wind energy: research on environmental impacts*. Springer-Verlag, Berlin.

- Investigations on the collision risk for birds, e.g. using Thermal Animal Detection Systems (TADS);
- Monitoring of harbour porpoises by visual surveys and Acoustic Porpoise Detectors (PODS);
- Aerial surveys, satellite tracking and video monitoring of seals;
- Monitoring of fish communities e.g. sand eel investigations and studies on the effects of electromagnetic fields of cables on fish migration;
- Hard bottom substrate monitoring;
- Infauna monitoring;
- Modelling of morphological changes;
- Sociological investigations of the acceptance of windfarms by local communities;
- Noise measurements.

United Kingdom (funded by the Crown Estate (COWRIE), Defra, DTI (and its successors BERR/DECC))

- Assessment of the significance of changes to the inshore wave regime as a consequence of an offshore wind array;
- Development of generic guidance for sediment transport monitoring programmes in response to construction of offshore windfarms;
- Investigation of the potential range of socio-economic impacts on the fishing industry from offshore developments;
- Aerial surveys of water birds in strategic windfarm areas;
- Further developing and enhancing the capacity of surveyors collecting acceptable quality of data on seabird distribution in UK waters;
- Production of methodology for assessing the marine navigation safety risk of offshore windfarms;
- Guidance for offshore windfarm developers on Seascape Impact Assessment;
- A study to assess fishing activities that may be carried out in and around windfarms.

The Netherlands (funded by the Dutch Government under the CO_2 reduction policy)

- Birds: flight patterns, occurrence, intensity, season, day/night in relation to estimated collision risk;
- Birds: disturbance of habitat/forage area;
- Birds: barrier effects;
- Valuation of landscape and habituation to the windfarm;
- Impact of underwater noise on fish and marine mammals;
- Variation and densities of underwater life and the function as a refuge;
- Consequences of North Sea users, particularly commercial fishers;
- Risks to shipping and consequential damage;
- Consequences for mining of minerals and raw materials;
- Morphological changes.

Sweden (funded by the Swedish Government)

- Fish;
- Marine invertebrates;
- Marine mammals (especially Baltic harbour seals);
- Hydrography;
- Migrating bats;
- Wintering seabirds; and
- Inventory of habitats and species in twenty offshore banks.

In general the research conducted at windfarm sites (UK and elsewhere in Europe) appeared to be operationally-based (and thus EIA-related) by assessing the status of biological components (benthos, marine mammals, birds, and fish) to define baseline conditions for the measuring potential impacts during construction and operation (decommissioning is not included [although it should be under any EIA]). In no case did this include long-lasting or whole ecosystem assessments with functional integration of various biological elements. Given the industry and applied focus of most of this research, it has not surprisingly, included very little 'blue skies' speculative conceptual science.

2.1.2 Status of offshore windfarms in the UK

As an indication of the level of development, the UK now has many operational offshore windfarm sites as well as three further sites being proposed for the Greater Wash Region: Dudgeon East (300MW, Warwick Energy), Triton Knoll (1200MW, **nPower** renewable) and Westernmost Rough (240MW, DONG Energy).

Table 1 – Review of the progress - Round 1 and Round 2 offshore windfarm developments in the UK (BWEA, 2007[3]).

Windfarm	Location	Region	Turbines	Power	MW	Status	Developer
Barrow	7km Walney Island	North West	30	3	90	Operational	DONG Energy / Centrica Renewable Energy
Beatrice	Beatrice Oilfield, Moray Firth	Scotland	2	5	10	Operational	Scottish & Southern
Blyth Offshore	1km Blyth Harbour	North East	2	2	3.8	Operational	E.ON UK Renewables
Burbo Bank	5.2km Crosby	North West	25	3.6	90	Operational	DONG Energy
Cirrus Array (Shell Flats)	7km Cleveleys	North West	90	0	270	Withdrawn after submission	Celt Power / DONG Energy / Shell Wind Energy
Cromer	7km Cromer	East of England	30	4	108	Withdrawn after approval	EdF
Docking Shoal		Greater Wash	0	0	500	Submitted (S36)	Centrica Renewable Energy Ltd
Greater Gabbard	26km off Orford, Norfolk	Thames Estuary	0	0	500	Approved	Airtricity
Gunfleet Sands I	7km Clacton-on-Sea	East of England	30	3.6	108	Under construction	DONG Energy
Gunfleet Sands II	8.5km off Clacton-On-Sea	East of England	18	3.6	64	Under construction	DONG Energy
Gwynt y Mor	13-15km offshore	North Wales	250	0	750	Approved	nPower renewables
Humber Gateway	Withernsea	Yorkshire & Humber	70	3	300	Submitted (S36)	E.ON UK Renewables
Inner Dowsing	5.2km Ingoldmells	East Midlands	27	3.6	16	Under construction	Centrica Renewable Energy Ltd
Inner Dowsing	5.2km	East	27	3.6	81	Operational	Centrica

[3] BWEA, 2007. British Wind Energy Association. Website Accessed April 2009. www.bwea.com

(Part)	Ingoldmells	Midlands					Renewable Energy Ltd
Kentish Flats	8.5 km offshore from Whitstable	South East	30	3	90	Operational	Vattenfall
Lincs	8km off Skegness	Greater Wash	0	0	250	Approved	Centrica Renewable Energy Ltd
London Array	24km off Clacton-on-Sea	Thames Estuary	271	0	1000	Approved	DONG Energy / Shell Wind Energy / E.On Renewables
Lynn	5.2km Skegness	East Midlands	0	3	16	Under construction	Centrica Renewable Energy Ltd
Lynn (Part)	5.2km Skegness	East Midlands	30	3	81	Operational	Centrica Renewable Energy Ltd
North Hoyle	7.5km Prestatyn & Rhyl	North Wales	30	2	60	Operational	nPower renewables
Ormonde	off Walney Island	North West	30	5	150	Approved	Eclipse Energy
Race Bank		Greater Wash	88	0	620	Submitted (S36)	Centrica Renewable Energy Ltd
Rhyl Flats	8km Abergele	North Wales	25	3.6	90	Under construction	nPower renewables
Scarweather Sands	5.5km Sker Point (nr Porthcawl)	South Wales	30	3.6	108	Approved	DONG Energy/ E.ON UK
Scroby Sands	3km NE Great Yarmouth	East of England	30	2	60	Operational	E.ON UK Renewables
Sheringham Shoal	Sheringham, Greater Wash	East of England	0	0	315	Approved	Scira Offshore Energy Ltd
Solway Firth/Robin Rigg A	9.5km Maryport/8.5km off Rock Cliffe	North West	30	3	90	Under construction	E.ON UK Renewables
Solway Firth/Robin Rigg B	9.5km Maryport/8.5km off Rock Cliffe	North West	30	3	90	Under construction	E.ON UK Renewables
Teeside/Redcar	1.5km NE Teesmouth	Yorkshire & Humber	30	0	90	Approved	EdF
Thanet	11-13km Foreness Point, Margate	Thames Estuary	0	0	300	Under construction	Warwick Energy
Walney	14km Walney Island, Irish Sea	North West	42	3.6	450	Approved	DONG Energy
West of Duddon Sands	N. Irish Sea	North West	160	3.6	500	Approved	DONG Energy/ ScottishPower Renewables/ Eurus Energy

2.1.3 Summary of wind energy research status

Although the development of the offshore windfarm sector is well behind that anticipated by government, there have been major policy and financial issues which have led to some developers withdrawing from some sites. Developers, regulators and scientists have already recognised major issues which require research input emerging from the present developments and these have yet to be taken up by the research community. These mainly relate to the opportunities for socio-economic benefits, which many scientists believe could contribute to de-risking and improving

public acceptability of OWFs by diversifying employment opportunities for the host community. These are discussed in more detail later.

2.2 Tidal-stream energy research in the UK and Europe

2.2.1 Tidal energy research

The development of the so called "wet renewables" tidal-stream and wave (see below) energy extraction is considerably behind the offshore wind industry which has benefitted from the experience of onshore developments. Thus taking wet renewables offshore has meant starting with clean slate for almost all aspects – moorings, fundamentals and specifics of energy capture, water column location and so on. With such strong political and economic drivers now in place, these two industries are now expanding extremely quickly. But this rapid growth and lack of terrestrial parents has meant that a wide diversity of fundamentally different concepts are being progressed simultaneously and the inevitable winnowing of designs has yet to happen to any significant degree. This poses a significant challenge to the academic research community interested in the environmental interface. Lessons learnt from studies of one device are unlikely to be applicable to another in the way that comparison of wind turbines has been performed. In addition, the early stage of development has also meant that studies of environmental interactions have been device or site specific in their nature. Almost all of the significant environmental studies of tidal-stream devices are ongoing and so, unlike wind, there is little yet in the peer reviewed literature upon which to draw here. Nevertheless, there are fundamental similarities between wind structures and other devices with respect to possible effects on ecosystems and some inferences could be drawn (i.e. effects of EMF, piling noise and behavioural responses, effects of the substratum, trawl hindrance, etc.). We have 5 decades of putting offshore structures in place, and have learnt lessons from the presence of structures, but many opportunities missed.

The following sections summarise the key studies/players that are at the forefront of addressing issues of environmental interactions of tidal-stream devices.

2.2.2 European Marine Energy Centre (EMEC), Orkney

As well as wave test facilities, EMEC provides multi-berth, purpose-built test facilities for tidal-stream energy converters in semi-sheltered marine waters. The tidal site is in the Fall of Warness off the island of Eday where currents run up to 4m.sec^{-1} (7.8 knots at spring tides). The facility offers five test berths at depths ranging from 25m to 50m in an area *c.*2km by 4km.

The concept is that EMEC provides assistance (physical infrastructure and logistics) for developers wanting to test scale-equipment at the prototype stage. As part of that service EMEC have developed generic Impact Assessments and it also has a developing research programme with diverse collaborators. To date these have focussed on marine mammals and seabirds because these are thought to be the main environmental sensitivities of that site. The research project underway are outlined below:

- **Wildlife Displacement: Observations Programme**
  This project aims to provide an overall understanding of whether or not a change or displacement has occurred in the resident wildlife due to the

presence and operation of marine energy devices. Observations began in July 2005 and are ongoing. An additional key output will be the production of a suitable methodology (generated in collaboration with SMRU), which could act as a guideline for future marine renewable developments, including further testing of devices at the EMEC facility.

- **Sub-Surface Interactions: Sonar System.**
  The possibility of damage to wildlife through physical collision with wave or tidal devices is an issue of concern across environmental stakeholders. With limitations on video coverage, due to both turbidity and natural light constraints, EMEC together with SMRU are using sonar to investigate possible collision damage.

- **Tidal Rapid Seabed Ecology: ROV analysis**
  This project will utilise the large catalogue of EMEC data from seabed video surveys to assess benthic impacts and contribute to the development of suitable surveying guidelines.

- **Acoustic Output from Devices: Acoustic Characterisation and Monitoring**
  Concern over acoustic emissions of devices for marine mammals, some fish species and possibly diving birds are widespread across the industry. This project has worked with SAMS to develop novel measurement technologies and acoustic mapping to assess the spatial acoustic footprint of the industry.

- **Energy Extraction by Tidal Devices**
  A large amount of physical modelling work has been completed in research programmes elsewhere (e.g. SuperGen Marine). EMEC is ground-truthing these models by utilising data collected using acoustic current doppler profilers (ADCPs).

  EMEC funding has come from BERR (now DECC), HIE, the Scottish Government (SG), Orkney Islands Council, Scottish Enterprise, Carbon Trust, and the EU.

2.2.3 Marine Current Turbines Ltd / Sea Generation Ltd

Marine Current Turbines Ltd (MCT) are a leading tidal-steam turbine developer and have been operating a small test turbine (Seaflow) off Devon since 2003. They own a subsidiary company (Sea Generation Ltd) which operates a 1.2 MW tidal energy converter. This was installed in Strangford Lough, N. Ireland in April 2008. Owing to considerable environmental sensitivities of the site, an extensive EIA study was carried out and a FEPA licence to operate has been granted to operate for five years. Research / monitoring work is ongoing and being carried out by Royal Haskoning with Queens University Belfast and the Sea Mammal Research Unit providing the science input

2.2.4 SuperGen marine

The Sustainable Power Generation and Supply Initiative (SuperGen) Consortium focuses on the potential for exploitation of the marine energy resource. Funding is provided by EPSRC. SuperGen Marine Phase 1 (October 2003 - September 2007) brought together University research staff (Universities of Edinburgh, Robert Gordon, Lancaster, Heriot-Watt and Strathclyde) to undertake generic research on the extraction of energy from the sea; reduce risk and uncertainty and enable progression of marine technology into future energy portfolios.

Phase 2 (4 yrs, ongoing) aims to increase knowledge of device-sea interactions from model-scale to full size in the open sea. Crucially this phase includes the environmental impacts associated with these technologies.

2.2.5 Equitable Testing and Evaluation of Marine Energy Extraction Devices in terms of Performance, Cost and Environmental Impact (Equimar)

Equimar is a three year EC FP7 project that started in 2008. The project brings together a consortium of 22 partners to develop comparative metrics for tidal-stream and wave technologies for a wide range of disciplines from pure engineering to economic perspectives. One work stream is purely dedicated to environmental issues, covering standardisation of impact assessment, marine mammal monitoring techniques and collision risk assessment. One Portuguese (WAVEC) and three UK institutions (EMEC, SAMS, SMRU) are involved in this work package.

2.2.6 Summary of tidal-stream energy research status

Research on the environmental interactions of tidal-stream devices is at an early stage. The bulk of this work has either had a specific geographical focus (pre-installation surveys and data compilation - EMEC & SeaGen Strangford Lough) or predictive modelling (Scottish Executive, SEA). The imminent progression of the industry to producing scale installations will provide many more opportunities to test previous modelling work and investigate less predictable aspects (e.g. behavioural responses of animals to turbines). However a variety of factors in combination (diversity of the device concepts, short duration first-deployments, company specific research funding, complexity of target sites) is likely to hinder the development of a generic understanding of how this multi-faceted industry will interact with the environment. Accordingly, without funded research focussing on generic issues, our basic understanding of environmental interactions is likely to significantly lag behind site/device specific issues.

2.3 Wave energy research in the UK

As mentioned above the development of wave energy is well behind that of wind and because of the diversity of devices currently being progressed, the level of generic understanding applicable to the offshore wind sector is still a distant future goal in the wave industry. There are however already a variety of devices undergoing performance testing, and because of some similarities in the challenges, wave and tidal energy research can often transfer between sectors. Although there are several initiatives of note outside the UK, the main facilities at present are at EMEC and are in development off the north coast of Cornwall at the Wave Hub site.

2.3.1 Wave Hub

Wave Hub is a renewable energy demonstration project in the South West of England, that aims to create the UK's first offshore facility for the demonstration and proving of the operation of arrays of wave energy generation devices. The development of the Wave Hub has been financed by the South West of England Regional Development Agency (SWRDA) to provide the electrical infrastructure necessary to support and encourage developers of wave energy converter devices (WECs) to test the feasibility of generating electricity from wave energy. It will allow developers the opportunity to test groups (arrays) of devices over several years to

prove the technologies will operate effectively, in realistic offshore marine conditions and that they will produce the expected amounts of power. Wave Hub will support the UK government's energy policy by contributing towards the drive to meet the challenges and achieve the goals of the new energy policy including a 60% reduction in carbon emissions by 2050. In addition, Wave Hub will support the South West region's commitment to encouraging technologies for renewable energy generation that will contribute to the region's renewable energy target of 11% - 15% of electricity production by 2010. If the necessary consents are granted, it is expected that the Wave Hub will be installed in the spring/early summer of 2010 and for the first WECs to be installed from that time.

2.3.1.1 PRIMaRE

In addition to supporting the Wave Hub infrastructure, a new research cluster developed by the Marine Institute of the University of Plymouth in partnership with the University of Exeter, PRIMaRE (Peninsular Research Institute for Marine renewable Energy), brings together a unique team of world-class researchers to provide expertise and research capacity to address the wider considerations of all aspects of marine renewable energy.

PRIMaRE has identified and is currently focussed on the following six priority research areas at the Wave Hub site:

- Resource Characterisation
- Marine Renewable Energy Systems
- Environmental and Biodiversity Impacts
- Safe Operations and Navigational Risk
- Underwater and Surface Electrical Systems
- Socio-Economic Factors

Within the 'Biodiversity impacts' priority area, 4 projects are currently running[4]:

- **Benthos – invertebrates and fish associated with the seabed**

  The benthos team is monitoring infauna, epifauna and benthic fish to assess the direct effects of the Wave Hub construction and Wave Energy Convertors on the benthos. They will also assess indirect effects to the benthos caused by the implementation of the Wave Hub safety zone, which will exclude other maritime activities, so that we can advise on how to maximise the benefits of future offshore renewable energy installations. Quantitative assessment of benthic assemblages is mainly achieved using multi-season video sampling at each site using cameras mounted on drop-down frames and Remote Operated Vehicles. This is supplemented by non-destructive trapping and potting programmes to determine whether the Wave Hub boosts local populations of commercial species such as crabs and lobsters.

- **Marine Vertebrates**

  Marine renewable energy installations are likely to have impacts at both local and wider ecosystem scales. The potential negative impacts have been well documented although many of these effects have yet to be convincingly demonstrated empirically.

[4] All these 4 projects are also relevant to wind and tidal devices

There is also the possibility that the marine renewable developments may be beneficial to the local ecosystem. In effect, sites will have reduced fisheries pressure, and form 'artificial reefs' which have, in some cases, been shown to benefit benthic communities and fish populations, which in turn, via trophic cascade effects, may benefit higher vertebrates.
The 'Wave-Hub' project may have direct and indirect impacts on the surrounding ecosystem, including local marine mammal and bird populations. Many of these populations have large ranges and are migratory or transient which makes detecting any impacts rather difficult unless sampling is carried out in a rigorous and systematic manner. We have, therefore, developed a survey program, utilising distance sampling survey techniques and static acoustic arrays to maximise our ability to detect any effects of the 'Wave Hub'.

- **Fisheries (pelagic and demersal)**
  Population structure, distribution and movements of marine bioresources associated with the Wave Hub

  This programme will monitor fish movements and distribution, population structure, and genetic variability of commercially important species and those of conservation importance to detect any changes as a result of the Wave Hub. The team will also deploy a state-of-the-art acoustic monitoring array to track the long-term movements of tagged fish and model their behaviour, before, during and after the development.
  Data storage tags fitted to fish in the same area will determine their broader scale dispersion, space use and behaviour. Additional sampling will enable population-level genetic variability to be determined for commercial and vulnerable species in comparison to populations from other regions.

- **Habitat enhancement**
  Incorporating biological habitat enhancement into marine renewable schemes

  Increasing amounts of artificial habitat are being placed in the marine environment, particularly as a result of the expansion of the offshore renewable energy sector. However, there are concerns that this may have negative impacts on the environment. Using a cross-disciplinary engineering and ecological approach the habitat enhancement team are currently developing and trialling marine engineering construction to maximise the potential outcomes for marine life, including commercially important species. Specifically we are manipulating various types of engineering to enhance the outcomes for marine biodiversity at a hierarchy of spatial scales. The outcomes will be of direct relevance for a range of marine engineering applications (e.g. renewable energy devices, coastal defence etc.) as well as fisheries and the environment.

2.3.2 EMEC (European Marine Energy Centre)

In addition to the tidal testing site at the Falls of Warness, EMEC provides multi-berth, purpose-built, open sea test facilities for testing wave energy converters at Billia Croo, on the west of Mainland Orkney. The wave test site receives uninterrupted Atlantic waves of up to 15m. The monitoring currently underway at the wave test site is as follows:

- **Wildlife Displacement: Land-based Observations Programme**

The aim of the wildlife observations monitoring project is to detect any change or displacement that may occur in the resident wildlife due to the presence and operation of marine energy devices.
Whilst the tidal site observations are ongoing, in the project at the wave site, funded jointly by Scottish Natural Heritage (SNH) and nPower, the process and statistical approach to data analysis will be re-assessed and amended to make it appropriate for the very different environment at the wave test site. This project will also operate in combination with a dedicated camera (also funded by nPower) to investigate wildlife interactions visible at the sea surface.

- **Surface Interactions with Wave Devices : High Specification Camera Observations**
  The objective of this project is to inform wave energy device operators, as well as regulatory and other decision makers, about the frequency and nature of specific interactions between marine mammals and birds, and those parts of devices which are on or above the sea surface. The outcomes should help allay some of the concerns about possible interactions. The project is funded by nPower and has seen a dedicated high magnification camera placed at the existing lookout post on Blackcraig. It is hoped that this investigation will provide a methodology for assessing the effects of the protruding elements of wave devices on marine mammals and birds, using a high resolution camera. It is also hoped that a correlation between the tow observations datasets may indicate the adequacy of using the camera alone for monitoring surface interactions.

- **Resource Assessment: Monthly Reports**
  EMEC continuously collects real time data at its wave test site, covering variables such as wave and current alongside weather parameters such as wind, precipitation and temperature. EMEC has commissioned ICIT (International Centre for Island Technology) to undertake routine monthly analysis of the MetOcean data gathered. The reports produced are available to developers deploying at the wave site, and inform in sufficient detail on the conditions, which help in device design and assessment.

2.3.3 Oregon State University (OSU) / Hatfield Marine Science Center (HMSC), USA.

Research scientists in the USA, notably at the Hatfield Institute are now becoming interested in the potential of wave energy, which held a workshop with Oregon State University in October 2007 on “Ecological Effects of Wave Energy Development in the Pacific Northwest”. During this workshop, participants repeated concerns that the lack of information and data describing the nature of the wave energy technologies, and the incomplete understanding of marine resources and coastal zone dynamics, introduce substantial uncertainty into the assessment of cumulative effects. All groups pointed out that given the lack of baseline information and information concerning effects of the construction and operation of wave energy structures, monitoring is a key component of the development of wave energy projects. Monitoring specific fauna (e.g., sea birds, marine mammals) is needed to understand the changes that could occur for project construction and implementation. There is therefore an urgent need for environmental studies of wave energy conversion and associated interactions with biodiversity. Throughout the workshop, the importance of evaluating ecological effects at any wave energy demonstration study sites or pilot scale facilities was stressed.

The Oregon Wave Energy Trust (OWET) have recently awarded funds to a consortium of consultancies to initiate data collection and analysis to prepare the methods for undertaking cumulative impacts assessment in relation to wave energy. Following the recent visit of Prof George Boehlert from the Hatfield Institute, PRIMaRE and PML are developing relationships with OWET and the Hatfield Institute with a view to closer cooperation in future.

2.4 Summary of wave energy research status

None of the ongoing European projects for testing wave energy devices (except at WaveHub and EMEC) have – to our knowledge – an environmental dimension. The Equimar project will however provide developers with a suite of protocols for EIA and monitoring, but the need for fundamental underpinning research remains, as highlighted by the Oregon workshop.

