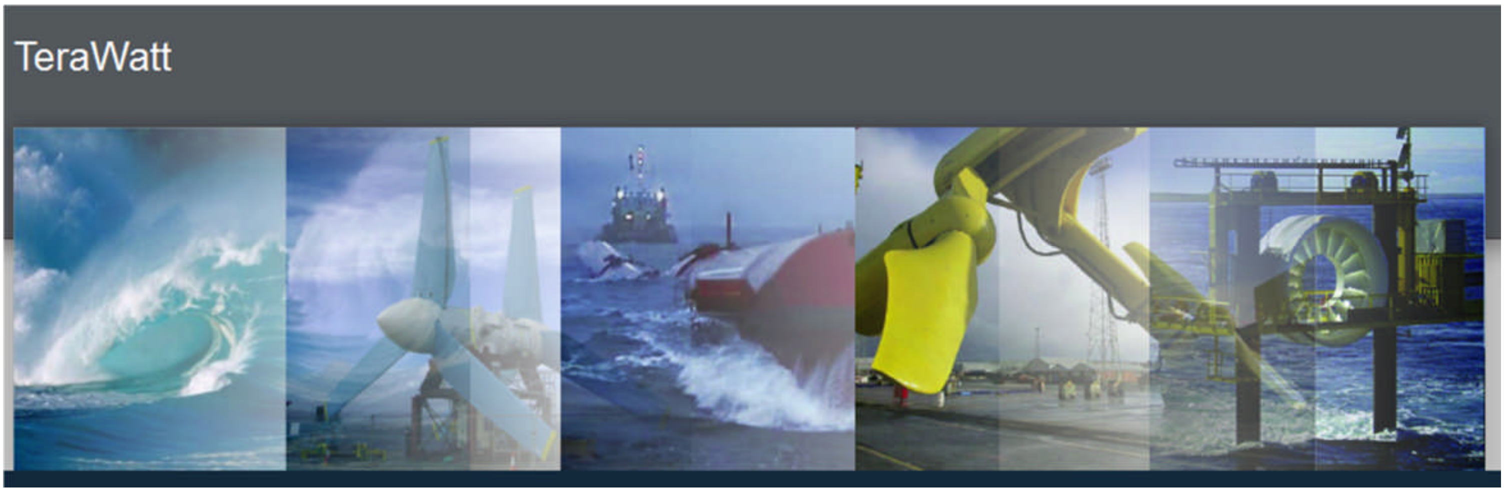
TeraWatt Project – Workshop 1 Report



<u>Workshop Agenda</u>

Title: TeraWatt – EPSRC Marine Challenge Fund - Wave and Tidal Energy Project
Date: 23-5-12
Time: 11:00 – 13:00
Location: All Energy – Room 2

Purpose: To provide stakeholders with an opportunity to understand what the TeraWatt project is designed to achieve, invite their comment and potential participation through access to data, facilities and expertise/knowledge.

Objectives:

- Provide a detailed overview in laymen's language of the Terawatt project
- Introduce the organisations and individuals involved
- Explain some of the key challenges
- Identify potentially useful outputs
- Engage stakeholders in a structured discussion re potential issues that the project might help them overcome (potential "impacts")
- Initiate potentially useful working relationships with organisations and individuals who may be able to provide material support to the project

Format

1. Welcome and Introductions - Dr Mark James

2. Project Overview (15 minutes) - Prof. Jon Side

3. Brief presentations (15 minutes) followed by Q&A session

   WORKSTREAM 1: The Research Questions, and Monitoring Progress towards
   Project Aims/Deliverables and the Methods Toolbox (Lead Marine Scotland Science - MSS)

   WORKSTREAM 2: Wave and tidal stream modelling (Lead Edinburgh University)

   WORKSTREAM 3 Sediment Dynamics (Lead Swansea and Strathclyde)

   WORKSTREAM 4 Ecological Consequences of wave and tidal energy extraction (Lead HWU and SAMS)

4. Industry participation – how can you become involved in the project – what can the project deliver for you!

5. Summary and Close – Prof. Jon Side

<u>Output:</u>
Brief report identifying any key issues/opportunities that have emerged during the course of the workshop.