Table 2 below provides a summary of wave energy device test sites in Europe. We are aware of two additional sites in Australia off Perth and Sydney but have no details to hand at present. Although we are still awaiting information from developers who are carrying out trials of prototypes, only Wave Hub and EMEC are undertaking or have undertaken environmental baseline surveys and are considering detailed environmental monitoring / research projects

Table 2 – Wave energy device test sites in Europe

Name of project/site	Developers / Devices	Location	Environmental monitoring
Wave Hub	Orecon – Orecon buoy Ocean Power Technologies – PowerBuoy Fred Olsen – FO3 WestWave – Pelamis	Cornwall, UK	Yes – PRIMaRE ▪ Benthos – invertebrates and fish associated with the seabed ▪ Marine Vertebrates ▪ Fisheries (pelagic and demersal) ▪ Habitat enhancement
EMEC	Pelamis Wave Power – Pelamis AW Energy – WaveRoller Aquamarine Power – Oyster (Autumn 2009)	Scotland, UK	Yes ▪ Wildlife Displacement ▪ Surface Interactions
Ocean Energy Test Site	Wavebob Ltd – Wavebob (¼ scale) Ocean Energy Ltd – OE Buoy (¼ scale)	Galway Bay, Ireland	No
Limpet	Wavegen – Limpet	Scotland, UK	No
Wave Dragon MG	Wave Dragon	Denmark	No
Aguçadoura Wave Energy Park	Pelamis Wave Power – Pelamis	Portugal	Apparently soundscape only (WEAM project)
SEEWEC	Fred Olsen – FO3	Norway	No
Wave Star – small scale prototype	Wave Star Energy – Wave Star	Nissum Bredning, Denmark	Video recording each year in August, noise measurements

2.5 Summary of status of renewable research in UK and Europe

Although offshore wind, wave and tidal sectors are at different stages of development, and the environmental research in relation to wet renewables is in its infancy, research and monitoring to date has been focussed primarily on supporting developers and regulators to get devices deployed and tested. If anything, environmental considerations are regarded as a barrier to progress by developers, but by those with an awareness of environmental issues, there is recognition that their industries face an uncertain future unless research quality evidence is available to support the project development and implementation processes. Some of the most enlightened device designers have incorporated environmental mitigation measures into their designs – but whether this has lead to reduced energy conversion performance has yet to be tested. Consequently we see a continuing need to push ahead with integration across all research areas, to work towards sustainability through major advances at design, commissioning, construction and throughout the operational life of offshore energy projects. This constitutes a major challenge to the research councils and researchers themselves in building multi-disciplinary teams.

2.6 Summary of status of renewable projects outside Europe

Although North-West Europe is currently leading offshore wind, wave and tidal energy development, the USA, Canada, New Zealand and Australia have all joined the race to develop marine renewable energy (see list of projects in Annex 5).

In the USA more than 6 offshore windfarms developments have been proposed, all of them on the Atlantic coast, but as yet no offshore windfarm is operational. Tidal and wave projects have been increasing in number for the past few years, with 27 (East coast) and 10 (West coast) pre-permits granted by the Federal Energy Regulatory Commission. A few tidal (e.g. RITE) and wave (e.g. Rhode Island) projects seem to be on a promising track. Canada has at least 2 offshore windfarms being considered, whilst two ambitious tidal projects (CORE and Bay of Fundy) are also being developed, and possibly one wave project. New Zealand has several tidal projects in Kaipara Harbour and Cook Strait whilst Australia has at least 3 wave projects being considered. In South Korea 2 potential tidal developments are underway with government funding. The information on offshore renewable energy in China is limited (or not available in English). Apparently a cooperation agreement was signed between the Chinese Government in Dandong City and Tidal Electric in 2004 to develop a tidal lagoon, but no recent information has been found to confirm this. We have encountered a high degree of interest in marine renewables during a recent mission to China and are aware of initiatives through UKERC to assist with capacity building and knowledge transfer.

It is clear that an international network of relationships is developing across UK universities and research institutions with their counterparts worldwide, especially in North America and Australia / NZ, and across all the renewable energy sectors. The current interest in using UK research know-how and demonstrator sites to test new devices, and the challenging legislative context within which we have to operate, has resulted in the UK already playing a leading international role in providing primary research input and advice across engineering, environmental and socio-economic disciplines. The continuing development of appropriate methods and research quality

evidence of the scale and significance of the impacts (both positive and negative) of renewable energy technologies, will lead to consolidation of the UK's position as a leading research provider for the benefit of ALL the marine renewable sectors, which could be lead and encouraged by appropriate international funding opportunities. However, existing research needs to be substantiated, with greater depth and confidence attributed to initial findings, through investing in whole system approaches which put environmental considerations ahead of the rush to deploy novel technology.

3 Organisations currently involved in marine renewable energy research

3.1 Introduction - research perspectives

3.1.1 The regulator

The predominant perspective of regulators is that current research needs to be targeted on species for which the UK has statutory obligations (e.g. Habitats regulations, European protected species etc.). For example, a recent workshop attended primarily by UK regulators (JNCC, SNH, FRS, SEPA etc) identified and prioritised as key issues impacts on pelagic marine vertebrates and other issues such as habitat alterations were ranked much lower (see Figure 1). Feedback from regulators on the NERC workshop (26th Feb, 2009) also indicated that they thought discussion had focussed on conceptual ideas for research and on topics of academic or commercial interest to the institutions concerned, rather than on the more pressing research needs of regulators to ascertain the environmental consequences, if any, that marine renewable energy developments might have. Regulators wanted to see research to address the urgent 'show stopping' scientific problems that need to be tackled now, if the industry (and especially wave and tide) is to progress beyond the demonstration stage and start contributing, significantly to government's renewable energy targets. Regulatory decisions for the offshore windfarm sector have to a large extent relied on the long term and detailed studies supported by the Danish government at the OWF sites of Nysted and Horns Rev. These studies provided crucial information and evidence over a sustained period of five years which allowed assessment of the impact of OWFs on natural resources off Denmark at least, and have been extrapolated to some extent, to UK locations. There are however many uncertainties with respect to construction effects, especially piling, noise and effects on behaviour of sensitive species like herring.

3.1.2 The developer

Most developers are currently focussed on the engineering challenge of getting their devices in the water and resolving these within their particular financial constraints. Most developers commission environmental consultants to obtain the necessary consents for deploying devices on their behalf. These invariably include initial environmental evaluation / scoping studies, baseline environmental characterisation studies, an EIA to accompany planning application then environmental monitoring of specific aspects as required by the regulator. There is often the problem of scant resources for these studies because of the need to focus on getting technology in the water and functioning properly, and from a research point of view, there are often questions regarding the usefulness of data generated by these studies. Although protocols for environmental sampling are available, monitoring is undertaken by a range of different survey / consultancy organisations and data is often not available to external bodies who might make use of it to design and progress more detailed research projects. In addition, the disconnect and budget constraints under which government has operated have lead to monitoring requirements being requested with little or no reference to adequate contextual information to ensure that the monitoring has a worthwhile and useful outcome. Rarely are the spatial or temporal

considerations of monitoring programmes scaled to adequately consider processes that operate beyond the scales of the development, leading to inevitable conclusion that for some species, monitoring is either completely pointless or raises more questions than it answers. This means that EIA studies and monitoring at device testing sites, outside formal managed facilities such as EMEC, probably have limited applicability for research purposes.

3.1.3 Research scientists

Currently the main activity of research scientists in relation to marine renewables is opportunistic in response to tender calls in their research area and by those scientists living near to existing or prospective marine renewable energy installations. Some research scientists have a historic interest in particular groups of organisms – and have transferred their interest to the range of issues raised by renewables. However, finding funds to support the research in this area has presented many marine scientists with a major problem – this applies particularly to those whose main source of funding has in the past been the NERC.

Current funding streams to support research are linked directly to the industry needs, which are in turn focussed on applied research. However, numerous scientists working on marine ecology, fisheries biology, behavioural ecology, marine protected areas, biotope classification and in general marine research at any level of organization, including socio-economic aspects, undertake funded research that is relevant to the effects of marine renewables on ecosystems. Thus, there are institutions and individuals that, given the possibility of funding will be able (and willing) to focus on direct linkages between their own research interest and research needs in the field of marine renewables. There is a major opportunity at the present time to ensure that biodiversity and ecosystem research in relation to wave and tidal energy does not suffer the same fate as the offshore wind sector, which is still managing (as risk) issues which could have been addressed by the research community when the first offshore windfarm sites were licensed.

3.2 Organisations delivering research in the UK

Table 3 – Principal organisations involved in biodiversity and ecosystems research plus main contacts and research capabilities

Sea Mammal Research Unit (SMRU) Dr. Ian Boyd and co-workers http://www.smru.st-andrews.ac.uk/	Interest in accumulating evidence and predicting the effects of some renewable energy technologies on marine mammals.
Scottish Association for Marine Science (SAMS) Drs. Ben Wilson, Bob Batty, Kenny Black, Tom Wilding http://www.sams.ac.uk/	Environmental interactions between Marine Renewable Energy Devices (MREDs or kinetic energy devices) and marine vertebrates (fish, mammals and diving birds) - risks of collision between marine vertebrates and tidal turbines - underwater acoustic impact of MRED technologies on sensitive species - artificial reef effects & design
Plymouth Marine Laboratory (PML) Drs Mel Austin, Stephen Mangi, Jerry Blackford, Jim Readman, Mike Kendall, Peter Miller, Jamie Shutler http://www.pml.ac.uk/	Ecosystem modelling, benthic community impacts, interactions fisheries and MREDs, potential for socio-economic benefits, biofouling problems associated with MREDs, remote sensing applications
Marine Biological Association (MBA)	Understanding the mechanisms underlying the

Professor David Sims and team http://www.mba.ac.uk/	spatial movements, behaviour and population structure of marine fish, and how this relates to larger scale responses of populations to climate and fishing impacts. Behaviour and ecology of sharks and rays, taxa that are particularly sensitive to electrical discharges associated with offshore renewable energy devices
NOC Dr Antony Jensen, Dr. Ken Collins http://www.noc.soton.ac.uk/	Artificial reef research and inshore fisheries Membership of the IAPEME expert panel that audited the science coming from the two Danish windfarms at Horns Rev (North Sea) and Rods (Baltic)
Universities Non NERC	
Queen's University Belfast Marine Laboratory Dr Graham Savidge http://www.qub.ac.uk	Close involvement in the development of the Environmental Impact Assessment for the MCT SeaGen Tidal Turbine in Strangford Narrows, Northern Ireland and the subsequent development and initiation of the Environmental Monitoring Programme (EMP) for the project Supervision of long-term ongoing contract for monitoring of large animal activity and benthic community structure and ADCP measurements as required for the SeaGen EMP Partner with Heriot-Watt University in WorkStream 10 (WS 10) of EPSRC-funded SuperGen 2 Consortium project investigating the ecological consequences of wave and energy extraction systems.
University of Exeter Dr. Brendan Godley http://www.exeter.ac.uk/ **University of Plymouth** Prof. Martin Atrill / Dr.Richard Thompson http://www.plymouth.ac.uk/ **PRIMaRE** http://www.primare.org/	Marine biology (fish, cetaceans and bird monitoring) and the physical/ coastal effects (sediment transport/ beach morphology/ currents). Biological habitat enhancement of structures for biodiversity benefit.
Cranfield University Dr Andrew B Gill http://www.cranfield.ac.uk/	Particular focus on fish foraging ecology and trophic interactions between predators and prey and how humans can influence them. potential effects on electromagnetic (EM) sensitive fish of EM field emissions associated with subsea electrical cables, particularly those associated with offshore renewable energy
Aberdeen University Dr. Beth Scott http://www.abdn.ac.uk/	Marine ecosystem studies focusing on the functional linkages between oceanographic processes, flexible individual life history traits and population dynamics. In particular using Individual Based Models (IBM) as tools that explore the variation in individual growth, maturation and reproductive output with temporal and spatial overlap in food resources.
Bangor University Prof Michel Josef Kaiser http://www.bangor.ac.uk	Biodiversity and ecosystems research focussing on fisheries management and marine protected areas.
Hull University Professor Mike Elliott http://www.hull.ac.uk/	Impacts and benefits of conventional and renewable energy generation in the coastal and offshore environment and my Institute has recently received >£0.75 million for researching the impacts of marine renewable energy in the UK and elsewhere (both windpower and tidal stream power). I have participated in and chaired workshops and meetings on these energy sources and tidal barrages, and co-

	authored evidence-based papers for Defra for the UK Marine Bill and for BERR-DECC on offshore windpower monitoring. I have reviewed Defra marine research programmes and led workshops on seabed disturbance; I chair the Expert Panel for BEEMS (*British Energy Estuarine & Marine Studies* project).
Non governmental Non NERC research	
British Trust for Ornithology Dr Mark Rehfisch, *Director of Development* http://www.bto.org/	Environmental factors that affect waterbird population dynamics, such as developments, including the Cardiff Bay barrage and renewables. Quality assessment of model used to estimate bird collision-risk from windfarms development of Population Viability Analysis approach to place windfarm loses in context of species population dynamics, and developing new methodological approaches for Cumulative Impact Assessment.
Consultancies	
ABP Marine Environmental Research Ltd Bill Cooper http://www.abpmer.co.uk	Developing guidance, best practice and industry standards to assist project development for offshore wind, tidal stream and wave energy project
Aquatera http://www.aquatera.co.uk	Fully integrated lifecycle support for renewable energy and other environmental projects ; Environmental assessment, surveying and management ; Technical and operational support ; Public and stakeholder communications Examples of projects: Highland Renewable Energy Strategy, Marine Renewables EIA Guidance Procedures (EMEC)…
Xodus http://www.xodusgroup.com/	The Xodus Group is an international, independent oil and gas and energy consultancy providing solutions for subsea, oil and gas, technological challenges with offices in the UK and in Australia: problem solving for marine renewable projects ; specialist input into environmental permit and consent applications ; inshore hydrographic, bathymetric and meteorological surveys in support of consent applications and EIA.
Hartley Anderson Ltd John Hartley http://www.hartleyanderson.com	Promotion of science to underpin environmental management decisions Independent environmental consultancy to governments, conservation bodies and the energy and other industries Programme manager for the portfolio of RAG research on marine renewables since July 2006
Marine renewable test sites (UK only)	
EMEC Dr Jennifer Norris Research & Consents Manager http://www.emec.org.uk/	Since its opening in 2004, EMEC has built up detailed knowledge of the processes relating to the consenting of wave and tidal energy devices, and the main issues of concern that are associated with such deployments. This has entailed very close liaison with regulators and key stakeholders
Wave Hub Nick Harrington, Project manager http://www.wavehub.co.uk/	Wave Hub is a renewable energy demonstration project in the South West of England that aims to create the UK's first offshore facility for the demonstration and proving of the operation of arrays of wave energy generation devices.

3.3 Agencies funding renewable energy research

Table 4 below summarises the review undertaken by Davies (2008)[5] of environmental research activities in relation to wet renewables (wave and tidal power generation). This review was part of a wider study which aimed to develop proposals for strategic research activities that would encourage the development of power generation from wet renewable sources in Scottish coastal waters.

Table 4 – Current major research activities in Scottish coastal waters (Davies, 2008).

Contractor	General research area	Funding
European Marine Energy Centre (EMEC), Orkney	Field testing of wave and tidal devices, environmental monitoring, interactions of wildlife with energy devices	SG Industry (developers)
MCT Ltd.	Field testing of a tidal turbine device in the entrance to Strangford Lough	Industry (developers)
SUPERGEN consortium project	SUPERGEN 1: Energy Resources & Converters: Environmental Interaction Device and environmental engineering, economics, field validation and testing procedure, etc. SUPERGEN 2: Numerical and physical convergence Combined wave and tidal effects Arrays, wakes and near field effects Engineering and moorings Economic analysis Ecological consequences of tidal and wave energy conversion	EPSRC (main funder) in partnership with BBSRC, ESRC, NERC and the Carbon Trust. SUPERGEN 1 received £32M, £2,61M for marine. SUPERGEN 2: formed and funded. Current EPSRC portfolio linked to SUPERGEN is £42M.
Sea Mammals Research Unit (SMRU) and SMRU Ltd. activities related to offshore renewable energy	Distribution and behaviour of marine mammals, interactions with marine energy devices, technology for the detection of mammals around energy devices.	NERC Government Industry
MREDS consortium project	Framework project including academia, SMEs, developers, oil industry etc. Lays out broad themes for work areas and associates key personnel and associated personnel. Seeking funding opportunistically for the various work areas.	Strategic Research Development Grant (£1M). £0.5M from Orkney sources to fund the Steering Group.
UHIE / Heriot Watt University / EMEC Project '*Advancing Marine Renewable*	Coastal Physical Processes, Hydrodynamics and Water Column Processes, Benthic Dynamics, Ecological Considerations and Consequences.	Strategic Research Development Grant (£1M). Part of MReds funding.

[5] Davies, I., 2008. Strategic research assessment for wet renewable. Fisheries Research Services Internal Report 11/08.

Energy Research Capacity in Scotland'		
COWRIE	Collaborative Offshore Wind Research Into the Environment (COWRIE). Effects of electromagnetic fields (EMF) on fish, aerial and boat-based bird surveys, displacement of birds from feeding areas, effects of underwater noise on marine mammals.	£450,000. From refundable deposits paid by developers and held by Crown Estate.
BERR RAG	UK Research Advisory Group on marine renewable energy. Wide range of research related to marine windfarms, now addressing wave and tidal energy. Further details are provided below (Appendix 1).	Projects funded by UK Government, mainly DTI (BERR) and Defra.

3.4 Research coordination

3.4.1 Role of BERR (now DECC) / COWRIE Research Advisory Group (RAG)

Table 10 (see Appendix 1) provides a summary of the current version of the DECC / COWRIE joint list of environmental research project needs to support licensing of wind, tidal and wave projects. Note: the project status reflects work funded by a range of bodies including RAG and COWRIE. These projects have been jointly identified by members of the RAG and prioritised amongst the RAG members and progressed under the supervision of Dr. John Hartley, chairman of the RAG. The activity progressed under this programme has acted as the main focal point for research associated with marine renewable energy, covering all the main issues from key elements of biodiversity – mammals and birds – to issues of conflict with navigation and fisheries.

3.4.2 EMEC RAG

Following a workshop in September 2008, EMEC set up both a Research Advisory Group and Monitoring Advisory Group to guide its activities in the future. The main objective of these groups is to make sure that EMEC makes use of all opportunities to attract research effort to the demonstrator sites for the benefit of developers and also that the monitoring needs are prioritised and adequately funded for regulatory purposes. (see also section 2 above details of ongoing monitoring)

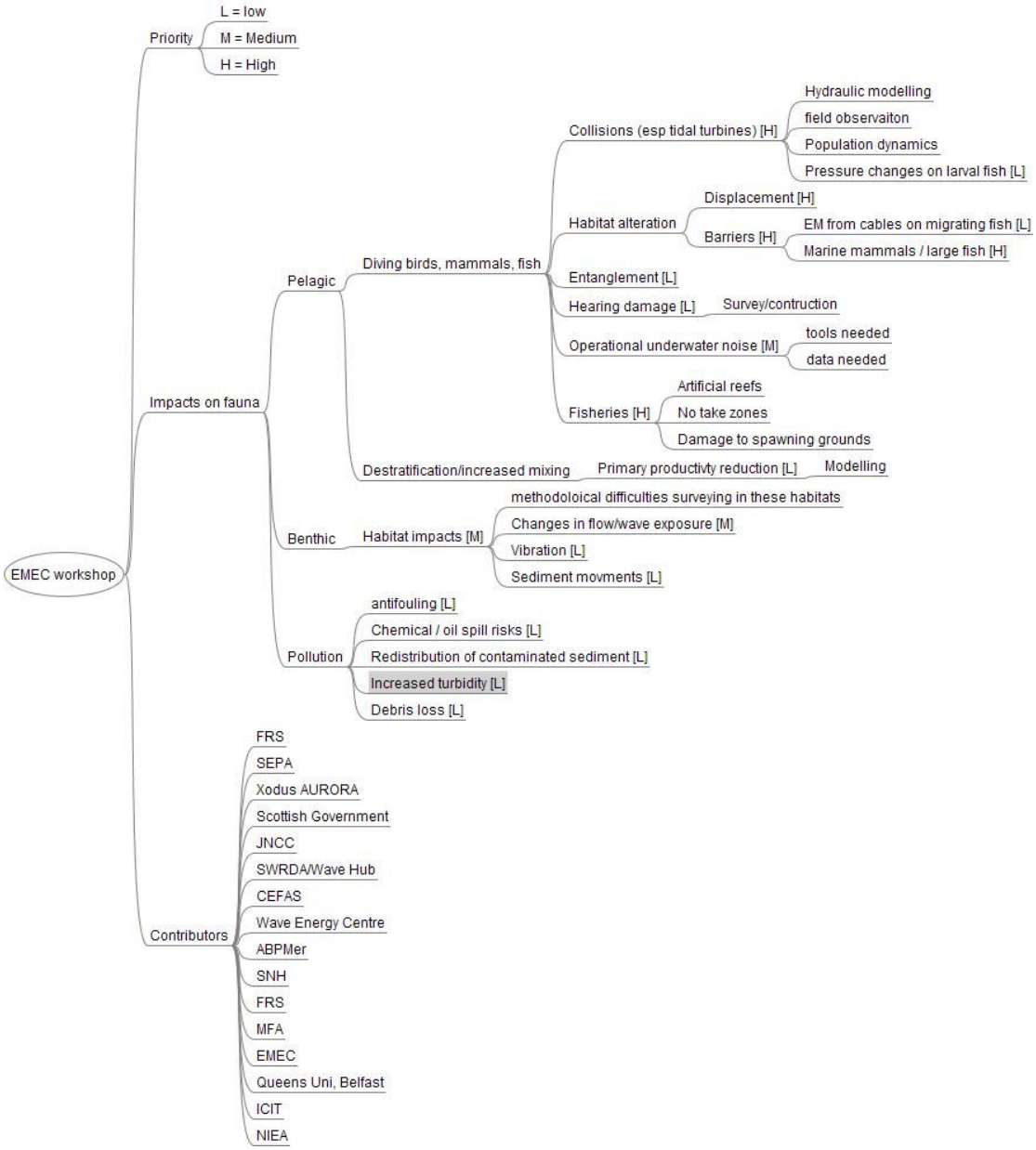

Figure 1 – Summary of the workshop "Environmental protection and management for wave and tidal energy converters: best practice approaches. 3rd September 2008
Contributors are shown on lowest branch.

Table 5 – EMEC research and monitoring projects

Project	2009									2010												2011					
	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
0024 - FoW Wildlife Observations*	■	■	■																								
0035 - Black Craig Observations Camera*	■	■	■	■	■	■	■	■	■	■																	
0041 - Monitoring Advisory Group*	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■						
0042 - Marine Safety/ADCP Deployment Course*	■	■	■	■	■	■	■																				
0043 - BC Wildlife Observations*	■	■	■	■	■	■	■	■																			
0045 - Equimar WP2 Data*	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■				
0045 - Equimar WP6 Environmental*	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■				
0054 - Developing Active Sonar*	■	■	■	■																							
0057 - Tidal Rapid Seabed Ecology*	Awaiting funding																										
0058 - Regulatory Streamlining *	■	■	■	■	■	■	■	■	■																		
0059 - OWET Cumulative Impacts	■	■	■	■	■	■	■	■	■																		
0050 - EMEC RAG*	No funding allocated																										
0032 - Hydrodynamic Modelling with DHI*	Finish date not set																										

*Summary project details on EMEC website: www.emec.org.uk/research

Further projects in discussion:

1. A review of the potential impacts of wave and tidal renewable energy developments on Scotland's marine environment.
    a. Scottish Government tender, applied jointly in three separate bids 23/02/09
2. Extension of EMEC DHI Model for use in the Pentland Firth
    a. Crown Estate tender, applied jointly on 08/04/09
3. Monitoring of the fishery in a no-take zone established at the Billia Croo wave test site.
    a. Scottish government request 04/03/09
4. Underwater acoustic characterisation in and around a wave energy device test area.
    a. Scottish government request 04/03/09
5. Continued surface marine wildlife detection
    a. Scottish government request 04/03/09
6. Alternative resource monitoring e.g. use of radar - funding yet to be sourced
7. Pre-EMEC facility - various discussions ongoing
8. Ongoing requests from academia for EMEC small scale data contribution to specific projects

EMEC is also involved with research projects coming forward from the ETI, however the detail will not available until the contracts are signed.

3.4.3 WAVE HUB research for developers

Although the research community centred on Wave Hub have yet to set up a research advisory group, the following issues have been identified by developers in their regular monthly meetings as important areas for further research:

- *Underwater Noise*

Better understanding of the impacts of noise from wave energy devices on different aspects of marine life and behaviour,

- *Device Specific Mitigation – anchoring strategies.*

Developers are currently required to remove all elements of an installation following decommissioning. Some developers may wish to leave moorings in situ for a number of reasons, further investigation into the benefits of not decommissioning sites entirely or novel means of enhancing moorings to support marine life through design may be beneficial.