Attendees

Jon Side – Heriot Watt University
Rory O'Hara Murray – Marine Scotland Science
Alejandro Gallego – Marine Scotland Science
Mike Bell – Heriot Watt University
Venki Venugopal – University of Edinburgh
Arne Vögler – University of the Highlands and Islands, Lews Castle
Chris McCaig – University of Strathclyde
Bill Ritchie – University of Aberdeen, TeraWatt SG
Garth Bryans – Aquamarine Power
Scott Couch – MCT, TeraWatt SG
Calum Miller – Scotrenewables, TeraWatt SG
Mark James - MASTS

Welcome and Introductions

- 50 people including representatives of all the main industry, Government and Regulatory bodies were invited to attend the Workshop and 25 had registered to attend. The number attending on the day number less than half those that had registered.

- The plan is to have a minimum of 2 workshops – at the beginning and end of the project. The low turnout on this occasion was attributed to conflicting meetings which may have been taking place at the All Energy exhibition and conference. It has subsequently been agreed that a workshop will be scheduled for October 2012 to encourage greater participation.

- The first project Steering Group (SG) meeting had taken place immediately preceding the workshop.

- Members of the TeraWatt SG were introduced as follows:

Sector	First Name	Last Name
Supergen UKCMER	Ian	Bryden
MCT	Scott	Couch
CNC Asset Group	Charley	Grimston
MASTS – SG Chair	Mark	James
Marine Scotland - Licencing	Jim	McKie
Scotrenewables	Calum	Miller
Independent Scientist	Bill	Ritchie
Heriot Watt – TeraWatt PI	Jon	Side

The following individuals were invited to become SG members:

The Crown Estate	Toby	Gethin
Marine Management Organisation	Shaun	Nicholson
Scottish Renewables	Johanna	Yates
Aquamarine Power	Garth	Bryans

- Toby Gethin and Garth Bryans have subsequently agreed to become members of the SG. Jim McKie agreed to liaise with and provide feedback to the Marine Management Organisation.

Project Overview

TeraWatt is a project designed to:

- minimise delays in array licensing by providing answers to three specific questions faced by the regulatory authorities, responsible for the licensing of wave and tidal developments; and
- to collect the methodologies used to answer these into a methods toolbox that can be more widely utilised for such assessments, and in which the marine developer community has confidence.

The questions to be addressed are as follows:

(1) What is the best way to assess the wave and tidal resource and the effects of energy extraction on it?

OBJECTIVES: Produce methodologies that will increase our knowledge and confidence in coupled hydrodynamic models of wave and tidal systems using illustrations validated by field data; Produce methodologies for the incorporation of multi-site wave and tidal arrays within these to illustrate changes in the resource in the near and far field from energy extraction ; Produce methodologies for the determination of resource potential under different scenarios of exploitation; Determine extreme conditions for the parameterisation of modelling of physical and environmental consequences. (These are mapped as deliverables from workstream 2)

(2) What are the physical consequences of wave and tidal energy extraction?

OBJECTIVES: Using outputs from workstream 2 produce methodologies for linking these to coupled models of sediment transport, again with illustrations validated by available field data; Demonstrate changes in sediment transport patterns occurring as a consequence of energy extraction and examine effects on seabed morphology; Determine the effect of energy extraction on suspended sediments; Determine effects on the shoreline and coastline using also additionally the extreme wave distributions from workstream 2. (These are mapped as deliverables in workstream 3)

(3) What are the ecological consequences of wave and tidal energy extraction?

OBJECTIVES: Produce methodologies for statistical models that will enable benthic biotope characterisation, using given physical parameters and outputs from workstreams 2 and 3, illustrating these and validating with field data. Demonstrate what changes in these may occur as a consequence of various energy extraction scenarios, and evaluate other potential ecological effects. (These are mapped as deliverables from workstream 3)

(4) The assembly of all appropriate methods, their review, and synthesis in a standardised methods toolbox.

OBJECTIVES: Encapsulate all methods used in the research, with illustrations of their use, into a methods toolbox, including in addition to the outputs of the 3 workstreams methodologies for parameterisation of inputs to shelf wide models from the regional scale models used.

The participation of Marine Scotland Science in TeraWatt, as the organisation responsible for providing scientific advice to the regulatory authority responsible for licensing wave and tidal array developments, is integral to the work of the consortium, as is a range of developer engagement activities planned, with the objective of building a broad consensus among the regulatory authorities and marine renewable developers on the methodologies produced.

- Mike 21 and Delft 3D will be the modelling tools used as these are used by both industry and regulators.
- Management of the project: Professor Jon Side is the Principal Investigator (PI) and each Workstream has a lead Co-Investigator (CI). The operation of the project is directed by a Project Management Committee (PMC) with a Steering Group providing independent oversight.
- TeraWatt has some funding for additional workshops to address particular issues as and when they emerge.
- For TeraWatt to achieve its full potential in delivering useful outputs for industry and the regulator it will need access to industry data.