- *Integrating WECs into different marine protected areas and Impacts on Coastal Landscape Designations*
- *Developing Cost effective Survey (Geotechnical, Geophysical and Ecological) Techniques and Protocols*
- *Collation / Coordination of National and International Research for Marine Devices*

It is difficult to assess, at this stage, where there may be key issues for long term monitoring, however the above list is based on consultation and preliminary consenting work undertaken by developers in relation to Wave Hub.

3.5 Research funded by NERC

Although we are not aware of specific proposals which have been progressed through NERC responsive mode in relation to marine renewable energy, research which is underway through the Oceans 2025 programme (Themes 1, 9, 10 and 6) can be adapted and developed to analyse some of the problems and issues facing the marine renewable sector. Also there are some small elements of the forthcoming phase 2 of UKERC which will represent an advance in modelling capability and development of economic valuation research methods to support the phase 2 project. Table 6 below (supplied by Phil Williamson, to meeting of directors 6th Feb, 2009) summarises research undertaken by Oceans 2025 partners to date in relation to marine renewable energy, and illustrates the breadth of funding which they have accessed to undertake research in this field.

On the other hand, we are aware of at least five proposals which have been submitted to NERC to support fundamental research needed to address problems raised by renewable energy sector, amounting in total to some £1.5m, which have not been successful. These have covered topics including physical impacts and trophic interactions downstream of renewable energy devices, and implications of devices and associated structures for enhanced populations of commercial species. None of the proposals was successful and the PIs were unsure whether it was the quality of the proposals or their direct reference to the need to conduct the research at renewable energy sites, (and thus implicating an applied research dimension) which had resulted in their failure to gain NERC funding.

4 Workshop and consultation

The NERC Marine Renewable Energy workshop on 26th February, 2009 identified the main gaps in knowledge and research opportunities, and these have been synthesised as a workshop report – *(draft submitted 14th April).* Gill (2005[6]) summarised the environmental impacts of renewable energy devices during the whole life cycle of offshore energy production, and discussed the significance of different types of impact. This analysis together with NERC workshop outputs provides a useful starting point for the analysis presented in this report.

The UKERC workshop on March 24th / 25th 2009 provided further input regarding the research priorities with respect to progressing sustainable arrays, and the key outputs of the UKERC workshop will be considered in our analysis below, as integral to the final recommendations of our report.

[6] Gill, A.B., 2005. Offshore renewable energy: ecological implications of generating electricity in the coastal zone. *Journal of Applied Ecology*, 42, pp. 605-615.

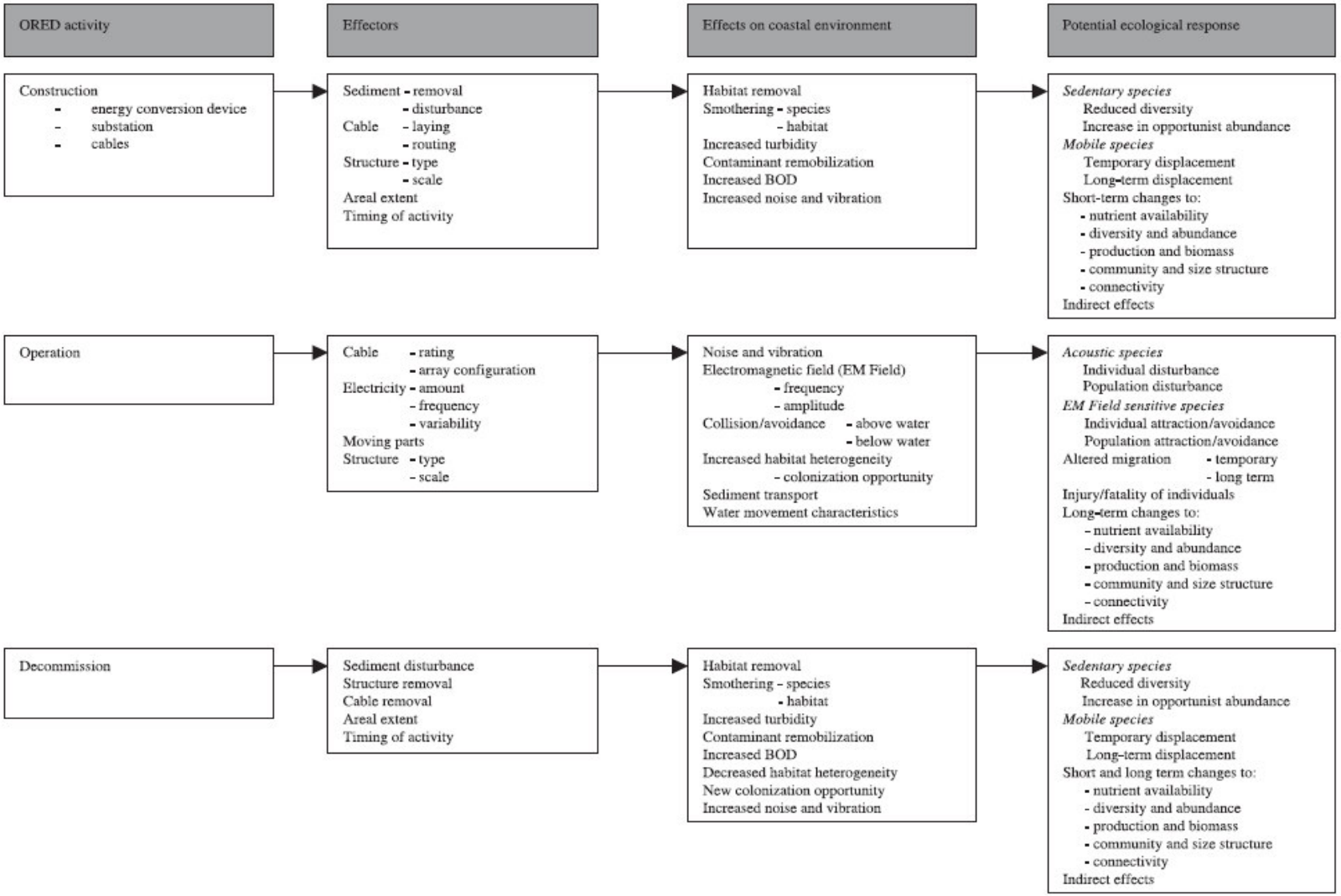

Figure 2 – Renewable energy developments and ecologically relevant interactions (Gill, 2005)

4.1 Summary of post-NERC workshop responses

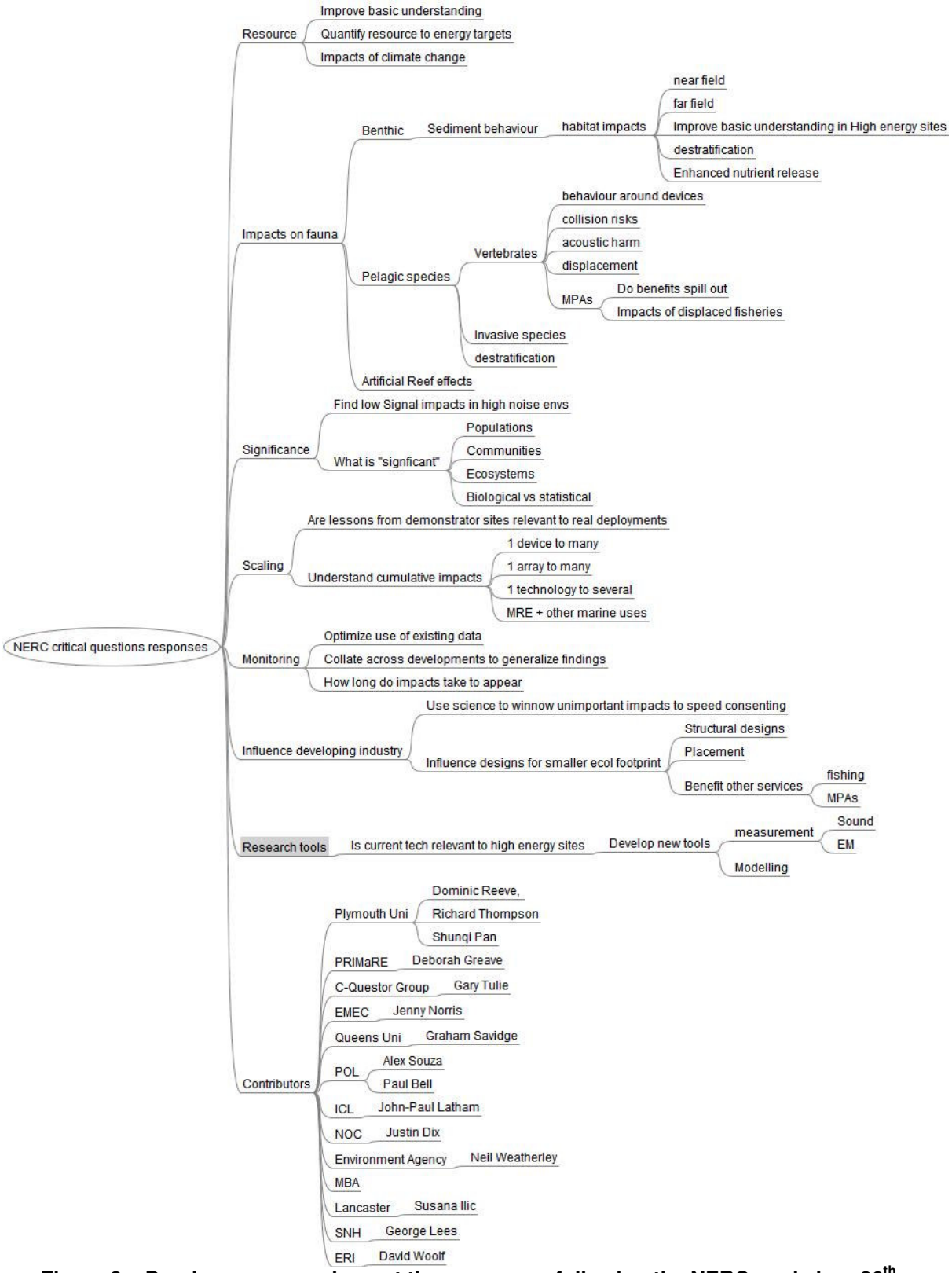

Figure 3 – Dendrogram mapping out the responses following the NERC workshop 26th Feb, 2009

4.2 Post workshop consultation on critical science gaps

The following sections summarise key discussion points which emerged from the NERC workshop and which lead to identification of the key science gaps.

4.2.1 Energy resource

A good understanding of the wind, wave and tidal resource available for exploitation is required to assess the potential of the marine renewable industry and its eventual environmental footprint. Although the research community can and no doubt will, play a role in developing new technologies to support resource assessment, the assessments of resource are most likely to be generated by Government agencies and the commercial sector (and not research entities). Nevertheless, the technology development and impacts of climate change on future wind and wave resource regimes (and to some extent tidal) fits well with NERC capabilities and strategic interests.

4.2.2 Impacts on Fauna and Flora

4.2.2.1 Mammals

Injurious noise and displacement of marine mammals during construction using pile driving is already an issue of key concern, partly as a result of studies associated with early stage offshore wind installations. This issue is likely to continue to be significant with the expansion of the offshore wind industries and tidal-stream developments. A better understanding of the impacts, the development of alternative construction methods and research into potential noise mitigation strategies are urgently required.

Once in place, offshore wind farms are likely to have less significant impacts for marine mammals than for other mega fauna – however, much depends on the degree of site optimisation in the first place. In terms operational interactions of wave and tidal energy devices much less is known. The key issues identified so far are as follows:

Collisions: A widely acknowledged potential “show-stopper” for the tidal-stream industry in particular is the issue of marine mammal collisions with rotating structures in moving water. The combination of swim speeds, turbine tip velocities, water motion, low visibility and recently recognised high incidence of ship-whale strikes, all make collisions with tidal-stream devices highly plausible. Several studies of this issue are ongoing, but they are basic, given the potential importance of the problem to the developing industry and regulators. Compounding this is the wide variety of tidal-devices being developed and their associated diversity of parameters relevant to strike risks (turbine blade number, rotation speed, size, placement in the water column etc). To address this issue, a combination of approaches is urgently required to assess the risk, determine the key parameters of device construction, investigate marine mammal behaviour when encountering such devices, determine what detection cues are available (acoustic or otherwise) and ways to monitor and evaluate any interactions. Collisions with other devices such as wave devices are less likely to be problematic though entanglement with mooring lines or collisions with surface devices in rough seas are possible.

The behavioural responses (attraction, avoidance etc) of marine mammals on encountering wind, wave and tidal-stream devices is little known and potentially of

importance when arrays of devices enter marine systems particularly movement in corridors or preferred habitats.

Other issues, such as chemical pollution, maintenance boat traffic etc, are less unique to renewable energy developments. However, several issues upon which there may already be substantial data collected may benefit from re-evaluation. For example, there has been substantial information collected on foraging, locomotory or other marine mammals' behaviours; however, its investigation relative to tidal flow rates and associated collision concerns may be valuable.

There is a need for further support for development of best methods for collecting data underwater, in the vicinity of underwater energy structures with moving parts. However, we think it is essential that as this is such a fast moving area, a detailed research mapping exercise is undertaken in relation to mammal research before decisions are made about new investment. New research needs to build on existing (best available) methods that have been or are being developed e.g. by EMEC and/or MCT, with involvement from SMRU (including SMRU Ltd), SAMS, QUB etc. However, methods being developed will have already moved on by the end of the year, when any funding decisions from NERC will be made.

4.2.2.2 Birds

Although some issues with respect to interactions of birds with wave and tidal energy have been identified, the primary concerns relate to the potentially significant effects of offshore windfarms. In summary these are:

Indirect Habitat Loss – avoidance of the turbines will lead to an effective loss of habitat, not just of the windfarm area but in a buffer zone area around it. In EIAs for offshore windfarms, a 'worst case' approach is typically taken in relation to this effect in which disturbance is assumed to lead to complete avoidance of the windfarm area (and buffer zone) and that there is no habituation. If alternative habitat is limited in quality or extent and already occupied – i.e. at or close to carrying capacity – then increased densities may lead to intense competition for available resources and thus increased mortality and a decline in the size of the local population.

Collision Risk – i.e. the risk of direct mortality and sub-lethal injury from collisions.

Barrier Effects – disruptions to the flight-lines of birds due to the barrier presented by windfarms may lead to an increase in the energetic costs of the daily movements of birds or of migrants.

In relation to these effects, there remains a need for research to address several issues:

i. Recent research has shown that it is currently difficult to detect changes in numbers of birds at sea using aerial survey data, primarily due to their natural variability (Maclean *et al.* 2006, 2007b). An improved approach incorporating oceanographic variables to explain some of this variation is required to be able to better detect changes in population resulting from displacement from windfarms.

ii. Further recent research has shown that for most species likely to be affected by offshore windfarms, sufficient demographic data exist to carry out population

viability analyses (Maclean *et al.* 2007a), which could be used to evaluate the impacts of collisions with turbines. However, there are some limitations with regards to what population viability analysis can achieve. Mortality resulting from windfarms may reduce competition for resources, thus reducing the rate of natural mortality. The extent of the latter cannot be determined solely through conventional population viability analysis, but also requires detailed understanding of the extent to which demographic parameters are density-dependent. Further work is thus still required to evaluate the impacts of collisions on populations.

iii. Following on from these two issues, there remains a need to evaluate the true cumulative impacts from multiple offshore windfarms of collisions, barrier effects and indirect habitat loss. Whilst further AMEC/BTO/PMSS work for COWRIE has addressed the need for a standard approach to the assessment of cumulative impacts in EIAs (King *et al.* 2009), the predictions used in these assessments require testing.

Likely Interactions between birds and wave and tidal-stream devices are less well known. Clearly such devices have less surface expression than wind turbines so in air-collisions are less obvious though problems of low flying birds at night colliding with wave devices has been suggested. Diving birds also have the opportunity to collide with subsurface structures particularly tidal turbines (Wilson et al. 2007). Little work has yet been done on this subject or the relationship between bird diving activity and tidal flow rates to determine how likely interactions might be at times of significant collision risk. However, observations are underway at EMEC and Wave Hub, and these need to be built on with behavioural and population functioning studies, to develop better impact prediction models with uncertainty/risk modelling, site-specific to generic assessments linked to mitigation and compensation issues. There is also a need for carrying capacity determination of offshore areas for large and mobile predators and to consider the cumulative impacts on populations.

4.2.2.3 Fish

Fish populations may potentially be affected by activities during the construction of marine renewable energy sites (e.g. by the noise and vibration from piling), and also by operational noise of devices. Our understanding of sub-lethal (mainly behavioural) and cumulative impacts on fish communities is lacking. For example, underwater noise and effects on hearing specialist species, such as herring, is urgently needed to devise proper mitigation measures during construction of new arrays. Moreover, production of energy/electricity interact with the coastal environment, particularly those key species (e.g. predators) that are sensitive to the operational disturbance such as electromagnetic fields emitted by the subsea cables and the noise transmitted by the devices through the water. Research linking these different trophic levels is required to establish the scale of this potential effect on fish populations and its temporal extent. Effects of energy capturing structures and whole arrays on recruitment and aggregating devices have received some consideration, along with the *de facto* creation of temporary or permanent no trawling zones and derived effects on diversity.

As with marine mammals, issues of collisions with fixed and moving structures in high velocity currents is a widespread concern. Concern should be particularly focussed on large species such as basking sharks (as the probability of encounter scales strongly with body size) and also with schooling fish (where the evasion behaviour of a group may be less appropriate than taken by an individual). In addition

to the simple risk of physical injury that is shared with marine mammals, the transient sound or pressure pulse associated with a turbine blade *near-miss* may or may not also have the capacity to impact the buoyancy and auditory structures of fish. In addition, this pulse may trigger an escape response and reduce (or maybe eliminate) collision at all times day and night or in turbid conditions. Research using modelling, experimental exposures and measurements on scale or full size deployments will be desirable, and require collaboration between biologists and physicists with expertise in fluid dynamics.

As with marine mammals and birds, the behaviour of fish relative to wave and tidal regimes is little known. It may be possible to re-examine existing data (for example, to look at swimming depth for basking sharks or herring) with respect to sea state or tidal flows, to investigate potential spatio-temporal overlap with MREDs and times of maximal risk.

In the longer term, renewable energy infrastructures may provide habitat for fish species, and the project scale developments refuges / areas for recovery with potential spill over effects. However any benefits need to be weighed against the implications of the displaced fisheries targeting other areas.

4.2.2.4 Benthos

Although there are studies underway to characterise communities potentially affected by installation of energy projects at both the Wave Hub site, EMEC and at several tidal demonstrator sites e.g. Deltastream project in Pembrokeshire, these are characterised by research and development of appropriate technology and methods development, to support industry needs. In the immediate future, experimental studies will be restricted to single devices or small groups of devices, so modelling (physical and ecological) will be a necessary tool. There will be a need to focus funding on selected life forms or communities e.g. high velocity benthic communities; bottom communities and scour from cables; sediment transport effects on soft bottom communities. Studies will inevitably require a mix of short term, or equivalently small distance scale, and long term or large distance scale studies investigating, for example, the consequences of changes in larval distributions or changes in large animal movements or migrations.

For the larger scale studies, the further development of interactive physical-biological modelling techniques will be required. A fundamental requirement for any modelling approaches is for sound base-line data: certain of these may be available from NERC climate change initiatives. Also there is a requirement for an assessment of available techniques for establishing state change in low signal to noise quality variables at biologically meaningful effect size.

4.2.2.5 Water column

As far as we have been able to establish, there has been limited research undertaken to address the implications of marine renewables for water column communities[7]. This is because the perspective of regulators is the impact of devices is unlikely to be significant, and there are no legal provisions covering lower echelons

[7] Broström, G. (2008). On the influence of large wind farms on the upper ocean circulation. Journal of Marine Systems **74**: 585–591

of the food web. However, the virio-bacterio-phyto-zooplankton assemblage is fundamentally important in delivering ecosystem services on which the entire marine food web ultimately depends, and thus too, productivity and biodiversity at all levels of organisation. Also, until we have investigated the possibilities, it is possible that arrays of some types of device do have local effects / interactions with particular sea conditions. Consequently, if we are to establish with confidence that the sustainable use of natural resources by the marine renewable energy sector does not compromise delivery of ecosystem services, whether in terms of carbon dioxide sequestration, nutrient regeneration, delivery of food, support for fishery and larval stages prior to settlement, research in relation to the water column assemblage has to be integral to whole system thinking. In addition, we need to project our thinking to consider future climate change scenarios and cumulative effects of intensification of marine space use, before our coastal zone becomes cluttered with more arrays of devices than is sustainable when whole system environmental carrying capacity is considered.

4.2.2.6 Whole systems approach

There are multiple synergies between the different ecosystem components and the spatio-temporal organisation of coastal environments. Impacts at one level may influence performance in a multiplicity of quality elements. Ultimately design constraints on the devices and design of arrays along with the construction methodology, will define the impacts on the pre-existing ecology. Conversely, in the longer term, renewable energy structures may provide habitat for new species or increase carrying capacity, and the project developments themselves act as refuges / areas for recovery with potential spill over effects. As far as we are aware there is no active research using an integrated ecosystem approach cutting across all scientific disciplines incorporating all biological quality elements (mammals, birds, fish, benthos and water column). A holistic approach - (multi disciplinary with for e.g. physicists working with biologists) which aims to define the 'whole system' carrying capacity is notably absent from the applied research approach which currently (understandably) prevails. There is a need for better defined conceptual models as a precursor to further quantifying and numerically modelling ecosystem processes, a need for different approaches for different groups (e.g. observational for pelagic, modelling for benthic) and at spatial and temporal scales relevant to the species / habitats concerned.

It is becoming clear that these whole system considerations need to be contextualised within the moving baseline resulting from climate change and ocean acidification, with assessments undertaken across the whole life cycle of projects (i.e. exploratory / construction / operation and decommissioning phases). At the scale of devices and arrays, there is a need to consider the role of devices in removing / impacting habitats negatively and conversely, as sites for species to colonise, (possibly even as sites for the encouragement of invasive species). Scour mitigation methods and creation of non-native habitats and their implications for ecosystems into which they are introduced need to be similarly investigated both in the short and longer term.

The challenge to scientists is to develop an approach to integrating all ecosystem components for assessing the risk of energy extraction from the natural environment to all populations / species – based on a whole system approach and qualitative and quantitative information. Decision tools need to be developed which provide appropriate guidance for regulators – both with regard to project design optimisation

and monitoring requirements. Then as projects are monitored decision tools can be tested and improved over time. The Oregon Wave Energy Trust has taken the step of thinking in terms of cumulative impacts of arrays of devices at the outset, by initiating the development of a framework for assessing cumulative / interactive effects of energy extraction with other energy arrays and / or uses of marine space. This leads to the further requirement for obtaining socio-economic information – which when integral to decision making tools, finally allows not only whole (eco) system considerations, but also an appraisal of overall sustainability.

4.2.2.7 Ecosystem restoration and resilience

The main focus of ecosystem and biodiversity research to date has been on understanding the negative consequences of energy extraction from the marine environment. However, it is clear that against the background of rapidly expanding human footprint, innovative thinking which puts the environment and sustainable use of natural resources at the forefront of research and before technology deployment is necessary at the present time. The policy imperatives which are driving the expansion of marine renewables indicate that we need to identify opportunities which allow the environment to recover against a background of increasing demand for resources and continued intensification of marine space use.

The main opportunities which have been consistently identified relate to the potential to promote, design and model optimal conditions for building resilience and ecosystem recovery in relation to renewable energy sites. There is perhaps a need to assess the value of practices from other earth systems applicable to marine ecosystems e.g. 'fallow' sea areas / rotating extractive uses of sea bed / new strategies for spatial management – to create reservoirs of restoration / resilience in a sea of over exploited / dredged and over fished sea bed. It is evident that innovative research in this area needs to acknowledge the constraints and requirements of the Marine and Coastal Access Bill and the EU Maritime Strategy and Marine Strategy Framework Directive, while informing the Defra 'Charting Seas' initiative, the inter-linked MPA projects and the OSPAR Quality Status Report requirements. But there is potential for exploring these concepts by using quantitative data from proxies and systems already in place elsewhere in the world. For e.g. beneficial / reef effects for 'whole systems', as well as different fisheries management alternatives at existing offshore windfarms and proxies such as artificial reefs in UK and in China (combined with aquaculture), all provide useful natural laboratories as the starting point for this research. There may also be some OWF areas where the proximity of species / communities under threat raises the possibility of potential benefits / gains at different levels - individual species (e.g. Native oyster) to communities and whole systems,

Renewable energy sites could also be used as monitoring hubs to learn from and support research endeavour – i.e. control / reference points vs other monitoring points and to test the connectivity of renewable energy footprints in regional seas (e.g. OWFs in Liverpool Bay). It is possible that when effectively closed to all activity other than maintaining turbines – do OWFs act as ecosystem reserves / recovery areas for the regional sea as a whole? In any event it is necessary to consider the whole range of scientific and socio-economic benefits and at different geographical locations and range of spatial scales – the connectivity of sites for biodiversity benefits, proximity to population centres, potential for regeneration of communities etc. In taking forward this type of research, there is a need to capture stakeholder

knowledge - including historical and anecdotal e.g. state of the environment and fishery knowledge, the benefits of liaison with adjacent sea user communities at an early stage of renewable projects can ultimately lead to much reduced lead times to project implementation and immediate take up of economic opportunities for the benefit of the wider community.

4.2.3 Significance

Although at present the perception of the engineering design fraternity is that marine renewable technologies are benign and only very low environmental impact, we do not at the present time have the evidence to substantiate this. How to define what is significant in ecological and spatial/temporal terms for all ecosystem components i.e. mammals, birds, fish, benthos, water column, and at seasonal, decadal, random frequencies as well as distinguishing 'signal to noise', is central to understanding ultimately, whether renewable technologies can be promoted as one of the solutions to living in a low carbon world. In the first instance, it is necessary to characterise (in physical terms) the impact of energy extraction from wind / wave / tidal devices and associated infrastructure (e.g. cables), then to assess the impact (in ecological terms) on ecosystems and biodiversity. There is also a need to be able to separate the different types of significance (statistical, biological and societal) depending on the interests of the stakeholder group concerned. It is increasingly important to be able to extrapolate to consider economic and socio-economic significance, and thence derive holistic measures of sustainability, (for e.g. devices which reduce fishing pressures (such as beam-trawling), and create *de-facto* MPAs whilst allowing ecological recovery and other economic activities). We therefore need to develop numerical tools which allow regulators to quantitatively compare the performance and environmental footprints of different device technologies. Some of the research tools development to support this type of analysis will shortly get underway in the forthcoming UKERC phase 2 programme.

4.2.4 Scaling up from device to array to multiple arrays

Although there are currently a small number of projects involving deployment of single devices, and arrays of wind turbines (30+ towers) are now accepted as the norm for offshore windfarms, scaling up to full scale arrays (whether tidal or wave energy) represents a major challenge to these sectors. It is already clear that it is important to determine which questions can confidently be answered during device scale testing, then used to inform scaling up to arrays. Even in trials involving the same device, it is likely that arrays will provoke a whole new set of impacts not necessarily noted or identified during single device trials. In addition, consideration of whole life cycle impacts needs to be included in research programmes for individual devices, as they can differ significantly during different life cycle stages and between devices. This is not the only reason why there was strong support at the workshop (and subsequently) for encouraging research at demonstrator sites for the benefit of the whole renewable energy sector. The question of how to resource them adequately is a vexed question which is central to the success (or otherwise) of steady R&D progress to support roll out of marine renewable technologies worldwide. Part of this formula is the need to agree an adequate management and decision making structure to support the broader stakeholder and research community with credible processes, as well as science leadership to help make decisions about for e.g. inclusion of agreed control areas for inclusion into long term monitoring programmes.

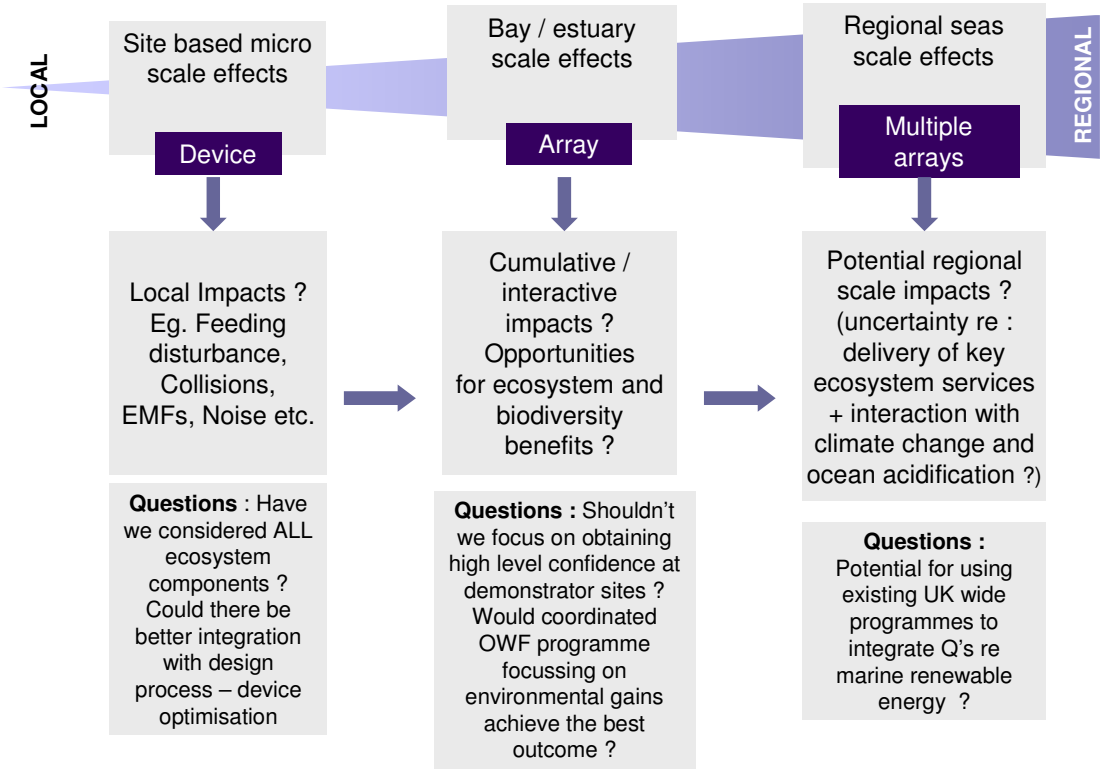

Figure 4 – Summary of research questions appropriate to device, array and multiple array scale projects

Whilst the industry as a whole is still at the stage of properly understanding the engineering performance and environmental impacts of individual devices – some devices will be deployed as arrays at the outset – for e.g. at Wave Hub, and this will allow us to consider interactive and cumulative impacts of energy generation over wider areas and in relation to other marine space uses such as fishing, navigation and aggregates production.

4.2.5 Research tools – technology and model development

The renewable energy sector is already driving significant innovation in technology – because of the challenge of measuring parameters which have as yet not been of significant interest, and also because they often need to be measured in hostile physical environments. Consequently one of the first priorities in relation to technology tools and model development should be to scope how existing measurement technology and modelling capabilities can be applied at locations such as Pentland Firth "to deliver a sustainable, environment-enhancing supply of energy from the marine environment" (Scottish first minister, March 2009)

It is clear that a new generation of methods, tools and technologies for observing, recording and monitoring, for prediction, analysis and interpretation of data as well as decision tools, are needed to support the marine renewable energy sector - including developing remote sensing (e.g. HF Radar applications), for measuring sediment processes, extending altimetry into coastal zone etc. and direct sensor technologies There is also a need to have an adequate understanding of risk and to be able to deliver an acceptable level of confidence to all stakeholders.

There is also a need to develop and improve the quality of predictive models, for some specific ecological / biological components but also for resource prediction in the context of a changing climate, and how this might affect physical locations of renewable energy sites. Predictive capability needs to be extended (ideally) to spatial and temporal scales relevant to energy project life cycles (~15 to 25yrs) and technology interaction with climate change, ocean acidification other factors (>25yrs to 2050?) needs to be built into research concepts.

Although it is useful to have thought in advance about which questions can be addressed in mesocosm / simulated laboratory based experiments or require appropriate observational context to support methods / tools and technology development – there is currently a major disconnect between what information is needed and what is collected at present. This is mainly because EIA baseline environmental characterisation surveys do not provide adequate quality data for developing models and in respect of some parameters. For example, as far as the soundscape is concerned, there is no noise baseline at all - not even methods guidance or agreement on the best technology to use.

Consequently, if the development of methods and techniques is to progress in a timely fashion it is imperative that it is integrated with decisions about scale of models to develop – (setting boundary conditions etc.) what baseline information needs to be collected to parameterise models, what should be collected at different scales of development (i.e. what questions and at what spatial and temporal scales). Then there is the question of prioritising technology development within timescales which are relevant to the end users – there are some developments for which we need input now, whereas for others the medium term (2020 / 2025) is adequate and for still others the longer term is fine (2050).

Over these timescales there is also likely to be a need for high power [super] computers to run 3D ecological models – as will no doubt become apparent as a result of the upcoming National Capability advisory group review.

4.2.5.1 Monitoring and accessibility of data

Developer led monitoring as a condition of their consents may slowly provide some answers to the questions of environmental impact of individual devices and ultimately of arrays - but only in a piecemeal, uncoordinated and poorly integrated fashion. It is also likely to be beset by difficulties surrounding commercial confidentiality and the fact that regulators can only require monitoring that is pertinent to the provision of consent, and not that which is necessary for the wider benefit of the industry or scientific community.

An answer to this would be a multi-disciplinary, comprehensive and objective monitoring programme of one or more of the early wave and tidal arrays, funded through a partnership of Regulators / Government, Industry, the Crown Estate (as 'landowner') and the Research Councils. The broad based nature of such funding reflects the fact that meeting renewables targets is a high level Government objective and not the responsibility of any one Department, Agency or Industry. An analogue may be found in the comprehensive monitoring programme established by the Danish Government of the Nysted Offshore Windfarm (http://www.ens.dk/sw42531.asp), a landmark initiative which now provides a unique resource for studies of the impacts of such developments not just in Denmark but worldwide.

Such a programme would have (indeed, require) three key characteristics not readily delivered through any developer led study, namely:

- Monitoring of a wide range of environmental parameters relating to hydrodynamics, sediment processes, species distribution and behaviour, meteorology etc. (i.e. all issues pertinent to answering the questions above) the results of which could be integrated;
- Establishment of control or reference sites at which at least some of these environmental parameters would be recorded, to enable discrimination of anthropogenic effects from natural variability;
- Establishment of a monitoring baseline, ideally at least 2 years prior to development.

Availability of historical data, new data acquisition and access to ongoing / recent research is a major issue which applies to all research scientists – any coordinated programme would need to include an agreed strategy for data collection (including who should be responsible for data management). Baseline (environmental characterisation) data collected by users as part of their licensing, has limited use in a research context – but is nevertheless useful in some cases. Similarly monitoring to support licence requirements has potential to facilitate adaptive management for sector and in the absence of primary research to underpin regulatory need, has proved to be invaluable.
Data sharing is essential if optimal outcomes are to be achieved – and this needs to occur across the sectors, with ultimately, integration with ALSF- MEPF (Geodata), MDIP, BODC, UKDMOS etc. the preferred outcome. Funding of long term monitoring studies is a major issue for all users of natural resources from the marine environment, as it is so crucially important, needs to be addressed collectively. We need to consider the potential role of NERC in contributing to long term studies in collaboration with other stakeholders.

4.2.6 Influence on developing industry

It would be entirely possible for the NERC community to focus exclusively on methodical measurement of interactions of marine renewable devices and arrays on the environment, and to provide evidence which inspires greater confidence in the industry to a wider group of stakeholders in the longer term. However, because these industries are growing and evolving rapidly themselves, there is a major opportunity for NERC to develop and invest in science capabilities to fundamentally influence the speed and nature of the sectors' (wind wave and tidal) continuing development in both the UK and further afield. At a most basic level, the NERC community should apply its expertise on the natural environment to help winnow out trivial environmental factors, where developers are currently required to demonstrate insignificant impact at the EIA stage. This exercise would simplify, cheapen and better focus the environmental consenting process. At a more strategic level, the input of a high-quality academic research understanding of how devices and environments interact, could help developers (essentially engineering companies) design their devices with inherently lower environmental footprints before reaching the EIA and consenting stages. It is also fundamental that we obtain evidence that the sustainable use of natural resources and biodiversity resources are not compromised by large scale development of renewables. A clean bill of health on environmental aspects will provide confidence to investors, regulators and managers of the marine environment. Closer cooperation between scientists in developing novel devices and engineering proposals with an environmental (and socio-economic) dimension will help facilitate this process.

5 Fundamental 'Blue skies' vs applied science

There is a need to shed light on the blue skies vs applied science debate, to generate better understanding of who does what in relation to renewables environmental research, and where NERC fits into this research continuum – and ultimately to communicate this to the wider stakeholder community. The 'fundamental' whole system research science which drives the SUNR and biodiversity themes is as significant in relation to marine renewables as it is to climate change itself – unless we fully understand the impact of renewables on our earth system, and on the integrity and functioning of marine ecosystems in particular, renewables will have no credibility or future as a solution to low carbon energy production. It became apparent both at the NERC workshop and in subsequent consultation that the majority of stakeholders believe that there is no other possible route to funding an adequate research effort, which mobilises marine scientists from across all disciplines to focus on these problems, unless NERC becomes involved and takes a leading role in this research.

The research which has been funded to date in relation to marine renewables has been focussed on regulator needs of DEFRA and DECC with strategic funding input from COWRIE. The approach is necessarily one of facilitating implementation of energy projects and environmental damage limitation – either through locating projects to minimise ecological impacts in the first place, or through commissioning studies which will contribute to an adaptive management 'pipeline' and thus inform future projects and decision making. Depending on how risk averse you are, research commissioned through RAG to support regulatory needs is only achieving an 'adequate' level of research understanding to support the wind, wave and tidal sectors against a background of considerable uncertainty in our changing world. The budget for DECC going forward for 2009 / 10 is £500K – and this is for all aspects of regulatory need in relation to marine renewables including navigation, fisheries, socio-economics etc. Only a limited depth of research is feasible at this level of funding. Consequently the whole system approach which puts the environment centre stage is needed to complement work already underway and provide additional depth and confidence in the conclusions from an environmental perspective.

There is open research ground for NERC to occupy in this inherently applied sector. By rising above the individual development or location issues focussed on by company funded or agency reactive research, NERC has the opportunity to focus on the generic issues of how these developments will interact with the environment. A non-specific approach to device-environment interactions (both within device families and between them) would provide a better academic understanding of the scale(s) of impact of renewable energy developments and provide regulators with tools to compare across different technologies rather than simply approving those with acceptable impacts (e.g. weighing up environmental consequences of exploiting wind vs wave energy for a region).

The potential future economic impact of research undertaken by NERC in the renewables sector is currently very difficult to assess. The UK currently has a leading international role in wind, wave and tidal energy development – but acquiring research quality evidence is crucial to support the development of the sectors worldwide, including the development of necessary policy and management tools through knowledge transfer. Our study has revealed significant opportunities to scale up and activate the KT / innovation pipeline through targeting appropriate funding for

the benefits of the marine renewable energy sector. The end user community – both developers and regulators – would benefit significantly from direct involvement of a wider academic community in focussing on the environmental research problems they are facing. For example, appropriate advice regarding design of monitoring programmes for offshore windfarms could have averted wastage of resources and funds – and unusable outcomes as a result of advice on spatial and temporal understanding of the characteristics of the communities involved (Prof. Mike Elliott, pers.comm).

Table 7 – Summarising the research responsibilities of organisations with focus on marine renewables sector

Research	Principal research areas	Responsibility
Fundamental strategic research which is applicable to NERC themes : SUNR Biodiversity Technology etc.	▪ Ecology and functioning of ecosystems / communities and individual species in response to energy extraction by devices or arrays of devices introduced into the natural environment, ▪ Responses – whether behavioural or physiological – to novel physical factors potentially disrupting status quo – again at ecosystem, community or species level – e.g. hydrodynamic / sediment characteristics, noise, EMFs, etc. ▪ Medium to longer term / climate change considerations ▪ Technology development, modelling and methods to support the necessary research, ▪ Innovative thinking about new sets of problems which arise as result of changes in the natural resource base	NERC
Applied research to support implementation and licensing of renewable sector projects focussing on actual obstacles to development	▪ Individual species with legal protection (Habitats Regulations and European protected species) or highly sensitive / significant in ecosystem terms ▪ Specific known problem species or communities / or known problems from other marine sectors ▪ Development of industry best practice in collaboration with industry representatives – including survey and monitoring guidance / protocols for different organism groups, training for observations etc. ▪ Development of industry standards including environmental standards	DECC RAG (includes issues raised by MFA, NE, developers) COWRIE
Strategic research linking environmental and socio-economic aspects for improving sustainability	▪ Focussing on better cross disciplinary development of tools and methods ▪ Including valuation of ecosystem goods and services and development of appropriate decision tools ▪ Carbon footprinting and links with LWEC	NERC – ESRC
Strategic research linking environmental and engineering research for improved sustainability	▪ Focussing on better cross disciplinary development of tools and methods ▪ Needed at concept stage and for whole life cycle of technology ▪ For all marine renewable technologies – wind wave and tidal, as well as preliminary evaluation of novel ocean technologies ▪ Closer communication and relationship building between scientists in designing / undertaking research – not just high level communications between NERC and EPSRC research programmes	NERC – EPSRC

6 Potential future NERC Work Programmes

6.1 Overview critical research gaps

Appendix 1 summarises the current research inventory developed by the DECC Research Advisory Group, covering all the major issues which are of concern to developers, regulators and policy makers at the present time. The table also shows which projects have been completed and which are active. The NERC workshop yielded a remarkably similar list of issues and research gaps, and the draft workshop report submitted 14th April summarises the workshop sessions and identifies the main themes. The section below discusses briefly the main themes which emerged as research priorities for the NERC strategy, and the SUNR in particular.

6.1.1 'Whole system' approach to new research

It was generally agreed amongst those present at the workshop, that the science evidence base is not adequate or mature enough to support the decisions which are being made with respect to the impacts of renewable energy on biodiversity and ecosystems in the longer term, when questions of carrying capacity are considered. There is a need to provide greater confidence, depth and substance to some of existing research and the whole system approach needs to be used as the basis for designing a future research programme across all biodiversity groups and ecosystems. The research community in the UK is acutely aware of need to engage with the environmental research challenges presented by development of the renewable energy sector, but is currently limited by opportunities to seek appropriate funding to support research. Currently the PRIMaRE research programme underway with SWRDA support at the Wave Hub site, is the only managed programme which seeks to take a 'whole system' approach. However even this programme stops short of including funded studies into water column processes, which provide the essential parameters to feed into ecosystem models, and yield the information necessary for economic valuation of essential ecosystem services, such as carbon dioxide sequestration and nutrient regeneration.

6.1.2 Technology, ecosystem models and methods development

The consensus of the workshop was that technology and methods development to support the renewable energy sector is potentially a highly significant development science area for NERC. This is partly because of the need to measure / observe and record in hostile environments (as yet only poorly known to science) and to measure and record complex behaviours, such as vertebrates interactions with underwater devices. These needs require a step change improvement in existing technologies. Integration with existing NERC programmes will yield important synergistic outcomes by building capacity in existing research clusters. However, opportunities for new collaborations amongst academics were identified at the workshop, which would enable them to respond to the needs of renewables sector and these could be facilitated via a coordinated (or directed) programme.

6.1.3 Ecosystem restoration and opportunities for ecosystem benefits

Further discussion on this aspect at the UKERC workshop in Edinburgh, indicated that although this aspect is not currently a priority for regulators / developers, there is wide recognition that the opportunity presented by development of the renewable energy sector to explore the potential for ecosystem restoration and ecosystem benefits, needs to be fully investigated. This is particularly important as the UK environmental footprint continues to move offshore and pressure on marine space use from diverse stakeholder groups continues to exacerbate conflicts between different activities.

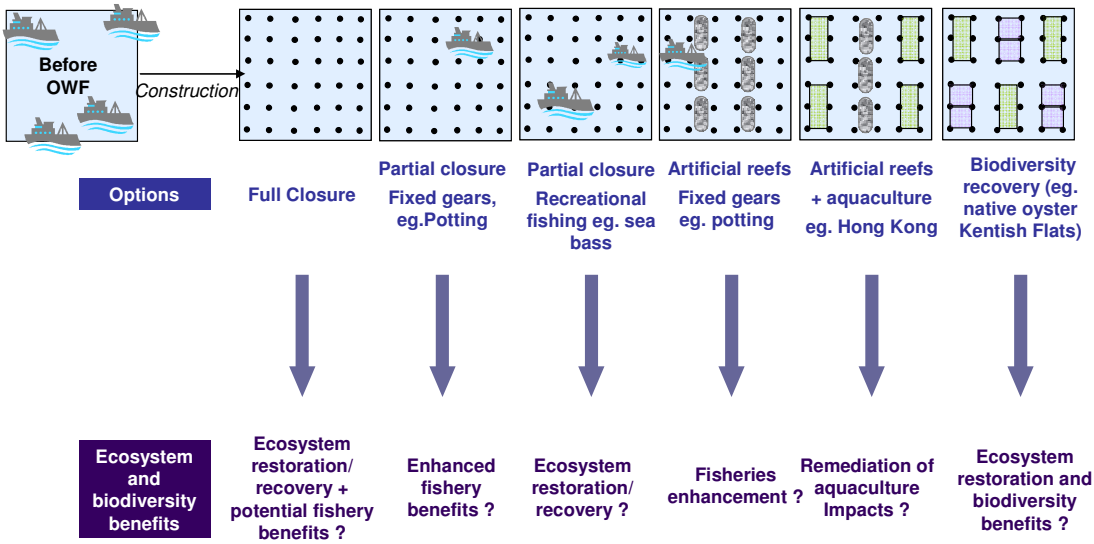

Figure 5 – Illustrating the potential for marine space use within offshore windfarm footprints

6.1.4 Nature of research (experiment, modelling, observation etc).

It is clear that in order to address the wide range of research questions posed by the interactions of biodiversity, ecosystems and marine renewables, that the nature of the research undertaken will need to include modelling, observational studies and experimental studies involving mesocosms and other experimental systems. The Oceans 2025 partners between them have access to all the necessary facilities to progress the entire range of studies. There is however, an important issue with regard to the device testing / demonstrator sites, since neither EMEC nor Wave Hub have their future assured in terms of infrastructure funds to maintain their staff and supporting facilities. EMEC is actively seeking funds from diverse sources to meet the needs of specific developers for research, as well as addressing generic research needs of the wave and tidal sectors. Wave Hub has set up a developer discussion forum, and has yet to progress to more coherent structures to respond to the sector needs directly. Nevertheless, both sites have the potential to contribute significant opportunities to wave and tidal device developers to test the performance of their technologies, and by encouraging research scientists to undertake their research at these sites, it helps to build up a body of understanding and research quality evidence which is of direct value to the whole industry, not only in the UK but internationally. Government advisors and developers from overseas are already seeking advice from UK institutions on the environmental research which is underway at demonstrator sites and in various UK universities.

6.2 Risk, advantages / disadvantages

The opportunities presented by the marine renewable sector to NERC in terms of research challenges, constitute very low risk research science. A significant body of the research which needs to be undertaken in the first instance, is desk based and /or the experimental systems are already in existence and therefore need not involve significant investment in new capital equipment. As mentioned above, experimental facilities such as mesocosms are available in at least two of the partners institutions, and artificial reef facilities are available through SAMS and NOC. By building on research capability which is already present within the Oceans 2025 community and encouraging participation by external partners, the core team collaborating within the Oceans 2025 programme are able to ensure efficient resource use, avoid time lost in setting up new structures and add value through their experience of working collaboratively. The main risk that we have identified is that because of competing demands on NERC's resources, this programme is under resourced, and despite the challenging targets set by government, and the urgent need to obtain appropriate research evidence, that the programme fails to deliver on the research as a result.