1. **Workstream Presentations**

Each of the Workstream Presentations is appended to this report. Key points raised during each presentation are noted below.

WS1 - Rory O'Hara Murray
- Briefly noted the renewables atlas and highlighted some of its limitations.
- Highlighted the need for the development of a methods tool box from the licensing authority's perspective.

WS2 - Venki Venugopal
- Highlighted the need for coupled models – wave and tide
- Parameterisation of these models was a requirement
- Overviewed WS2.2: Wave-current modelling using Mike 21/3 and Delft 3D to perform an advanced estimation of the theoretical resource for the PFOW
- Model inter-comparison will be performed
- The PFOW build out map was shown, together with the wave energy resource map from the renewables atlas highlighting the limited resolution of the atlas
- Some Mike 21 output at high resolution for the PFOW was shown
- Overviewed WS2.3: hypothetical energy converters, individual and cumulative impact of developments. The impact of build order on potential resources was discussed
- Overviewed of WS2.4 on extremes

WS3 - Chris McCaig
- Briefly overviewed WS3.1 and WS3.2
- WS3.3 focussing on large scale sediment transport and how turbidity may be altered by wave and tidal energy extraction
- A satellite image processed at Strathclyde was shown as an example of how surface water turbidity can be remotely sensed using satellites
- Illustrated how the work will start with the MSS Stonehaven data set and develop a Mike 21 model and a 1DV statistical model
- Models will be validated using the MSS dataset

- The statistical model will be applied to a variety of other positions and compared with satellite data
- The effect of turbidity on light attenuation and subsequent photosynthesis has implications for primary production

<u>WS4 - Mike Bell</u>

- Described how water movements define the energy resource and a suite of ecological factors determining distribution and abundance of organisms
- A biotope is a description of both biological communities and habitats, including both physical variables and the organisms abundance. Existing datasets together with novel data collection will be used to develop statistical models which will be used to predict biotope changes under a number of possible future energy extraction scenarios

Questions and Answers Session

Q1: Bill Ritchie (BR) welcomed the focus on the physical environment as this was the main driver for many of the potential impacts which might be associated with large scale wave and tidal energy extraction. BR raised some concerns regarding the scale of the proposed modelling work and made reference to oil spill modelling as an exemplar. BR also noted some reservations regarding the coastal geomorphological aspects of the project.
A1: Nested models will be used to address the scale issue. However, validation of models will be made at single points.

Q2: Garth Bryans (GB). With respect to the work packages GB asked if there was scope for the industry and other stokeholds to review the technical methodology?
A2: Knowledge exchange events will be held during the course of TeraWatt and direct engagement with developers will be fundamental to the success of the project:
WS1: MSS will work with developers to gain a realistic understanding of proposed array scenarios
WS2: Mimicking the effect of devises in the physical models was recognised as an issue and it would be important to engage developers in understanding this process.

Q3: GB. There is potentially some overlap with other wave and tidal modelling such as The Crown Estate (TCE) modelling initiatives. GB queried whether there was an opportunity to use some outputs from existing models.
A3: The TeraWatt team were aware of the 2D models being developed by TCE and the potential for this work to be extended to 3D. The team would welcome the opportunity to work with the TCE to share data and would continue to liaise with the TCE. The only note of caution was that TeraWatt's Mike 21 licence was for academic research only and it would be important not to compromise this status if the TCE work was for commercial purposes.

[*Post meeting note* - ETI have recently commissioned a UK Telemac tidal model, minimum resolution at coastline is 200m, of the UK shelf. This will be made available via the web in due course. Black and Veatch, HR Wallingford and UoE, Scott Couch, have been involved. Model includes energy extraction – barrage and tidal].

Q4: Will the toolbox and methodologies developed be packaged into something useable by developers?
A4: All methodologies will be captured. MSS have responsibility to collate these methodologies.

Q5: Defining ecological thresholds. At what point do ecological effects become significant?

A5: It was acknowledged that ultimately, Marine Scotland would need to regulate on this basis, but will be constrained by the Marine Strategy Framework Directive and definition of Good Environmental Status (GES). GES descriptor 7 has yet to be defined.

Q6: BR noted that impacts can be positive. For example coastal defence is generally reliant upon the removal of energy, and coastal engineers have been striving to do this for decades.
A6: A follow-on proposal to TeraWatt, called EcoWatt, hopes to address the idea that we can use the deployment of devices to mitigate/offset changes occurring due to climate change. Generally the impacts of renewable energy will not be significant compared to climate change.