6.3 Fit with existing research themes and activities

- **NERC integration with existing DECC RAG research**

The need to convince NERC of the urgency of engaging with marine renewable energy research in competition with other pressing areas of research, leaves the science community wondering if development of wet renewables will follow the path of wind – with the UK once again losing its leading international position because of inadequate support to address the risks – including those relating to environmental sustainability. The environmental and socio-economic research needs relating to licensing and progressing deployment and testing of renewable energy sites have been clearly identified, and those which appear on the DECC RAG inventory have already been collectively prioritized by RAG members.

Given the need to establish contact with the end user community, it is clear that rather than set up its own research forum, one route for NERC to explore is partnership with the DECC RAG, combined with the offer of matching funds to progress the critical research needed by the sector. There seems little point in replicating the stakeholder forums already in existence and the fastest route from research to knowledge transfer within and across a broad range of private /public and NGO sector interests, would be for NERC to become directly involved in both the RAG and OREEF – the stakeholder forum where regulators, policy makers, coastal and marine managers, users of marine space (fisheries, aggregates, navigation oil and gas, nature conservation) and their institutional representatives, developers of renewable energy projects and their consultants are all represented. This option needs to be discussed directly with DECC.

- **Key partnerships with demonstrator sites**

There was a high degree of consensus at the workshop and subsequently in post workshop consultation, that NERC funded research can be effectively and efficiently progressed by building on existing science communities associated with EMEC and PRIMaRE. This will optimize integration of new research effort and ensure sustainability of science programmes at both demonstrator sites. EMEC will primarily support testing at single device scale, whereas Wave Hub will host arrays of devices (four bays) and encouraging research focus at these sites will ensure maximum

opportunities for data sharing and collaborative programmes across all ecosystem components. Possibly the most important contribution to understanding the impacts of offshore wind to date have developed from intensive research and monitoring at Nysted and Horns Rev offshore windfarms. Even the UK regulators know more about the impact of offshore windfarms on biodiversity and ecosystems from these studies supported by the Danish government, than from any of the monitoring required as part of licensing at UK sites. As in Denmark, focussing effort at EMEC and Wave Hub will also facilitate KT at all levels and across all science disciplines between device developers, DEFRA, DECC, MFA, NE and through the BERR RAG project developers and other commercial interests.

- **RCEP integration**

Although government thinking is gradually seeping into the collective consciousness, there is still a degree of confusion amongst engineering, environmental, social and economic scientists about how the different initiatives for energy join up. In particular the roles of UKERC and ETI – and how integration will be achieved - how collaboration between EPSRC – NERC – ESRC might yet develop to address a new set of issues. Although there are embryonic indications that EPSRC through SuperGen, is beginning to recognize the need for integration, there is much greater need for pro-activity than is apparent at present. On the ground research collaborations are evolving to address this need.

- **International collaboration**

Although we are aware that many research scientists have diverse international relationships with countries developing marine renewables, there is a degree of replication which could be rationalized for everyone's benefit across the UK. Because of the high degree of specialisation, there is in fact only a small degree of overlap in research interests and ideally there needs to be research representation on behalf of UK marine renewable energy sector research community – to present an outward facing front to the rest of the world. It may be possible to embed this function within UKERC, but wherever located resources will be needed to support development of the UK profile in the sector to the international community.

6.4 Overview of structural / coordination issues

Research need	Issues	Solutions
Biodiversity and ecosystem characterisation - environmental setting of MRE sites Post implementation monitoring	Common approaches to baseline surveys Data storage/ management including QA Data quality for research purposes Data availability to research community	Joined up strategy for data acquisition, management, and access involving all stakeholders – (e.g. one possible route is expansion of OREEF to include research community)
Assessment of what is significant in temporal and spatial terms for all ecosystem components	Research currently commissioned on agreed needs basis by RAG – need holistic approach Significance determined through licensing process Research often not available to support decisions	This report identifies priorities for individual species Re-balance research effort to reflect whole system approach KT effort needs to be stepped up

	Existing research could be better packaged	
Assessment of what is significant against background of moving baseline (natural / climate change induced)	Research could be made available to decision makers in more accessible format	As above
Step change in technologies / methods / models to support industry	Information needed for hostile environments – to date not well studied – new approaches needed Lack of integration with research community – potential for application of existing models not exploited	Engage research community more directly with end user community (ie. regulators / developers) Build on EMEC and PRIMaRE emergent stakeholder liaison groups
Framework integrating all ecosystem components for assessing risk to populations / species – based on qualitative and quantitative information	Needs developing using research quality information No programme in place to consider cumulative / interactive effects	Set up UK wide managed programme to integrate findings from disparate sources Need coordinated research programmes at demonstrator sites

7 Bibliographic review

The purpose of this section is to investigate the literature published within the scope of the current study. The articles were identified using Web of Science[8], and as such only include peer-reviewed articles. This section does not attempt to review the literature available on coastal and offshore renewable energy, but aims to give an indication of where published studies have been focussed.

Gill (2005) reviewed offshore renewable energy, in particular the ecological implications of generating electricity in the coastal zone. As part of his review the number of peer-reviewed articles with the term 'renewable energy' (or derivative terms) published between 1974 and 2003 were presented. These results have been updated as part of the current review. A total of 9,413 peer-reviewed articles are highlighted (Figure 6) within this field between 1974 and 2009. There is a clear increase in the number of publications within this field since the start of the 1990s, from less than 100 publications per year in 1990 to more than 1500 articles being published in 2008.

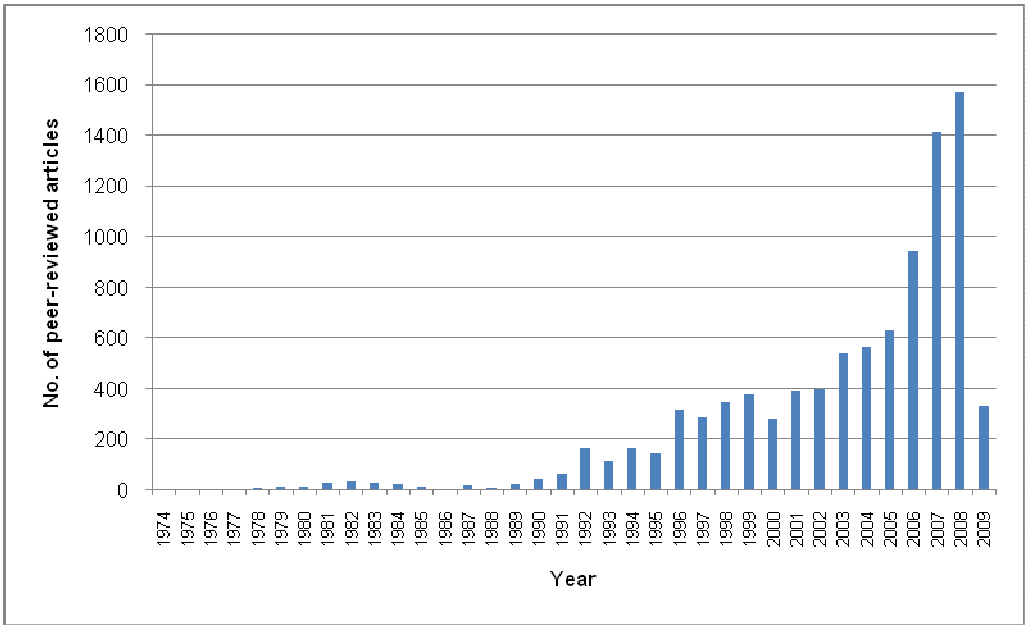

Figure 6 – Number of peer-reviewed articles with the term 'renewable energy' (and derivative terms) published between 1974 and 2009 (after Gill, 2005).

This approach has been further developed here to include the number of peer-reviewed articles specifically related to coastal/offshore renewable energy during the same period (see Figure 7).

[8] All of these searches have been carried out using Web of Science data from the expanded Science Citation Index (SCI-EXPANDED), Social Science Citation Index (SSCI), Arts and Humanities Citation Index (A&HCI) and Conference Proceedings Citation Index – Science (CPCI-S).

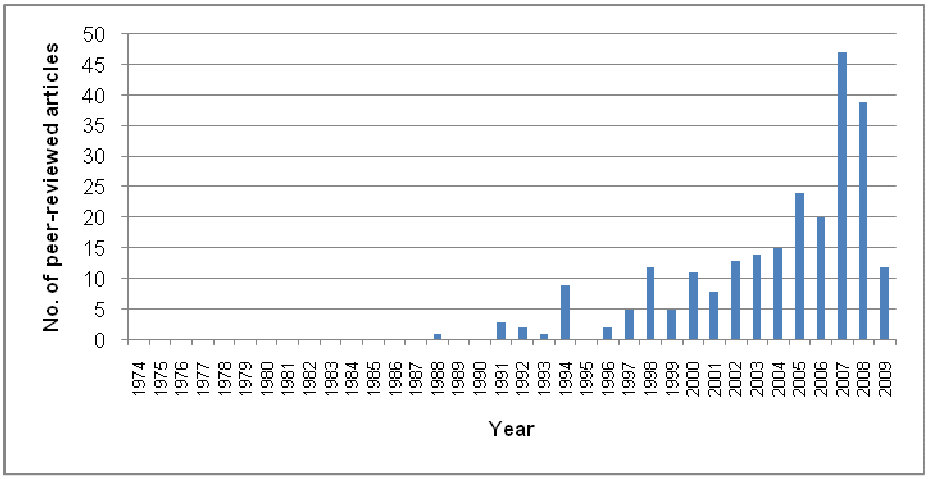

Figure 7 – Number of peer-reviewed articles with the term 'renewable energy' AND 'coastal or offshore' (and derivative terms) published between 1974 and 2009.

A similar pattern is observed, with increasing publications since 1990, however, it is of note that there are relatively few published papers relating to coastal/offshore renewable energy (243 articles) when compared to the general renewable energy literature as discussed above (9,413 articles).

Further analysis of these results shows that the majority of these papers were published in the USA (21%), UK (17%) and Germany (9%), with Australia, Denmark, Japan and Sweden each accounting for 3% of the total papers published (8 articles each).

These articles (243 in total) were further analysed with respect to the subject area(s) within which they were published (Figure 8). A total of 77 subject areas were included within the analysis however for the purpose of this report similar categories were grouped together for example 'Environmental & Biological Sciences' and 'Engineering' both include 11 individual subject areas and the 'Others' category includes 54 individual subject areas, with very few papers published in each of these individual fields. It is clear that the majority of the published articles relate to engineering aspects of offshore/coastal renewable energy (35%), with the remaining subject areas having a similar number of articles within their respective fields (22% each).

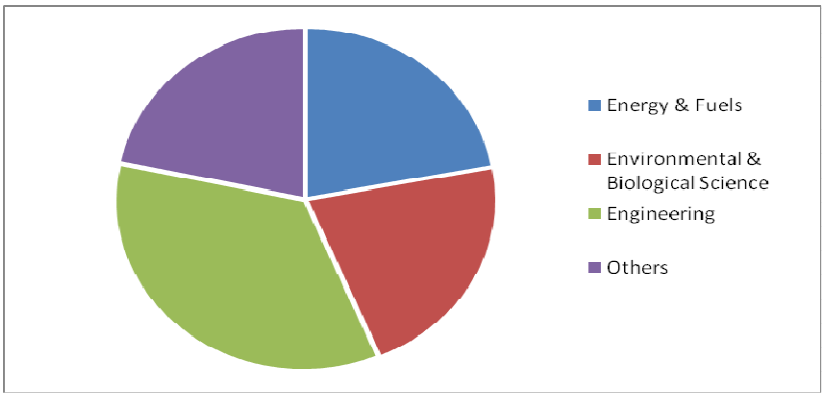

Figure 8 – Breakdown of subject areas within which the published articles were included (243 articles in total).

Given the scope of the present study, the articles within the environmental & biological science category only were further analysed with respect to the type of

offshore/coastal renewable energy they discuss (e.g. wind, wave and tidal stream) and the various ecological aspects of the marine environment (birds, fish, mammals, benthos and water column) which may be impacted upon (Table 8). The majority of literature within this subject focussed on wind energy, followed by wave and tidal stream, respectively. The majority of the papers within this subject discussed fish, followed by benthos (invertebrates), birds, the water column and marine mammals, respectively.

A full list of these articles is provided in the list below.

Table 8 – Articles broken down by renewable energy type and ecological component

Element	No. of articles (out of 87)	%
Renewable Energy Type		
Wind	17	20
Wave	9	10
Tidal Stream	7	8
Ecological Component		
Birds	3	3
Fish	10	11
Mammals	1	1
Benthos (Invertebrates)	4	5
Water column	2	2

This brief review has therefore demonstrated that although there has been a growing literature on renewable energy since the early 1990s, there is still not a great deal of published information relating to offshore and coastal renewables. Within this limited literature, the majority of articles relate to the engineering aspects of offshore/coastal wind energy generation with only very few peer-reviewed articles relating to potential impacts of such developments on the marine ecosystems and biodiversity. Those which do exist are summarised in the reference section of this report – this being a synthesis of references used in two major recent reviews by Linley and Laffont (2009) (for Rolls Royce) and Inger et al (in press). Surprisingly, we were not able to identify any articles which appeared in both the inventory below in Table 9 and the reference section of this report, suggesting a sharp division between the research groups working on environmental and engineering research in the renewable sectors.

Table 9 – Results of the initial literature search undertaken in Web of Science (87 articles in total)

Authors	Title	Journal	Year	Volume	Issue No.	Pages	
Angeles, ME; Gonzalez, JE; Erickson, DJ; Hernandez, JL	The impacts of climate changes in the renewable energy resources in the Caribbean region	Proceedings of The ASME International Solar Energy Conference	2007			467	481
Asamoah, J	Greening electricity generation in South Africa through wind energy	Greenhouse Gas Control Technologies, Vols I And Ii, Proceedings	2003			1349	1352
Baker, C	Tidal power	Energy Policy	1991	19	8	792	797
Banat, F; Jwaied, N; Rommel, M; Koschikowski, J; Wieghaus, M	Performance evaluation of the "large SMADES" autonomous desalination solar-driven membrane distillation plant in Aqaba, Jordan	Desalination	2007	217	01-Mar	17	28
Bermudez-Contreras, A; Thomson, M; Infield, DG	Renewable energy powered desalination in Baja California Sur, Mexico	Desalination	2008	220	01-Mar	431	440
Campbell, DE	Evaluation and emergy analysis of the Cobscook Bay ecosystem	Northeastern Naturalist	2004	11		355	424
Colombo, D; De Gerloni, M; Reali, M	An energy-efficient submarine desalination plant	Desalination	1999	122	02-Mar	171	176
Cooper, WS; Hinton, Cl; Ashton, N; Saulter, A; Morgan, C; Proctor, R; Bell, C; Huggett, Q	An introduction to the UK marine renewable atlas	Proceedings of The Institution Of Civil Engineers-Maritime Engineering	2006	159	1	1	7
Davies, PA	Wave-powered desalination: resource assessment and review of technology	Desalination	2005	186	01-Mar	97	109
Demirbas, A	Global renewable energy resources	Energy Sources Part A-Recovery Utilization And Environmental Effects	2006	28	8	779	792
Ducrotoy, JP; Elliott, M	The science and management of the North Sea and the Baltic Sea: Natural history, present threats and future challenges	Marine Pollution Bulletin	2008	57	01-May	8	21
Elhadidy, MA; Shaahid, SM	Wind resource assessment of eastern coastal region of Saudi Arabia	Desalination	2007	209	01-Mar	199	208
Falnes, J; Lovseth, J	Ocean wave energy	Energy Policy	1991	19	8	768	775
Fan, J; Sun, W; Ren, DM	Renewables portfolio standard and regional energy structure optimisation in China	Energy Policy	2005	33	3	279	287

Authors	Title	Journal	Year	Volume	Issue No.	Pages	
Fath, HES; El-Shall, FM; Vogt, G; Seibert, U	A stand alone complex for the production of water, food, electrical power and salts for the sustainable development of small communities in remote areas	Desalination	2005	183	01-Mar	13	22
Faulkner, RD	Fossil water or renewable resource - the case for one Arabian aquifer	Proceedings of The Institution Of Civil Engineers-Water Maritime And Energy	1994	106	4	325	331
Gaudiosi, G	Offshore wind energy potential in the Mediterranean	Renewable Energy : Technology And The Environment, Vols 1-5	1992			1622	1633
Gibbons, J; Papapetrou, M; Epp, C	Assessment of EU policy: Implications for the implementation of autonomous desalination units powered by renewable resources in the Mediterranean region	Desalination	2008	220	01-Mar	422	430
Gill, AB	Offshore renewable energy: ecological implications of generating electricity in the coastal zone	Journal of Applied Ecology	2005	42	4	605	615
Gill, AB; Kimber, AA	The potential for cooperative management of elasmobranchs and offshore renewable energy development in UK waters	Journal of The Marine Biological Association Of The United Kingdom	2005	85	5	1075	1081
Heimiller, D; Haymes, S; Schwartz, M; Musial, W	Offshore wind resource potential of the United States	2007 Oceans, Vols 1-5	2007			675	682
Hlebcar, B	Influence of dispersed electricity production on distribution networks	Energy And The Environment 2004, Vol II	2004			165	173
Hlebcar, B	Dispersed electricity production on the open electricity market	Energy And The Environment 2002, Vol Ii	2002			193	199
Horvath, L	Wind energy as a part of a coastal zone sustainable development strategy	Periodicum Biologorum	2000	102		531	535
Inoue, K; Abe, Y; Murakami, M; Mori, T	Feasibility study of desalination technology utilizing the temperature difference between seawater and inland atmosphere	Desalination	2006	197	01-Mar	137	153
Jin, D; Grigalunas, TA	Environmental compliance and energy exploration and production - application to offshore oil and gas	Land Economics	1993	69	1	82	97
Jo, CH; Jeong, H; Park, RS; Cho, WC	Application of Floating Tidal Current Power System in Cooling Water Channel	Proceedings of The Eighteenth (2008) International Offshore And Polar Engineering Conference, Vol 1	2008			466	468
Jones, AT; Rowley, W	Global perspective: Economic forecast for renewable ocean energy technologies	Marine Technology Society Journal	2002	36	4	85	90

Authors	Title	Journal	Year	Volume	Issue No.	Pages	
Jones, AT; Rowley, W	Recent developments and forecasts for renewable ocean energy systems	Oceans 2001 Mts/Ieee: An Ocean Odyssey, Vols 1-4, Conference Proceedings	2001			575	578
Jungbluth, N; Bauer, C; Dones, R; Frischknecht, R	Life cycle assessment for emerging technologies: Case studies for photovoltaic and wind power	International Journal of Life Cycle Assessment	2005	10	1	24	34
Junginger, M; Agterbosch, S; Faaij, A; Turkenburg, W	Renewable electricity in the Netherlands	Energy Policy	2004	32	9	1053	1073
Kannen, A	The need for integrated assessment of large-scale offshore windfarm development	Managing European Coasts: Past, Present And Future	2005			365	378
Kershman, SA; Rheinlander, H; Gabler, H	Seawater reverse osmosis powered from renewable energy sources - hybrid wind/photovoltaic/grid power supply for small-scale desalination in Libya	Desalination	2003	153	01-Mar	17	23
Kershman, SA; Rheinlander, R; Neumann, T; Goebel, O	Hybrid wind/PV and conventional power for desalination in Libya - GECOL's facility for medium and small scale research at Ras Ejder	Desalination	2005	183	01-Mar	1	12
Kim, YC	Assessment of California's ocean wave energy recovery	California And The World Ocean '97 - Taking A Look At California's Ocean Resources: An Agenda For The Future, Vols 1 And 2, Conference Proceedings	1998			175	182
Kull, A; Laas, A	Sustainable management of wind resources in coastal areas in Estonia	Sustainable Planning And Development	2003	6		69	78
Kuo, C; Sukovoy, O	Contributions of naval architecture to offshore windfarm developments	Proceedings of The Fourteenth (2004) International Offshore And Polar Engineering Conference, Vol 1	2004			136	141
Lai, CM; Huang, JL	Combination of renewable energies and a simple desalinator used in land aqua-farms in Taiwan	Water Resources Management Iii	2005	80		221	226
Lai, CM; Lin, TH	Potential assessment of the use of green energy to meet the electricity demand in a land aquafarm	Sustainable Development And Planning II, Vols 1 And 2	2005	84		653	660

Authors	Title	Journal	Year	Volume	Issue No.	Pages	
Larsen, JK; Guillemette, M	Effects of wind turbines on flight behaviour of wintering common eiders: implications for habitat use and collision risk	Journal of Applied Ecology	2007	44	3	516	522
Livnat, A	Desalination in Israel - emerging key component in the regional water-balance formula	Desalination	1994	99	02-Mar	275	297
Madsen, PT; Wahlberg, M; Tougaard, J; Lucke, K; Tyack, P	Wind turbine underwater noise and marine mammals: implications of current knowledge and data needs	Marine Ecology-Progress Series	2006	309		279	295
Magadza, CHD	Climate change impacts and human settlements in Africa: Prospects for adaptation	Environmental Monitoring And Assessment	2000	61	1	193	205
Mahmoudi, H; Abdul-Wahab, SA; Goosen, MFA; Sablani, SS; Perret, J; Ouagued, A; Spahis, N	Weather data and analysis of hybrid photovoltaic - wind power generation systems adapted to a seawater greenhouse desalination unit designed for arid coastal countries	Desalination	2008	222	01-Mar	119	127
Majdandzic, L; Sauer, DU	Project of a self-sufficient solar building on the island of Krk – Croatia	Energy And The Environment 2002, Vol I	2002			85	90
Majstrovic, M; Jelavic, B; Vujcic, R	Renewable energy sources and their role in the sustainable development of the Adriatic littoral area	Periodicum Biologorum	2000	102		469	474
Mander, S	The role of discourse coalitions in planning for renewable energy: a case study of wind-energy deployment	Environment And Planning C-Government And Policy	2008	26	3	583	600
Mangin, A; Guevel, P; Murray, CN	Renewable energy sources and requirements needed to substitute one million tons of CO2 atmospheric emissions in Europe	Greenhouse Gas Mitigation: Technologies For Activities Implemented Jointly	1998			513	521
Markevicius, A; Katinas, V; Marciukaitis, M	Wind energy development policy and prospects in Lithuania	Energy Policy	2007	35	10	4893	4901
Marshall, N	Mangrove conservation in relation to overall environmental considerations	Hydrobiologia	1994	285	01-Mar	303	309
Masud, J	Wind power project at Pasni	Greenhouse Gas Mitigation: Technologies For Activities Implemented Jointly	1998			595	604
Morthorst, PE	Offshore windfarms and a green certificate market.	Greenhouse Gas Control Technologies	2001			845	850

Authors	Title	Journal	Year	Volume	Issue No.	Pages	
Morthorst, PE	The cost of reducing CO2 emissions - Methodological approach, illustrated by the Danish energy plan	Biomass & Bioenergy	1998	15	04-May	325	331
Musial, W	Offshore wind electricity: A viable energy option for the coastal united states	Marine Technology Society Journal	2007	41	3	32	43
Muyungi, RS	Managing land use, protecting land and mitigating land degradation: Tanzania case study	Climate And Land Degradation	2007			437	445
Ohman, MC; Sigray, P; Westerberg, H	Offshore windmills and the effects electromagnetic fields an fish	Ambio	2007	36	8	630	633
Osawa, H; Miyazaki, T	Wave-PV hybrid generation system carried in the Offshore Floating Type Wave Power Device "Mighty Whale"	Oceans '04 Mts/Ieee Techno-Ocean '04, Vols 1- 2, Conference Proceedings, Vols. 1-4	2004			1860	1866
Paredes, AR; Gonzalez, BR	Green power for protected natural areas in Mexico focused on conserving and improving the quality of life	Proceedings of The Fifty-Fourth Annual Gulf And Caribbean Fisheries Institute	2003			709	715
Paulsen, K; Hensel, F	Design of an autarkic water and energy supply driven by renewable energy using commercially available components	Desalination	2007	203	01-Mar	455	462
Pelc, R; Fujita, RM	Renewable energy from the ocean	Marine Policy	2002	26	6	471	479
Portman, M	Involving the public in the impact assessment of offshore renewable energy facilities	Marine Policy	2009	33	2	332	338
Rheinlander, J; Perz, EW; Goebel, O	Performance simulation of integrated water and power systems - software tools ipsepro and resyspro for technical, economic and ecological analysis	Desalination	2003	157	01-Mar	57	64
Rodgers, M; Olmsted, C	Engineering and regulatory challenges facing the development of commercially viable offshore wind projects	Marine Technology Society Journal	2008	42	2	44	50
Sagie, D; Feinerman, E; Aharoni, E	Potential of solar desalination in Israel and in its close vicinity	Desalination	2001	139	01-Mar	21	33
Sandyswinsch, C; Harris, PJC	Green development on the cape-verde islands	Environmental Conservation	1994	21	3	225	230
Santora, C; Hade, N; Odell, J	Managing offshore wind developments in the United States: Legal, environmental and social considerations using a case study in Nantucket Sound	Ocean & Coastal Management	2004	47	03-Apr	141	164
Sclavounos, P	Floating offshore wind turbines	Marine Technology Society Journal	2008	42	2	39	43

Authors	Title	Journal	Year	Volume	Issue No.	Pages	
Shim, S; Kim, MH	Rotor-floater-tether coupled dynamic analysis of offshore floating wind turbines	Proceedings of The Eighteenth (2008) International Offshore And Polar Engineering Conference, Vol 1	2008			455	460
Side, J; Jowitt, P	Technologies and their influence on future UK marine resource development and management	Marine Policy	2002	26	4	231	241
Smit, T; Junginger, M; Smits, R	Technological learning in offshore wind energy: Different roles of the government	Energy Policy	2007	35	12	6431	6444
Stancyk, SE; Golde, HM; Papelindstrom, PA; Dobson, WE	Born to lose .1. Measures of tissue loss and regeneration by the brittlestar microphiopholis-gracillima (echinodermata, ophiuroidea)	Marine Biology	1994	118	3	451	462
Steiner, ZB; Steiner, I	The role of oil and gas in contemporary energetics and in the future	Energy And The Environment 2002, Vol I	2002			299	303
Stephens-Romero, S; Samuelsen, GS	Demonstration of a novel assessment methodology for hydrogen infrastructure deployment	International Journal Of Hydrogen Energy	2009	34	2	628	641
Stewart, GB; Pullin, AS; Coles, CF	Poor evidence-base for assessment of windfarm impacts on birds	Environmental Conservation	2007	34	1	1	11
Stuyfzand, PJ; Kappelhof, JWNM	Floating, high-capacity desalting islands on renewable multi-energy supply	Desalination	2005	177	01-Mar	259	266
Svel-Cerovecki, S	Petroleum hydrocarbons and the Mediterranean	Energy And The Environment 2004, Vol I	2004			67	74
Takagi, K; Yano, W; Yamamoto, K	Utilization of a very large mobile offshore structure for clean energy conversion	Oceans 2003 Mts/Ieee: Celebrating The Past...Teaming Toward The Future	2003			866	872
Takeuchi, M; Matsumiya, N; Niwa, S	Study on CO2 global recycling system	Greenhouse Gas Control Technologies	1999			433	438
Tavner, P	Wind power as a clean-energy contributor	Energy Policy	2008	36	12	4397	4400
Thompson, R	Reporting offshore wind power: Are newspapers facilitating informed debate?	Coastal Management	2005	33	3	247	262
Uyterlinde, MA; Junginger, M; De Vries, HJ; Faaij, APC; Turkenburg, WC	Implications of technological learning on the prospects for renewable energy technologies in Europe	Energy Policy	2007	35	8	4072	4087
Valerio, D; Beirao, P; DA Costa, JS	Optimisation of wave energy extraction with the Archimedes Wave Swing	Ocean Engineering	2007	34	17-18	2330	2344

Authors	Title	Journal	Year	Volume	Issue No.	Pages	
Van Der Veen, HH; Hulscher, SJMH; Lapena, BP	Seabed morphodynamics due to offshore windfarms	River, Coastal And Estuarine Morphodynamics: Rcem 2007, Vols 1 And 2	2008			1061	1066
Waters, JK; Mayer, RH	Ocean energy design projects at the US Naval Academy	Oceans 2005, Vols 1-3	2005			1415	1420
West, AD; Caldow, RWG	The development and use of individuals-based models to predict the effects of habitat loss and disturbance on waders and waterfowl	Ibis	2006	148		158	168
Wilhelmsson, D; Malm, T	Fouling assemblages on offshore wind power plants and adjacent substrata	Estuarine Coastal And Shelf Science	2008	79	3	459	466
Yuval; Broday, DM	Assessing the long term impact of power plant emissions on regional air pollution using extensive monitoring data	Journal of Environmental Monitoring	2009	11	2	425	433

8 Conclusions

The marine renewable sector represents a significant commercial opportunity for the UK economy, and the recent targets set by government across all low carbon sectors constitute a major challenge to all research science sectors to support its development. The focus on technology development and performance testing to date, has resulted in the environment being seen as an impediment to progress, with the result that research effort has been focussed on UK statutory obligations to protect designated or European protected species. The research which is now urgently needed, to derive an adequate holistic understanding of the interaction between natural resources and new technologies, and research quality evidence of the impact of deploying arrays of renewable energy devices in our coastal waters is, however, essential if development of marine renewable energy is to fulfil its potential – not only in the UK but worldwide. Consequently, putting the marine environment centre stage and posing fundamental questions about environmental carrying capacity and maintenance of biodiversity and ecosystem functions, will enable us to assess whether low carbon technologies deployed into the marine environment are compatible with sustainable use of the natural resources. This current situation represents a major opportunity for NERC to make an impact on the progress of the industry, by engaging the excellence in uk marine research science to answer the fundamental questions about the sustainability of marine renewable energy.

As a result of recent meetings and workshops (EMEC, September 2008, NERC workshop (Feb 26^{th,}) and the UKERC workshop (March 24th 25th) we have derived as complete a synthesis of the research needs of policy makers, regulators and developers relating to biodiversity and ecosystems as possible. An updated inventory of the research needs was produced recently by DECC and it is clear that there is a very significant body of research covering all elements of biodiversity and environmental impacts of marine renewables which is needed to support sector development, but not yet funded. Many of the research questions and issues were confirmed and discussed in depth during our consultation and workshop sessions as constituting priority research issues for regulators, developers and policy makers. The main hurdle to progressing more research projects in the short term appears to be lack of resource. Our recommendation therefore is that NERC considers the possibility of feeding funds through the DECC RAG as a partner organisation in the RAG, to progress research in areas which map directly onto NERC strategic science. This would need to be discussed at the highest level with those concerned, but rather than create a new stakeholder / end user forum to bring academics closer to the end user community, this would avoid replication and provide a ready made route for businesses, policy makers and regulators to benefit directly from novel research delivered through NERC strategic programmes.

In addition to the possible partnership with DECC RAG, we strongly recommend that NERC develops a managed programme of research focussed on the fundamental questions relevant to the SUNR, Biodiversity, Natural hazards and Technology themes. Because of the complexity of the current research landscape, NERC research focussing on the main opportunities / needs and gaps identified in this study in relation to whole systems, technology / methods development and ecosystem restoration and socio-economic opportunities, we believe that the most efficient way to deliver the research in a timely and cost effective manner is to opt for a managed programme. This would minimise the project management time in research groups and ensure proper integration across all research areas, including potentially with research underway and coordinated by the DECC RAG.

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10 Appendices

Appendix 1: Marine Renewable Energy Developments: Compiled List of Environmental Issues and Research Topics (RAG & COWRIE, 2007)

Table 10 provides a summary of the fourth revision of the RAG list of issues raised and research needs for offshore renewable energy originally compiled in early 2004 for the Government's Research Advisory Group (V4-170206) and the COWRIE Environment Working Group list (V2-050406). The list covers windfarms and wave and tidal stream devices. Note, project status reflects work funded by a range of bodies including RAG and COWRIE.

Table 10 – Marine Renewable Energy Developments – Compiled list of environmental issues and research topics.

Theme	Issue Ref.	Subject	Description	Application	Status	Funder
Birds	1.1	UK gap analysis	Review and analysis of existing offshore seabird survey effort (ESAS database) to identify significant gaps in spatial and temporal coverage.	All	**Active** Draft Report Received	DTI through SEA programme
Birds	1.2	Baseline surveys of R2 strategic areas	Winter and summer aerial surveys of water bird distribution and abundance in the Thames Estuary, Greater Wash and Liverpool Bay Round 2 areas. The programme is aimed at providing site specific regional data on the distribution, abundance and main feeding/roosting patterns of water birds. Project in 2 phases covering surveys in year 04-05 and year 05-06.	Wind (chiefly)	**Active** RAG Project No. 1.2	DTI, Defra, developers, CCW (yr 1), EN (yr 2)
Birds	1.3	Indicative Sensitivity Mapping	Garthe & Huppop (2004) developed a Windfarm Sensitivity Index (WSI) for seabirds. This may provide a strategic tool for use in planning future UK offshore wind leasing and with modification and further work may also be applicable to other devices.			
Birds	1.4	Observer training for boat based surveys of birds.	JNCC to provide two residential ship-board training courses for seabird surveyors working for or to be employed by ecological consultants	All	**Active** RAG Project No. 1.4	DTI
Birds	1.5	Survey Best Practice Guidance	A comparison of ship and aerial sampling methods for marine birds, and their applicability to offshore windfarm assessments. Guidance produced.	All	**Completed** COWRIE Project No. BAM-02-2002	COWRIE
Birds	1.6	Displacement of birds (especially common scoter) from benthic feeding areas	Field studies in the eastern Irish Sea and development of a model to assist in predicting the effect of offshore windfarms (individually and cumulatively) on Common Scoter due to habitat loss and change. Guidance on the use of the model to assist developers in carrying out Environmental Impact Assessments (EIAs).	Wind	**Completed** COWRIE Project No. BEN–03–2002	COWRIE
Birds	1.7	Field testing of radar (flight pattern and collision risk)	To field test radar to provide baseline information on distribution, altitude, movements and flight behaviour, seasonality, weather conditions, including nocturnal, assessment of migration flights and risk to migrants. (Technique development).	Wind	**Not active**	N/A
Birds	1.8	Post-Construction - Use of Radar Techniques (Flight patterns and collision risk)	To deploy radar, post-construction in R2 strategic areas, to provide information on distribution, movement and flight behaviour, including avoidance of turbines and collisions.	Wind	**Not active** (Some developer surveys using radar have been undertaken).	N/A
Birds	1.9	Field testing of Infra-Red Systems (flight patterns and collision risk	Once suitable Infrared systems have been identified trials of the systems will take place at suitable offshore windfarms.	Wind	**Not active**	N/A
Birds	1.10	Review of monitoring	Collate and interpret site monitoring results at national/regional scale	Wind	**Not active**	N/A

		results from R1 and R2 sites.	and report on changes in distribution, movement and Birds behaviour to determine disturbance, exclusion, flight patterns, collisions, habitat loss and direct mortality on populations, from the results of individual site monitoring. Determine if any consistent patterns or trends evident.		(Awaiting sufficient monitoring data.)	
Birds	1.11	Collision Detection Systems	To develop and test collision detection systems e.g. vibration sensors in R2 strategic areas.	Wind	**Not active**	N/A
Birds	1.12	Deterrents and other mitigation to reduce bird impacts	To develop mitigation measures, eg shutdown, warning paint, turbine spacing & alignment, navigation lighting etc (taking account of potential visual intrusion implications). Establish database of mitigation measures together with documentation of their effectiveness (or lack of) under different circumstances.	Wind	**Not active**	N/A
Birds	1.13	Best practice guidance for the use of remote techniques for observing bird behaviour in relation to offshore windfarms	Desk based study and international workshop. Project aims were to provide: 1) An objective assessment of the utility of remote technologies for the specific study of bird/wind turbine and bird/windfarm interactions and specifically their ability to meet objectives set for their use 2) Guidance on current best practice of the most suitable technologies 3) Recommendations for further methodological development to increase utility.	Wind	**Completed** COWRIE Project REMOTE-05-2004	COWRIE
Birds	1.14	Manual of post development monitoring requirements	Establishment of guidelines for good monitoring practice and to detail data gathering protocols in a methods manual. These guidelines would ensure that data gathered as part of Before-After-Control-Impact (BACI) studies provide a good cost/benefit return in terms of assessing the impact of projects on their environments, and also that the data collected can contribute to multi-site analyses aiming to generate results of generic value.	Wind	**Not active** (Potential linkage to issue 1.10 above)	N/A
Birds	1.15	Impacts of sub-surface structures on birds	Investigation of the potential impacts of wave and tidal generation devices on birds (particularly diving birds), including collision.	Wave and Tidal	**Not active**	N/A
Birds	1.16	Windfarm casualties and bird population viability	Development of demographic models for a set of species selected to be representative of the range of life-histories encountered in the UK i.e. small, short-lived species to large long-lived species. These models should make it possible to estimate the number of birds that can be lost before a population is affected.	Wind	**Not active**	N/A
Birds	1.17	Migration corridors	Establish large scale (radar) study to investigate migration across the North Sea to UK waters. Migration volume, timing, altitude and spatial distribution.	Wind N/A	**Not active** (Software is being developed to allow bird migration to be observed from Met Office radar.)	

Birds	1.18	Predictive modelling	Predictive modelling of seabird distributions – i.e. having an idea of where the birds will be before going to look for them.	Wind	**Dormant**	N/A
Birds	1.19	Seabird movements	Marking, ringing and/or tagging studies to clarify site fidelity and wider movement patterns of key species e.g. common scoter	All	**Not active**	N/A
Birds	1.20	Energetic costs of barrier effects on birds	Desk research on the potential energetic costs to birds of the presence of offshore windfarms	Wind	**Active** RAG Project 1.20	DTI
Birds	1.21	Monitoring at Kentish Flats	Additional ornithological monitoring at Kentish Flats	Wind	**Not active**	
Birds	1.22	Tern tagging pre-construction	Expand on EON's investigation of little tern using Scroby Sands by looking at their movements on the north Norfolk coast pre-construction	Wind	**Not active**	
Birds	1.23	Offsetting bird impact	Consideration of mitigation for displacement e.g. managing other areas of sea as seabird feeding roosting areas	Wind	**Not active**	
Birds	1.24	Develop design protocol for maintenance boats and recommendations for carrying out visits	Assess effects of disturbance and nature of response by birds to boat profile, approach speed, noise and frequency of passage by boats	Wind	**Not active**	
Birds	1.25	Displacement and habituation	Study of enhanced measurement of displacement distances from turbines under different conditions. Long term assessment to determine the degree of habituation	Wind	**Proposed**	COWRIE DISP-02-2006
Bats	2.1	Collision	Risk Identify if any migration routes and flight paths between feeding and roosting/resting areas impinge on offshore windfarms.	Wind	**Dormant**	N/A
Marine Mammals	3.1	Survey methodology - standardisation of marine mammal survey, assessment and monitoring techniques	Survey methodology - Best practice guidance - Develop standard survey methodology. A 2 stage project, the first phase to review existing techniques and guidance including the recent JNCC Marine Mammal Common Standards Guidance and the second phase to produce guidance.	All	**Not active** (Linked with RAG issue 3.5.)	N/A
Marine Mammals	3.2	Remote survey techniques for marine mammals	A possible project to expand on the remote techniques and birds evaluation, but to include marine mammals and other wildlife groups. For example we are all being asked to consider use of e.g. hydrophones and porpoise detectors in surveying marine mammals but the equipments available appears to be problematic in some environments	All	**Not active**	
Marine Mammals	3.3	Determine sensitivity of selected marine mammals and other receptors to underwater noise and vibration: physical damage,	Collate results at a national / regional scale and report on changes in the distribution of marine mammals recorded at individual sites. Assessment of implications at a population level to be included. Interpretation in light of Phase 1 and 2 of COWRIE study (see issue 5.1 and 3.6)	Wind	**Not active**	N/A

		behaviour				
Marine Mammals	3.4	Improving the information base on the distribution of marine mammals	Review of existing understanding for significant gaps and potentially initiate new studies of the distribution of marine mammals: • day/night • seasonal • migration routes • seal haul out sites • breeding/pupping sites	All	**Not active** (Variety of local regional & international studies recently completed or planned)	N/A
Marine Mammals	3.5	Seal tagging	Use of seal satellite tagging to investigate behaviour and ecology during and post-construction.	All	**Active** Potential to extend existing developer seal tagging studies	DTI SEA
Marine Mammals	3.6	Response of marine mammals to underwater noise from construction, operation and/or decommissioning	There is currently insufficient information on the likely response of marine mammals to subsea noise. Information is particularly required on impacts on behaviours. Indirect impacts may occur. Likely cumulative impacts, particularly in respect of noise from construction activities occurring simultaneously at different sites, are also not well known. However the issue is much broader than renewables and there is potential for a high level review paper as a first step. COWRIE project should inform.	All	**Not active**	N/A
Marine Mammals	3.7	Tidal stream rotor interaction with marine mammals	Studies needed to clarify if current turbines present risks of physical injury or behavioural change to marine mammals. Results may have application to bird and fish interactions.	Tidal stream	**Not active**	N/A
Marine Mammals	3.8	Entanglement of marine mammals (and other animals)	Wave generators will typically entail a range of surface equipment and mooring cables. Some cetaceans and turtles are known to become entangled in for example lobster pot buoy ropes. Although entanglement in wave generator installations seems unlikely in view of the size, rigidity and tension, the subject needs to be explored through an initial review of evidence.	Wave	**Not active**	N/A
Seascape	4.1	Effectiveness of visual limits used in R2	Testing and refining for future licensing rounds the visual limits used in R2 (Note CCW, and SEA, for R2 used modified 'Sinclair' threshold distances for high, moderate and low visual impact.) Empirical study (Perception issues dealt with in 4.2)	Wind	**Not active**	N/A
Seascape	4.2	Monitoring windfarm - seascape interactions (Public acceptance of offshore renewables)	Collate results at a national/regional scale and report on changes in public perception in communities near individual sites (questionnaire surveys) Monitor change in UK public perception of offshore windfarms (internet based tools, focus group, Beaufort omnibus) Ground truth photomontages used in individual site EIAs Interview representatives of tourist industry, visitors, sea users, residents and other target	Wind	**Not active**	N/A

			groups. Undertake a tourism cost benefit analysis			
Seascape	4.3	Seascape baseline	Assessment of regional seascape units: • visibility of the sea • character of coastline • quality • value • capacity to accommodate change	All	**Not active** (However extensive work has been undertaken by CCW, SNH and others)	N/A
Seascape	4.4	Development of seascape assessment tools/techniques and mitigation	Desk-based study to produce practical guidance for developers and their landscape consultants for offshore windfarm sites on seascape issues. A further objective of the work was to assist standardisation of the guidance offered to developers by Government agencies in England and Wales thereby improving the quality of seascape assessment.	All	**Completed** RAG Project No. 4.4	DTI
Soundscape	5.1	Monitoring of underwater noise and vibration generated by windfarm construction and operation	Project aims to provide field data in relation to the potential impact of sub-sea acoustic noise and vibration produced from offshore wind turbines. Building on existing desk based research the field data will be assessed to determine any behavioural or other effects on marine wildlife. **Phase One** – literature review and measurements at one or more existing windfarms. **Phase Two** - field measurements from pre-construction to operation	Wind	**Completed** COWRIE NOISE-03-2003 **Active**	COWRIE
Soundscape	5.2	Sources of underwater noise and vibration generated by wave and tidal installation construction and operation	Collate information on the nature of noise and vibration generated from these devices as a basis for assessing whether further work is required (along the lines of 5.1 above) on noise from the construction, operation and decommissioning.	Wave and Tidal	**Not active**	
Soundscape	5.3	Noise and vibration mitigation study and guidance (for construction, operation and decommissioning)	A review of the efficacy of proposed mitigation and possible alternatives (e.g. bubble curtains etc) is required studying the technical solutions available and the efficacy, reliability and practicality of those solutions. The development of guidance on industry best practice for effective mitigation for e.g. piling A review of the efficacy of deterrents such as pingers and scarers is required particularly in the context of long periods of construction or similar during which receptors may become conditioned to such measures	All	**Proposed**	N/A
Soundscape	5.4	Methods for prediction of	Guidance for developers is required dealing with assessment of noise	All	**Not active** (Phase 1	N/A

		underwater noise levels and propagation, and assessment of effects	levels from piling and the prediction of impacts (models, differing site conditions and bathymetry).		and 2 of COWRIE study should inform – see issue 5.1 above).	
Fish, Shellfish and Benthos	6.1	Statistical basis for seabed benthic monitoring as a tool for environmental management in the offshore windfarm industry	Study aims are to: • Review and evaluate the ability of currently applied or recommended benthic survey strategies to detect and monitor the anticipated diffuse and subtle effects of windfarm construction and operation in shallow water areas with high natural variability in sediment and biological conditions. • Develop guidance for government and developers on suitable benthic biological effects monitoring strategies for offshore windfarms	All	**Active** Contractor selected, awaiting sufficient data to initiate	DTI/Defra
Fish, Shellfish and Benthos	6.2	Benthic survey techniques	It has been agreed that work already exists in this area and this research project will not continue.	N/A	**Dormant**	N/A
Fish, Shellfish and Benthos	6.3	Review of cabling techniques and effects applicable to the offshore windfarm industry.	The project aims to provide an information resource and guidance to government and developers on the range of cable installation techniques available, their likely effects and potential mitigation, drawing on windfarm and other marine industry practice and experience.	All	**Active** RAG Project 6.3	DTI/Defra
Fish, Shellfish and Benthos	6.4	Methods for EMF measurement	Develop standard survey methods for EMF measurement in the field. Largely addressed by COWRIE studies	All	See 6.5 below	N/A
Fish, Shellfish and Benthos	6.5	Measurement and effects of EMF	**Phase 1** of the COWRIE EMF study was a desk based study to calculate the strength, frequencies and wavelengths of the electromagnetic fields produced by 33 kV (EPR) and 132 kV (XLPE) cables. The study also calculated the effects of burial and / or shielding (at various depths, strata, sediment type and thickness) on electromagnetic fields. The interim investigation **(Phase 1.5)** aimed to prioritise those fish species most likely to interact with the EMFs generated by offshore windfarm cables. A key objective was to produce practical guidance to developers where possible for discussion of FEPA licensing conditions. To assist in this process, the study considered monitoring that would be appropriate in light of the review undertaken. An overview of possible survey methods for electrically and magnetically sensitive species was included, together with advantages and disadvantages. This included suitable monitoring that could be	All	**Complete** COWRIE EMF-01-2002 **Completed** COWRIE EMF-06-2004	COWRIE

			undertaken and an overview of possible survey methods for electrically and magnetically sensitive species, their advantages and disadvantages. **Phase 2, Stage 1 -** Development of project execution plan and experimental Methodology **Phase 2, Stage 2 -** Experimental mesocosm study		**Active** COWRIE EMF-01-06 **Proposed** COWRIE EMF-04-06	
Fish, Shellfish and Benthos	6.6	EMF mitigation measures and guidance	A project to investigate mitigation measures relative to: cable type, cable burial depth in different sediments, cable shielding, and cable voltage strength. To produce guidance on: maximum fields, cable type, and burial depth. Largely addressed by COWRIE studies.	All	See 6.5 above	N/A
Fish, Shellfish and Benthos	6.7	Underwater noise and vibration and fish and invertebrates	Effects of noise and vibration on fish and invertebrates - linked with marine mammals/noise and vibration studies.	All	See 5.1, 5.2 & 3.6	N/A
Fish, Shellfish and Benthos	6.8	Reef effects, guidance and mitigation	The aim of the project is to provide a scientifically credible review of two aspects of the physical presence of windfarm structures: 1. the likely reefs effects on fish, shellfish and other marine biota 2. the potential to enhance the reef effect for commercial species The review is expected to result in testable predictions on these two aspects and proposals for field studies necessary to test the predictions.	Wind	**Active** RAG Project 6.8	DTI/Defra
Fish, Shellfish and Benthos	6.9	Included in 6.8				
Fish, Shellfish and Benthos	6.10	Spawning/nursery areas – risk assessment for Habitats Directive and UKBAP species	Review of information base on the distribution of spawning / nursery areas for priority marine species	All	**Dormant**	N/A
Fish, Shellfish and Benthos	6.11	Recovery rates	To collate and synthesise the benthic monitoring results from the R1 sites. Note this will be informed by the results of project 6.1 - see above	All	**Not active**	N/A
Fish, Shellfish and Benthos	6.12	Biological implications of the removal of energy from the marine environment	Monitoring to confirm the validity of predictions for different technologies. Review of the reliance of habitats and species on energy (wave and tidal stream) in the marine environment. Predictions of the biological impact of energy extraction (wave and tidal). Assessment of the scaling up of projects from demonstrator to commercial farms will require consideration in the future – for example what will be the	Wave and Tidal	**Active**	CCW/CE project will address primarily biological issues CCW & CE

			impact of arrays on wave regimes? First step in a broader consideration could be a high level position paper developed by physical oceanographer, sedimentologist and ecologist.			
Fish, Shellfish and Benthos	6.13	Tidal rapid communities	There is a need for strategic information in tidal rapid communities to inform decisions on tidal stream generator deployments. Information needed includes habitat distribution, biological characteristics, controlling variables etc. A staged approach is proposed starting with a review of existing UK and other relevant information, potentially followed by targeted field surveys.	Tidal stream	**Not active**	N/A
Fish, Shellfish and Benthos	6.14	Non commercial fish	Information on marine fish is heavily skewed to commercial species. There are numerous other fish species some of which are of conservation interest but comparatively little is know of their distribution, ecology or status. Although it is difficult to envisage significant threats to these species posed by marine renewable developments, a review of the scale of the information gap and existing work in progress or planned is proposed.	All	**Not active**	N/A
Fish, Shellfish and Benthos	6.15	EMF	Sensitive species and life stages. Identification of key species and their sensitivities to EMF to be established (including consideration of different life stages)	All	**Not active**	N/A
Fish, Shellfish and Benthos	6.16	Fish tagging	The lower cost "non-electronic" tagging of fish and their recording of their activity. This could be a long duration project, therefore of generic use amongst the wind and fishing industries	Wind	**Not active**	N/A
Fish, Shellfish and Benthos	6.17	Impacts of offshore windfarms on commercial fisheries and shellfish	Further monitoring work is required on commercial fisheries and shellfisheries - to assess impacts because of offshore windfarm development. Due to spatial and temporal variations monitoring would have to be over a long time period (10 years+) and large geographical area to determine the impacts and assess causality. Given the timeframes and scale the costs of such a study could be overly burdensome/prohibitive for individual developers to undertake so a COWRIE/RAG (government) funded project would seem sensible. London Array development in the Thames lends itself to this type of assessment	Wind	**Not active**	N/A
Fish, Shellfish and Benthos	6.18	Potential impact of chalk cuttings on the marine environment	Research into the issue of chalk cuttings/slurry and their potential impacts on the marine environment. Also appropriate disposal of this waste stream.	Wind but All	**Not active**	NB UKOOA PhD Studentship on effects of cuttings
Seabed and Coastal Processes	7.1	Review of Round 1 sediment process monitoring data – lessons learned	Sediment process monitoring work carried out on Round 1 developments will be drawn together and reviewed. The review will assess the requirements, methods, data, results and impacts in order to make recommendations for monitoring of R2 developments.	Wind	**Active** RAG Project 7.1	DTI/Defra

Seabed and Coastal Processes	7.2a	Scroby Sands sediment transport monitoring for offshore windfarm construction	Measurement and models to predict effects on seabed and coastal processes. Effect of seabed scouring and sedimentation caused by windfarms on shipping lanes. To assess the magnitude and significance of changes to the nearshore sediment transport and sediment transport pathways as a result of the construction of an offshore windfarm on Scroby Sands. Consider: wave diffraction, coastal process impacts; erosion pits, cable depths and seabed morphology; the extent of erosion around piles of different types; the effectiveness of different scour protection. Would look at seabed scouring and sedimentation affecting navigable channels including port approaches and anchorages. Might consider a range of possible future seabed scenarios based on both construction and operation. Would need to be capable of generic application to gain Government support. Thames estuary seen as exceptionally important area. Cumulative impact issues with projects such as new container port and EA flood defence schemes need assessing.	Wind	**Active** RAG Project No.7.2a; DEFRA AE0262)	Defra
Seabed and Coastal Processes	7.2	Dynamics of scour pits and scour protection	The project will proceed in two stages. The first stage will be to review sediment scour and scour protection. Stage 2, if necessary, will involve marine surveys to collect new data that would enable reliable modelling of the processes. Finally the results will be published to give recommendations on the use of scour protection.	Wind	**Active** RAG Project 7.2	DTI/Defra
Seabed and Coastal Processes	7.3	Monitoring of actual impacts in context of natural change of dynamic systems.	A methodology for the studying of long-term impacts and a programme of monitoring is required to confirm the validity of predictions	Wind	**Not active** (Should be reviewed in light of results of RAG Project 7.1)	N/A
Seabed and Coastal Processes	74	Identification of subtidal features of potential importance	Geophysical mapping and ground truthing of some SEA areas. Map extent of subtidal features of earth science importance (equivalent to GCR sites)	All	**Not active** (However developer, DTI SEA and other mapping has filled some gaps)	N/A
Seabed and Coastal Processes	7.5	Impacts of tidal stream and wave devices on coastal processes	Information is needed on the physical influence of wave and tidal stream marine renewable technologies on the water body and coastal processes including effects of energy removal, turbulent wake effects, sediment movement etc. See 6.12 for biological aspects. It is proposed that strategic data is obtained from prioritised studies at demonstrator projects so that the potential implications of large scale deployment can be modelled and assessed. Following initial review it may prove necessary to investigate rotor and wave effects separately.	Wave and Tidal	**Not active** (But see 6.12)	N/A
Seabed and	7.6	Channel migration	A review of evidence for past natural migration of navigation channels	Wind and	**Active**	DTI/Defra

Coastal Processes			in UK waters with emphasis on R1 and R2 areas. Aims to identify whether potential for channel movement is a significant factor for siting of windfarms and wave generators.	wave	RAG project No. 7.6	
Seabed and Coastal Processes	7.7	Impact of gravity base and hybrid structures on coastal processes	Review and potentially modelling of the hydrodynamic and other effects of gravity base and hybrid structures. A range of alternatives to the currently deployed turbine base structures exist and there is limited information on the relative differences in terms of effects on coastal processes.	All	**Not active**	N/A
Seabed and Coastal Processes	7.8	Cumulative impact of monopile wakes	A review or studies to answer the question "Are wakes from monopiles (and by extension, other structures) cumulative and are they of sufficient magnitude to cause effects on water column structure and seafloor sediments".	Wind	**Not active**	N/A
Seabed and Coastal Processes	7.9	Upgrading the WaveNet site in the Greater Wash to full SmartBuoy	The Thames and NW strategic areas already have SmartBuoys providing good quality data to underpin EIA and monitoring (this is coincidental to, and not because of, the Strategic Areas). A modest cost of £15-20K would allow the existing WaveNet Buoy in the Wash to be upgraded so that each strategic area has access to comparable and consistent data.	Win	**Not active**	N/A
Socio-Economics	8.1	Impacts on recreational users of the sea	Understanding spatial and temporal use of coastal seas for recreation and potential conflicts of renewable energy projects with various recreational user groups (yachting, surfing, kiting etc). Consideration of relative economic values of loss of recreational space and increasing of generation capacity.	All	**Not active**	N/A
Socio-Economics	8.2	Socio-economic issues with offshore windfarm projects	Research into better integration of windfarm projects (development phase through to operation) with local economics and general issue of socio economics and offshore wind	Wind	**Not active**	
Water Quality	9.1	Impact on water quality	Consider effects of antifouling paints, cathodic protection etc and report on incidents and spills during construction and maintenance Best practice guide based on other industries	All	**Dormant**	N/A
Navigation	10.1	Marine traffic survey database	Two phase project. Primary objective is to develop a database, which can be used in a uniform process, initially to assess Round 2 offshore windfarm siting and layout proposals. Its primary users are expected to be the Maritime and Coastguard Agency (MCA) and the windfarm developers. Updating will take account of changes in routeing, shipping movements, and fishing patterns.	All	**Active**	DTI
Navigation	10.2	Interference by windfarm structures with marine communications, navigation and radar	Desk, laboratory and field investigation. Research enabling mariners, emergency services, offshore oil and gas installations, VTS and Port Authorities to assess the potential effects of offshore windfarms on their operational activities and safety. These groups to include all	All	**Complete**	DfT/ MCA/**nPower** renewables

		systems	recreational and fishing craft. To be used also in assessing the siting of shore based radar, the application of safety zones and the optimum clearances of windfarm boundaries from navigational routes.			
Navigation	10.3	Marine navigational safety risk assessment methodology for offshore windfarms	Project aimed to develop a consistent methodology for use by both developers and Government in assessing the effects of offshore windfarms on navigation risk and marine safety	Wind primarily	**Complete**	DTI
Cumulative Impacts	11.1	Assessment of cumulative and synergistic effects	Develop and agree standard cumulative methodology	All	**Dormant** Not just a marine renewable issue, MSP implications, other work underway	N/A
Cultural Heritage	12.1	Location and features of archaeological remains and historic landscapes	Appraisal of historic environment issues in nominated SEA areas. More detailed and consistent data on archaeological features needed in assessments. Reviews conducted for SEA process and through Aggregate Levy Sustainability Fund	All	**Not active**	N/A
Cultural Heritage	12.2	Strategic guidance for offshore industry: general	New edition of JNAPC Code of Practice for Seabed Developers issued	All	**Completed**	N/A
Cultural Heritage	12.3	Strategic guidance for offshore developers	Development of offshore renewables specific guidance for determining, recording and responding to the presence of archaeological material encountered or discovered during preliminary site assessment, the construction phase, operational maintenance and decommissioning of offshore windfarms and other offshore renewable power generation projects.	All	**Active** COWRIE-ARCH-11-05	COWRIE 2
Other	13.1	Identification of monitoring requirements - Lessons from Round 1	Production of a report identifying all s36, FEPA and TWAO conditions applied to Round 1 projects, which would be a useful reference when monitoring requirements discussed for Round 2 projects.	Wind	**Not active**	N/A
Other	13.2	Round 1 framework document	All issues subject to monitoring by R1 projects: - A structure for period collation, analysis and dissemination of information arising from the R1 projects is required - A framework should be provided for regulators and advisors to use R1 data to appraise FEPA conditions and inform future conditions for R2 and beyond	Wind	**Active** DEFRA have produced a draft process	
Fishing	14.1	Investigation into fishing activities that might take place within and around windfarms	Study objectives are to: • Determine whether the interactions between offshore windfarms and fishing will necessarily produce conflicts of interest or whether they can work together successfully. • Review fish and shell fish species and their related fisheries in R2 areas	Wind	**Active** Draft report received	DTI

			• Review fishing vessel and gear types operating in R2 areas • Assess potential effects of seabed infrastructure on fishing operations • Identify which fishing activities might be possible in or around offshore windfarms.			
Fishing	14.2	Investigation of the potential range of socioeconomic impacts on the fishing industry from offshore developments	Review existing approaches to determining the usage of the sea by commercial and amateur fishermen in the areas of proposed windfarms. If necessary, undertake complementary surveys of fishing communities utilising such areas. Consider possible socio-economic losses or gains to the fishing industry and make recommendations on the feasibility of different options.	Wind	**Active** Draft report received	Defra
Fishing	14.3	Voluntary Log Book Scheme	Voluntary Log Book Scheme to encourage the sub-10m vessels to divulge activity. Objective is to better understand important areas for small fishing vessel activity	All	**Not active**	

Appendix 3: Summary of Workshop – Tidal Energy and the Marine Environment

Hosted by University of Aberdeen and Robert Gordon University
Thursday 8th March, 2007, Aberdeen University

Purpose : To provide an opportunity for knowledge dialogue concerning the development of tidal energy and the understanding of the interaction of devices with the marine environment and to identify the current knowledge gaps and the challenges in filling those gaps. This interaction took place between engineers, developers, modellers, regulators and ecologists. To this end the consensus was that the meeting was very successful, with a greater awareness between disciplines and that more of this type of cross discipline interaction needs to occur.

Summary

Development and regulatory process

At the spatial and temporal scales at which tidal energy will be extracted there is a general lack of knowledge of both the possible physical and biological effects due to the placement of devices. Over the last few years, the collective group within the SuperGen project has gone some way to producing mathematical models, tank models and supporting work on full scale devices like the SNAIL which can be deployed as collectors of both biological and physical information in the areas of high speed tidal currents. The detailed hydrological models are revealing that the scale or dimensions at which we view the physical process can give very different answers but that physical effects can be felt at least 7 km from the location of deployment.

Developers are acutely aware of the current level of uncertainty and that the best practice is to review the entire 'life cycle' of a development. This requires a much greater level of certainty than we currently have as well as much better coverage of basic baseline data. There is general concern that the current practice in the production of Scoping documents, which are not encompassing, relies too much on desktop studies such that the unknowns remain unknown.

There are environmental guidelines from current European Directives (Birds and Habitat) and UK DTI deployment policies. However, due to the lack of uncertainty concerning the possible environmental effects of tidal development, the statutory advisory bodies stress that this has to be an adaptive/learning process, with a flexible approach which changes with gains in knowledge (as envisaged by regulatory guidance issued by the DTI). This requires a high level of interaction and knowledge dialogue between all interested parties taking into consideration changes to the current regulatory processes. The transposition of the Water Framework Directive into transitional and coastal waters for engineering works not regulated by the Water Environment (Controlled Activities) (Scotland) Regulations 2005, and the introduction of the Marine Bill may coincide with the expansion of prototype energy deployments within and outside designated test facilities.

The DTI Research Advisory Group (RAG) provides the knowledge transfer between statutory groups, government, developers and consultants. DTI and Cowrie have provided the funding and tender opportunities for the vast majority of research projects in the marine renewables arena. However the system needs to be more flexible and inclusive to new concerns, understandings and data gathering techniques. At present there is an under representation of academic input to the various advisory groups.

Current data collection and analysis

It was clear from this exchange of current knowledge that so much less is known about the ecology and exact physics of the marine environment than the equivalent area of study for terrestrial regions where wind renewables have been sited. Ecological effects of tidal mixing on ecosystems are both direct, influencing the ability of animals to catch their prey and indirect, determining the level of primary production which ultimately determines the fate of food availability up the entire trophic chain in marine ecosystems.

At present MCT and EMEC are at the forefront of the novel collection of physical, biological and behavioural data at appropriate biological spatial and temporal scales in the locations of actual tidal device deployment in the UK. The ecological research is coordinated by SMRU (and SMRU Ltd.), and focuses on the visible behaviours of marine mammals and seabirds. The MCT study also covers research on the before and after aspects of tidal deployments on benthos and sediment but there is a gap in the study of fish and plankton. SMRU is moving towards the establishment of a generic marine mammal monitoring methodology and is putting the data into a risk framework such that levels of probability of specific events/longer term changes can be quantified. They also are investigating the set up of a data gateway.

Desk-top studies by SAMS and CEH have highlighted the large gaps in knowledge of direct and indirect effects of tidal schemes on marine mammals, fish and birds. However models that draw on work from other studies (e.g. boat / propeller strikes on marine mammals, fish behaviour in relation to fishing nets, behavioural strategies, range shifts, population dynamics) increases our understanding of the risks proposed by tidal devices.

Studies at U of Aberdeen are indicating that the amount and location of primary production may play a more important role in determining when and where seabirds and marine mammals spend their time foraging than has previously been thought. These 'hotspots' are very limited in space, but all evidence points towards them being driven mainly by small differences in the amount of tidal mixing and potentially being affected by changes in tidal energy extraction.

As tidal energy extraction development comes closer to a reality more will be demanded to be known about both the direct and indirect ecological effects of the placement of tidal devices and the need for long-term, continuous tidal stream datasets that encompass a range of seasonal and spatial influences. How we get to the point of being able to deliver such needs depends on filling the following gaps and challenges.

Gaps and challenges to fill

Gaps in knowledge dialogue

There is a strong case to be made for more academic (ecological and engineering) input into the established network of statutory government groups, developers and consultants. *How to achieve this* – apply for funding for a working group to develop the following research areas set out below.

Gaps in marine ecology

Ecologists need to investigate the basic behavioural / food web /ecological interactions that are key for a wide range of animals and plant species in areas of high tidal flows. *How to achieve this* - there is good possibility of a Consortium NERC grant application.

Gaps in monitoring techniques/ data analysis

Engineers, ecologist and regulatory bodies need to work together and decide what exactly needs to be monitored/surveyed, and how best/efficiently that can be done:

How to achieve this – a series of small targeted projects and a greater usage of existing data already being collected by MCT and EMEC. Not all variables can be satisfactorily and cost-effectively measured with existing protocols. What locations will the DAQ kit operate from; seabed, water column, surface, aircraft and satellite all offer different aspects. Possible funding routes can include the DTI, EU, EPSRC and NERC projects with joint Post-doctoral positions and PhD studentships.

Gaps in site specific developments
Developers, engineers, ecologists and regulatory bodies should help each other in choosing appropriate sites for the collection of baseline data and dealing with funding issues for supporting the necessary research: *How to achieve this* - possible funding for larger scale projects from DTI / Cowrie and energy companies. Careful and well resourced application of marine spatial planning (through the marine bill) and Strategic Environmental Assessment (as required by legislation).

List of attendance

Ainsworth, David	MCT
Burnett, Robin	SSE Ltd.
Boyd, Ian	SMRU
Daunt, Frances	CEH
Goucher, Tim	SSE Ltd.
Hartley, John	DTI representative
Hayes, Peter	FRS
Mitchell, Paul	University of Aberdeen
Norris, Jenny	EMEC
Owen, Alan	RGU
Prior, Andrew	JNCC
Ruscoe, John	HW ICIT
Scott, Beth	University of Aberdeen
Thompson, Paul	University of Aberdeen
Wilson, Ben	SAMS

Not present – but involved

Couch, Scott	University of Edinburgh
Crutchfield, Zöe	JNCC
Gibberd, George	Tidal Generation
Heath, Malcolm	E.ON
Meade, Simon	Lunar Energy
Priestley, Ruth	SNH
Side, Jon	HW ICIT
Wratten, Angela	DTI

Appendix 4: Summary of UKERC workshop Edinburgh, March 24th / 25th

Summary of notes from UKERC Sustainable marine renewable arrays workshop Edinburgh March 24th / 24th

Session 1 – Fisheries

Issues:

- Space use
  - ⇨ Consequences of displacement
    - Conflict
    - Safety of fishers (J.S)
    - Fleet viability
    - Knock-on effects
    - Behaviour of fishers
- Lack of data / knowledge (*) + research / integration ⇨ to inform policy + management
  (*) Local knowledge of resource, working in area (MS)
- Relationship with other activities / sectors
  - Marine conservation
  - Energy sites (all) (opportunity for local fishing vessels supporting marine developments – MS)
  - Wild vs mariculture / aquaculture
  - Habitat protection
  - Coastal defence / protection

  Learn from oil industry experience (J.S)

Research gaps:

- Spatial / temporal (and methodological!! J.S.) scale of research needs extending. Biological too! (SB)
  To include research on biological impacts of projects/devices (positive as well as negative) (M.C.)
  De facto MPAs? (E.S.) – Potential for MSP compromises
- Geographical scope of research too limited
- Detailed studies at single sites needed (demonstrator at OWF)
- Cross-disciplinary studies

Governance

- Join up please!
- Proactive
- Crown Estate steeling their thunder!

On post-its:

- Fishing shipping communities ⇨ loss of access safety
- Displacement of fishing activity
- Behavioural responses to displacement
- Multiple uses of sea areas: use of commons. Strategy crucial. Cannot simply assume prior use constitutes right to priority ongoing use
- Near shore pre-commercial marine energy arrays – interaction with static gear fishermen
- Research to underpin policy development for fisheries
- Vulnerability to displacement of fishing and other marine activities
- How do you handle space use by small fisheries ⇨ poor data

Session 1 – Energy extraction

Priorities:
- Resource understanding (for wave / tidal / wind)
- Regarding tidal: technology (improve existing + new?) / methods development (RASCAL) (tidal equivalent of wave buoy?)
- Resource assessment
- Future proofing resources ⇨ wind/wave
- Near + far field effects (different for each technology)

Developers – major barriers to development is understanding resource (tidal)
(same for policy makers / regulators)

Session 1 – Healthy ecosystem

Gap / needs:
- Create understanding of ecosystem (what about physical environment?) functioning to parameterize models being developed, then link to risk-analysis / risk-management framework (relevance to policy makers)
- Define health at levels of biological organisms + focus on fitness for survival / harm (clarity of goals)

Address issue:
- Studies on ecosystem functioning (overcome reliance on structure of ecosystem)
- Assess / quantify ecosystem resilience
- Use manipulative field experiments

Migration routes??

Implications for:
- Policy makers: clarity of objectives, introduces ecological / operational realism, improves derivation / use of indicators
- Developers: clarity of objectives, introduces "ecological operational realism"?
- Integrative approach: "it focuses on the ecosystem"! (focus on functioning of system), acknowledges the ability of ecosystem to absorb change

Session 1 – Monitoring

Description of knowledge gap/issue
Coordinated monitoring plans to support consenting
True monitoring involves a well defined, quantitative end point – have we got these? (S.E.)
Clearly define monitoring objectives (J.P.H.)
Need for SMART objectives
- Environmental baseline (acknowledging climate change effects)
- Monitoring guidelines/protocols/SOPs (work planned by SNH)

How could gap/issue be addressed:
- Environmental baseline – ensure appropriate baseline first
  - Prioritise data to be collected
  - Public sector led data collection (new for surveys, existing from desk study)
  - Identify pilot areas (areas that are available for lease vs areas that are not yet available for lease)
- Feedback from existing development
- Early feedback from new developments – iteration
- Development of modelling tied to actual survey work to reduce / optimise future survey work
- One stop shop for data – visibility + accessibility of all data
- Collaboration across national + international boundaries

Implications for:
- Policy makers
  - Define/ standardise methods
  - Investment plan
  - Define acceptable impacts
- Developers
  - Encourage developers to feedback/collaborate
  - Potential reduction in burden on developers
- Integrated approach
  - Develop plans with stakeholders

Session 1 – Ports and harbours

Description of knowledge gap/issue
What is required, where and when, to support developments, and at what cost/benefit

How could gap/issue be addressed:
- Leave to market forces
- Initial study on potential sites /developers requirements / timings / CBA. Fit with competing industries (e.g. offshore oil and gas)
- Strategic planning (stemming from initial study)
  - Regional
  - National
- Confirmation of funding package

Implications for:
- Policy makers
  - Fund/execute initial study
  - Regional/national responsibility?
  - Support achieving targets + policy objectives
  - Budgeting for investment
  - Deliver strategic planning
- Developers
  - Fund/feed in
  - Reducing financial risk
  - Available facilities may restrict device design, deployment, maintenance and project development
  - Potential for shared facilities
- Integrated approach
  - Iterative process to reflect state of industry as it develops
  - Facilities need to accommodate other industries (offshore oil and gas, shipping, marinas/leisure, fishing) – all important to economy
  - Liaising with UK government and Scottish government

On post-it:
Development of port facilities for marine energy – differing requirements of developers – how to coordinate for best fit rather than commercially led?

Session 1 – Public perception

Knowledge gap
- Who are the relevant stakeholders and public?
- What different values do people have?
- What info are they lacking
- How do we give them the info they need?
- How do they interpret that info?
- Are we imagining that public perceptions on land will be exported to open marine areas? (unlikely) – are 'public (Who?) perceptions for the sea' a red-herring? (ME)

- Let's find out!

How do we address this?

- Local immersion
  - Proactive
  - Identify local experts
  - Use local knowledge
  - Dialogue
- Case by case approach – enables identification of key local issues
- Learning from un/successful cases
  - Understand level of knowledge
  - How people access info
- Understanding value conflicts between groups

Implications for:

- Policy makers
  - Allow a bottom-up approach
    - People opportunity to input into research agenda
  - Consistency between entities
- Developers
  - Engaging people in the right way and at right stage
  - Understanding key issues
  - Cost effective
- Integrated approach
  - Making sure research feeds into development process
  - Improving communication between academics, developers, policy makers, communities, government
  - "Combine" consultation processes (Marine Bill, MSP. Local Plans, Coastal forums)

On post-its:

- Education:
  1. How to sell this essential technology
  2. how to make people see that they need to' give something back'
- Difference between public perceptions of the technologies and engineers' vision of wet renewables
- Are all offshore technologies (wind, wave, tidal, etc) perceived the same, or grouped together in public consciousness
- Gap-separate perceived public perception from actual public perception (i.e. don't assume land-based concerns become marine ones)
- Impacts can be positive as well. What about benefits? Not just of the device/array but upstream + downstream activity
- What are the recreational water users' perceptions?
- Establishing which communities are going to be impacted + their boundaries
- Identifying and engaging key stakeholders
- Public understand scale of project
- The change (decrease?) in social constraints with distance offshore

Session 1 – Shipping/navigation

Knowledge gap

- Compatibility of navigational interests (shipping + fishing) with Marine Renewables Development
  - Differs by area
  - Differs by vessel type
  - May differ by device/development type

  Is there liable to be a tending to concentrate wind farms near ports? (PJF)
  Surely port entrance lanes are avoided?

How do we address this?

- Decision by government, based on engagement with all relevant marine interests, within the context of marine spatial planning structures (e.g. Marine Scotland)
- Avoid case by precedents. From (wave and tidal) developers' perspective and marine org perspective it has to be case by case as devices differ significantly – different issues to address (NM)
- Yes, to a certain extent, case by case considerations apply. However compensation payments for example, set dangerous precedents.

Implications for:

- Policy makers
  - Need information in support of decision-making process
  - Express priorities clearly and INFORM
- Developers
  - AVOID SETTING DANGEROUS PRECEDENTS
  - Express site requirements clearly and INFORM
  - Be flexible (within reason) in site selection, mitigative measures
- Integrated approach
  - Yes! Seek opportunities for satisfying multiple interests (e.g. wave development arrays and marine protected areas)

On post-its:

- General navigation problems
- Existing users: (…) priority to (…) to shipping and navigation? *(part is missing)*

Session 1 – Stakeholder engagement

1) Early communication + awareness raising
   - Strategic plan, feedback, justification
   - Benefits
   - Local plan feedback
   - Empowerment

   Who? Developers, government

2) Best practice
   - Flexible
   - Different community types
   - Inclusivity:
     - national/regional
     - local
   - timing
   - continuous

3) System for lessons learned from other developments (all other developments, on + off shore)

Implications	P/M	DEV	INT
1)	Better communication strategies IPC/MMO/MS	Many doing, make sure all problem	Problem share confidential info for developments (pay) need government but gain credibility: how do across developers
2)	Enable development of BP but also flexible IPC/MMO/MS	Improve credibility + consistency	Consistent approach
3)	Existing fund networks/forum to convene	Shared database network/forum	To do 1) + 2)

On post-its:

- How to manage large numbers of numerically small groups of stakeholders
- What is an offshore community?
  - Fishing
  - Transport
  - Seabirds/mammals/fish (how are animals dealt with?)
- How communities where development is proposed can be linked to communities where development has been successful…
- Early engagement for wave and tidal projects. How successful
- How can remote communities be protected?
- What can be learned from other large rural developments? E.g. Sullom Voe, Flotta

Session 1 – Planning process

1) SEA

- Bringing together all the SEAs that have been done (mapping different requirements around UK)
  - Scotland / E+W
  - Oil+ gas / Offshore wind / Wave + tidal
  - Inside 12 nm / outside (12-200nm)

Why? The issues are different (I.D.)

Need to till basic physical baseline data gaps before SEA is done

Can't wait to have perfect knowledge in this until develop offshore renewables sector! MC

OUTPUTS:

- Consistency in (interpretation of…J.N):
  - A. legislative requirements
  - B. scientific guidance
- Mapping of SEA coverage
  ⇨ gaps in env/socio-economics aspects → True but is this a SEA matter? J.S
  ⇨ data gaps:
    - What?
    - Who fills?
      - Government?
      - Developer?

Flexible approach is required as lessons will be learned as development occurs. H.J

Utilise existing and proposed studies for other initiatives. J. Saundes

2) EIA guidance

Exists as ' helicopter study' rather than a true EIA

This already exists (I.D.)

No it doesn't

Consistency in approach

- Across UK
- Across regions
- Across (within) statutory agencies *
- < 12nm

2 stages EIA

Address location issues within R3 planning zones

* about relative impacts within planning areas

New guidance coming for wave + tidal in Scotland (I.D.)

- Survey methodologies – will be device dependent (SB)
- Monitoring requirements – will be site dependent (SB)
  - Guidelines being developed by SNH (L.S.)
  - Must be relevant to scale of the project – N.M.
- Best practices guidelines – not just minimum for legislative requirements

Yes, but some generic issues

⇨ greater certainty for developers
⇨ and stakeholders N.M.

3) Potential positive impacts

How do you assess whether positive or negative impact (N.M.)

- Fish refuges

Not strong drivers (I.D.)

New research re. efficacy exists but need further quantifying

- Habitat diversity

- Benefits of devices as means of exclusion
- Social/economic benefits to local community (how to we maximise this?)
- Coastal and flood defences (J.S.)

Session 2 – Group 6 – Cross-cutting themes

Knowledge gap
- Resource demonstrator sites to have a strategic approach to benefits and impacts and monitoring
- Processes of prioritising impacts
- Open, early and flexible deliberation processes
    - Need for an independent body to facilitate (adequate spatial data + best practices)
    - Good integration of all different work streams in industries in the world

How do we address this?
- Role for EMEC/UKERC/A.N. other group to bring together knowledge and research

Implications for:
- Policy makers
    - Need a clear steer
    - Comfort from incremental developments ⇨ feedback to all stakeholders
- Developers

Should all ease burden on developers

Session 2 – Mammals

1a) Visibility of devices / Detectability
- Visual, auditory, magnetic / surface-subsurface / species specific
- Use of colour
- Lessons to learn from other sectors – relevant to all
- Tools – deterrents – radar – birds; sonar – marine mammals
- Auditory passive detection

1b) Behaviour + collision
- what size of animal affected, i.e. plankton – no fish?
- Characterising flow
- Flow tank modelling + predictions
- Include array design testing
- Shut down operation (options for wind esp.)
- Behaviour in relation to device (then arrays)
- Different species = different responses
- Linking hydrodynamics + behaviour (wet)
- Linking wind flow etc. + bird response (wind)
- What happens at night? E.g. bat collisions
- Has anyone tried musak?

2) Adequate baselines
- Enables an assessment of impact
- Needs to be focussed

1) Marine features of interest
2) Understanding environmental change from range of devices

Even with the best baselines, will you still be able to detect a change of relevance?

2a) Habitat usage
- Spatial + temporal
- Do animals use e.g. tidal habitats at full flow
- Impacts of arrays on habitat usage

1.0. most important life history stage habitat use (time + spatial)

How / Who

- Much of this is fundamental e.g. hydrographic data
- Strategic management of research

Way?

- Industry has good data but commercially sensitive
- Developments too site-specific + device specific to answer fundamental issues
- Collective industry funding but fledgling industry therefore unlikely at present

When?

*** Now
** Later
* As part of adaptative management

3) EMF

- Gaps for other species (+ other life stage), e.g. crustaceans
- Results in a response but is this ecologically significant? No
- Separating the 2 components: Electric / magnetic e.g. migratory species + understand if any significant effect

4) Noise

- Construction, e.g. pile driving **
- Operational noise
- Which species of ecological importance *
- Cumulative impact assessment / mitigation (offshore wind)

Appendix 5: Wind, tidal and wave projects outside the UK

Table 12 – International offshore wind projects

Wind Power Projects In Progress	Country	Capacity	Expected Completion Date	Funding
NaiKun Offshore Wind Energy Project http://www.naikun.ca/	Canada	396MW	2014	
Trillium Power Wind 1, Lake Ontario http://www.trilliumpower.com/energy/project-wind-1/	Canada	710MW	TBC	Trillium Power Wind Corporation will invest approximately $2.5 billion
Buzzards Bay Wind Farm http://www.southcoastwind.org/index2.html	US	300MW	TBC	
Delaware Offshore Wind Park http://www.bluewaterwind.com/delaware.htm	US	450MW	TBC	Power Purchase Agreement between Delmarva and project company
Garden State Offshore Energy (GSOE) http://www.gardenstatewind.com/	US	345MW	2013	Deepwater Wind in association with PSEG Renewables
Galveston Offshore Wind (Texas) http://www.windenergypartners.biz/gow.html	US			multi-million dollar lease from the Texas General Land Office, signed with Galveston-Offshore Wind (a division of Wind Energy System Technology)
Cape Wind (Cape Cod / Nantucket Sound) http://www.capewind.org/article24.htm	US	420MW	Turbine construction in 2010	
Long Island – Bluewater Wind, part of LIPA Offshore Wind Park http://www.bluewaterwind.com/ny_overview.htm	US	140MW		private
Setana Port	Japan	1.2	Operational since 2004	financial support from NEDO (New Energy Development Corporation)

Blue = proposed
Green = construction started
Red = proposal has been abandoned
Grey = project complete

Table 13 – International tidal projects

Tidal Power Projects In Progress	Country	Capacity	Expected Completion Date / status	Technology	Funding
Roosevelt Island Tidal Energy Project (RITE) www.verdantpower.com	US	80MW	Demonstration Grid connected array		U.S. Dept of Energy (Advanced Water Power Project)
Oceana's tidal power projects at various stages in six states www.oceanaenergy.com	US		Site selection in progress	Oceana Energy Company - TIDES	Private
Piscataqua River	US		Applications withdrawn – not viable, env issues too sensitive		UEK Corporation of Annapolis + New Hampshire Tidal Energy Company
Puget Sound www.mytpu.org/tacomapower/conserve-energy/green-power/tidal-power.htm www.snopud.com/?p=3546 www.verdantpower.com	US			7 projects, 3 proponents	Various including Navy/Verdant power
CORE Project http://www.verdantpower.com/what-core	Canada	15MW	2011	Verdant Power – Free Flow™ Turbine,	Ontario Government investing $2.2 million (part of its Innovation Demonstration Fund)
Bay of Fundy www.openhydro.com	Canada	1 MW to start with	Autumn 2009	OpenHydro	$1.7 million contract with Nova Scotia Power + private funding
Race Rocks Pearson College - EnCana - Clean Current Tidal Power Demonstration http://www.cleancurrent.com/technology/rrproject.htm	Canada		1 turbine redeployed 2008 (Demonstrator)	Clean Current tidal turbine generator	Sustainable Development Technology Canada, Pearson College + EnCana Corp
Kaipara Harbour www.crest-energy.com	New Zealand	200MW	2018 Consent applied for	Crest Energy	NZ government announced the New Zealand Marine Energy Deployment

					Fund in 2007, Crest was awarded NZ$1.85 million in May 2008 (subject to the granting of consents for the project). Total cost is NZ$600 million
Cook Strait www.neptunepower.com	New Zealand	1MW	Resource Consent granted	Neptune Power	Private + Marine Energy Deployment Fund (Gov)
Cook Strait	New Zealand	12MW	Resource Consent requested	Energy Pacifica	Private + Alderney Renewable Energy
Wando Hoenggan Waterway www.lunarenergy.co.uk	South Korea	300MW	2015	Lunar Energy – Rotech Tidal Turbine	joint venture between Lunar Energy and Korean Midland Power Company - construction cost of £500 million
Tidal Power Plant in Garorim Bay	South Korea				Western Power Company Limited?
Dandong tidal lagoon http://www.tidalelectric.com/Projects%20China.htm	China	300MW	?	Tidal Electric	China has granted support to Tidal Electric
Alderney Race/Swinge www.openhydro.com	Channel Islands	Pilot array		Open Hydro	
Kvalsund www.hammerfeststrom.com	Norway		Prototype installed in Norway 2003/9.	Hammerfest Strøm	Statoil New Energy, Hammerfest Energi, Hammerfest Naeringsinvest, Origo Kapital, Alta Kraftlag, Scottish Power

Table 14 – International wave projects

Wave Power Projects In Progress	Country	Capacity	Expected Completion Date / status	Technology	Funding
Maui Wave Project http://www.oceanlinx.com/uploads/OCEANLINXSIGNSMOUWITHRHI.pdf	US (Hawaii)	2.7MW	2009	Oceanlinx wave energy converters	Cost to be borne by Oceanlinx and its investors - $20 million. MoU with Renewable Hawaii, Inc., for possible passive investment in the project.
Humboldt County WaveConnect, California Coast http://www.finavera.com/en/wave/humboldt	US	2MW	permit surrendered 2/09	Finavera Renewables – Aquabuoy	Pacific Gas & Electric (PG&E) will purchase 2MW from the wave device + financing from developer
Makah Bay, Washington http://www.finavera.com/en/wave/makah_bay	US	1MW	application to surrender license filed 2/09	Finavera Renewables – Aquabuoy	Commencement of the project is dependent on investor finance and a buyer for the power
Coos Bay Wave Park, Oregon	US	100MW	TBC	Ocean Power Technologies – PowerBuoy	?
Coos County Offshore, Oregon	US	100MW	permit cancelled w/o objection 6/08	Finavera Renewables – Aquabuoy	
Rhode Island http://www.oceanlinx.com/Currentprojects.asp	US	1.5MW then 15 to 20MW	TBC	Oceanlinx	Memorandum of Understanding ("MOU") with Rhode Island State authority for a 1.5MW unit, followed by a 15 to 20MW electricity generating facility
Aguçadoura Wave Park http://www.pelamiswave.com/	Portugal	Initially 2.25MW. Potentially 21MW	2008	Pelamis Wave Power - Pelamis	€8.2m funded by a Portuguese consortium led by Enersis. Joint venture company Companhia da Energia Oceânica (CEO), currently 77% owned by a subsidiary of Babcock and Brown Limited and 23% by Pelamis Wave Power Limited

Figueira da Foz http://www.finavera.com/en/wave/portugal	Portugal	100MW (2MW demonstration plant)	TBC	Finavera Renewables – Aquabuoy	Supported by Energias de Portugal, Portugal's largest power utility. Finavera Renewables is in the final stages of negotiations for a 1.3m Euro grant from the European Commission for this project.
Western Australia Wave Power Station	Australia	100MW	TBC	Ocean Power Technologies – PowerBuoy	joint partnership agreement announced between Ocean Power Technologies and Griffin Wave Power Ltd
Portland http://www.oceanlinx.com/Currentprojects.asp	Australia		progressing the permitting stage	Oceanlinx	
Port Kembla http://www.oceanlinx.com/Currentprojects.asp	Australia	prototype 450kW unit		Oceanlinx	Power Purchase Agreement ("PPA") has been signed with Australian utility Integral Energy for the supply of electricity from the prototype 450kW unit.
GPP and Oceanlinx project http://www.oceanlinx.com/Currentprojects.asp	Namibia	1.5MW unit then15MW	TBC	Oceanlinx	signed contract with GPP, part of the listed Southern African Utility SELCo for a 1.5MW unit
Rosarito, Baja California http://www.oceanlinx.com/Currentprojects.asp	Mexico		TBC	Oceanlinx	jointly developed with CFE and DEFAESA (renewable arm of Grupo R)
Santoña, Spain http://www.oceanpowertechnologies.com/spain.htm	Spain	Initially 1.39MW	In development; first phase complete	Ocean Power Technologies – PowerBuoy	Iberdrola S.A
Western Cape http://www.finavera.com/en/wave/south_africa	South Africa	20MW	TBC	Finavera Renewables – Aquabuoy	In process: micro-site assessment
Ucluelet, BC http://www.finavera.com/en/wave/ucluelet	Canada	5MW	TBC	Finavera Renewables – Aquabuoy	?

Table 15 – Other tidal and wave projects in the US: Issued Preliminary Permits for wave and tidal projects as of 7/05/2009
(Source: Federal Energy Regulatory Commission - FERC, www.ferc.gov)

Project	Project Name	Permittee	Waterway	State	Authorized MW	Issue Date	Expiration Date
TIDAL							
12744	CHEVRON COOK INLET TIDAL	CHEVRON TECHNOLOGY VENTURES, LLC.	COOK INLET	AK	80	06/11/07	05/31/10
12611	ROOSERVELT ISLAND TIDAL ENERGY	VERDANT POWER, LLC.	EAST RIVER	NY	5	02/17/09	01/31/12
12665	ASTORIA TIDAL ENERGY	NEW YORK TIDAL ENERGY CO.	EAST RIVER	NY	300	05/31/07	04/30/10
12666	KENNEBEC TIDAL ENERGY	MAINE TIDAL ENERGY COMPANY	KENNEBEC RIVER	ME	100	06/24/08	05/31/11
12668	PENOBSCOT TIDAL ENEGY	MAINE TIDAL ENERGY COMPANY	PENOBSCOT RIVER	ME	200	05/16/07	04/30/10
12670	CAPE & ISLAND TIDAL ENERGY	MASSACHUSETTS TIDAL ENERGY CO.	VINEYARD SOUND	MA	300	05/31/07	04/30/10
12679	COOK INLET TIDAL ENERGY	ORPC ALASKA, LLC.	COOK INLET	AK	32	04/17/07	03/31/10
12687	DECEPTION PASS TIDAL ENERGY	PUD NO 1 OF SNOHOMISH COUNTY	PUGENT SOUND	WA	2.8	03/01/07	02/28/10
12689	SPEIDEN CHANNEL TIDAL ENERGY	PUD NO 1 OF SNOHOMISH COUNTY	SPEIDEN CHANNEL	WA	8.3	02/22/07	01/31/10
12690	ADMIRALITY INLET TIDAL ENERGY	PUD NO 1 OF SNOHOMISH COUNTY	PUGENT SOUND	WA	22.1	03/09/07	02/28/10
12692	SAN JUAN CHANNEL TIDAL ENERGY	PUD NO 1 OF SNOHOMISH COUNTY	SAN JUAN CHANNEL	WA	5.3	02/22/07	01/31/10
12698	GUEMES CHANNEL TIDAL	PUD NO 1 OF SNOHOMISH COUNTY	GUEMES CHANNEL	WA	3.5	02/22/07	01/31/10
12704	HALF MOON TIDAL ENERGY	TIDEWATER ASSOCIATES	COBSCOOK BAY	ME	13.5	04/10/07	03/31/10
12705	CENTRAL COOK INLET TIDAL ENERGY	ALASKA TIDAL ENERGY COMPANY	COOK INLET	AK	1000	06/07/07	05/31/10
12718	WARDS ISLAND TIDAL POWER	NATURAL CURRENTS ENERGY SER, LLC.	EAST RIVER	NY	0.096	04/17/09	03/31/10
12729	Willapa Bay Tidal Power	NATURAL CURRENTS ENERGY SER, LLC.	Willapa Bay	WA	2	03/29/07	02/28/10
12731	ANGOON TIDAL POWER	NATURAL CURRENTS ENERGY SER, LLC.	KOOTZNAHOO INLET	AK	2	03/29/07	02/28/10
12732	LONG ISLAND TIDAL ENERGY	NATURAL CURRENTS ENERGY SER, LLC.	LONG ISLAND SOUND	NY	250	06/14/07	05/31/10
12794	CAPE COD TIDAL ENERGY	NATURAL CURRENTS ENERGY SER, LLC.	CAPE COD CANAL	MA	10	11/16/07	10/31/10
13015	EDGARTOWN-NANTUCKET TIDAL ENERGY	TOWN OF EDGARTOWN, MA	NANTUCKET SOUND	MA	10	03/31/08	02/28/11
13232	HELL GATE TIDAL	COASTAL POWER, INC.	EAST RIVER	NY	0.15	12/12/08	11/30/11
13245	INDIAN RIVER TIDAL ENERGY	UEK DELAWARE L.P.	INDIAN RIVER	DE	10	01/07/09	12/31/11
13247	KINGSBRIDGE MARINA TIDAL ENERGY	NATURAL CURRENTS ENERGY SER, LLC.	MANASQUAN RIVER	NJ	0.040	12/12/08	11/30/11
13276	CUTTYHUNK/ELIZABETH ISLAND TIDAL	NATURAL CURRENTS ENERGY SER, LLC.	ATLANTIC OCEAN	MA	0.1	12/30/08	11/30/11
13277	ROCKAWAY INLET/QUEENS TIDAL	NATURAL CURRENTS ENERGY SER, LLC.	ROCKAWAY INLET	NY	5	02/12/09	01/31/12
13278	FISHERS ISLAND TIDAL	NATURAL CURRENTS ENERGY SER, LLC.	LONG ISLAND SOUND	NY	250	02/12/09	01/31/12
13279	SHELTER ISLAND TIDAL ENERGY	NATURAL CURRENTS ENERGY SER, LLC.	SHELTER ISLAND	NY	36.2	02/17/09	01/31/12

			SOUND				
12743	DOUGLAS COUNTY WAVE & TIDAL ENERGY	DOUGLAS COUNTY	UMPQUA RIVER	OR	3	04/06/07	03/31/10
WAVE							
12749	CoosBay OPT Wave Park	OREGON WAVE ENERGY PARK PARTNERS (incl. OPT)	Pacific Ocean	OR	100	03/09/07	02/28/10
12750	NEWPORT OPT WAVE PARK	OREGON WAVE ENERGY PARTNERS II (incl. OPT)	PACIFIC OCEAN	OR	100	01/29/09	3/09: permit surrendered
12713	REEDSPORT OPT WAVE PARK	REEDSPORT OPT WAVE PARK, LLC.	PACIFIC OCEAN	OR	50	02/16/07	01/31/10
12777	CASTINE HARBOR & BADADUCE NARROWS	MAINE MARITIME ACADEMY	ATLANTIC OCEAN	ME	1.3	10/09/07	09/30/10
12779	PG&E HUMBOLDT WAVECONNECT	PACIFIC GAS AND ELECTRIC CO	PACIFIC OCEAN	CA	40	03/13/08	02/28/11
12781	MENDOCINO WAVECONNECT	PACIFIC GAS AND ELECTRIC CO	PACIFIC OCEAN	CA	40	03/13/08	02/28/11
13047	OREGON COASTAL WAVE ENERGY	TILLAMOOK INTERGOVERN DEVEL ENTITY	PACIFIC OCEAN	OR	180	05/23/08	04/30/11
13053	GREEN WAVE MENDOCINO	GREEN WAVE ENERGY SOLUTIONS, LLC.	PACIFIC OCEAN	CA	100	05/01/09	04/30/12
13058	GRAYS HARBON OCEAN ENERGY	GRAYS HARBOR OCEAN ENERGY CO. LLC	PACIFIC OCEAN	WA	6	07/31/08	06/30/11
13075	CENTERVILLE OPT WAVE ENERGY PARK	CALIFORNIA WAVE ENERGY PARTNERS (incl. OPT)	PACIFIC OCEAN	CA	20	06/27/08	05/31/11

Other pending projects:

- P-13308 San Francisco Ocean Energy Project (Grays Harbor Ocean Energy Company, LLC) filed 10/08
- P-13309 Ventura Ocean Energy Project (Grays Harbor Ocean Energy Company, LLC) filed 10/08
- P-13052 Green Wave San Luis Obispo Wave Park (Green Wave Energy Solutions, LLC) filed 10/07
- P-13376 Del Mar Landing Project (Sonoma County Water Agency) filed 2/09
- P-13377 and P-13378 Fort Ross Project- N & S (Sonoma County Water Agency) filed 2/09
- P-13379 San Francisco Ocean Energy Project (City and County of SF) filed 2/09