Observation 1: BR noted that whilst climate change is important, there are huge interannual variations such as the North Atlantic Oscillation which potentially introduces more variation.

Observation 2: GB noted that it was important to present the results of the project in context. The probability of of an effect/impact occurring as well as its potential scale and scope should be presented and defined relative to other equivalents.

Observation 3: BR also raised the issue of sentinel species being used to detect changes.

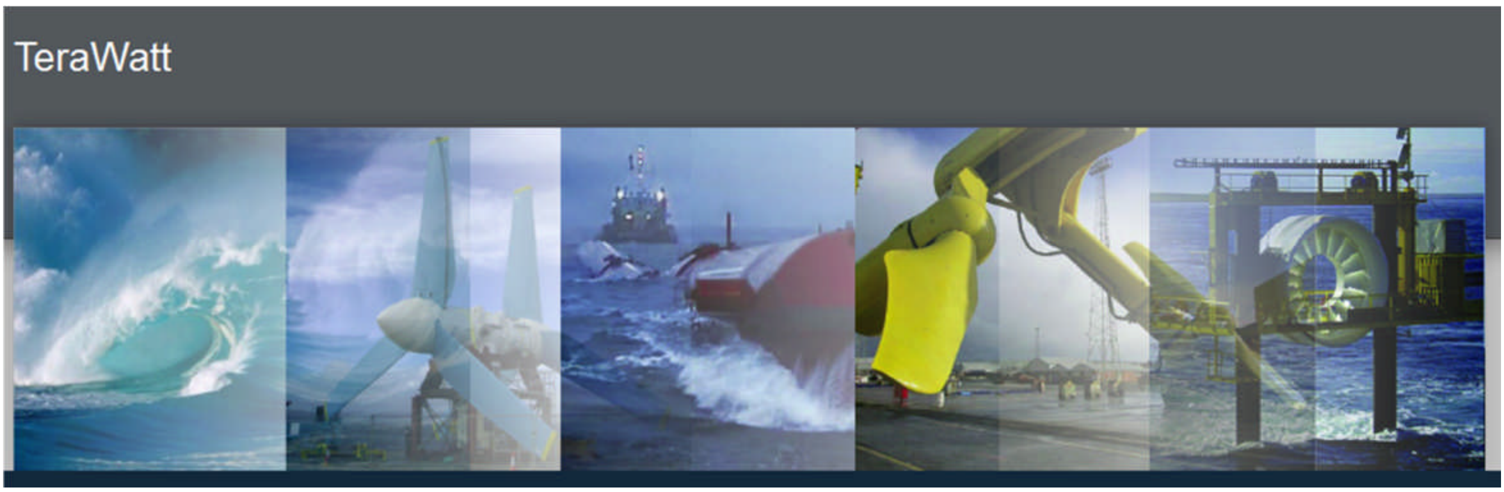
Observation 4: BR highlighted the importance of sediment supply and the overall sediment budget in defining the potential impacts on coastal geomorphology.

Response to Observations: Whilst the project had considered trying to address the impacts of climate change relative to those of marine renewables, the decision had been to focus on the consequences of energy extraction in the first instance.

With respect to sentinel species, it was acknowledged that these were important, but broader scale population and ecosystem changes would also be modelled in TeraWatt.

The need to understand sediment supply and budget would be fed back to those involved in WS3.

Introduction and Workstream
Presentations

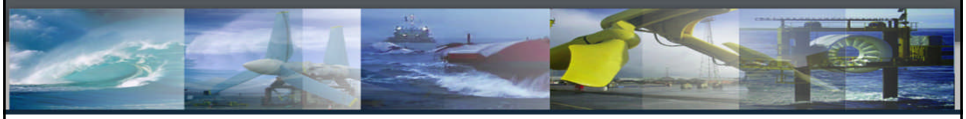


TeraWatt

WORKSHOP
23/5/12
Aberdeen – All Energy

TeraWatt Website
http://terawatt.weebly.com

TeraWatt



TeraWatt – EPSRC Marine Challenge Fund - Wave and Tidal Energy Project

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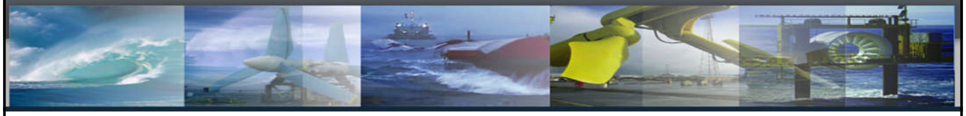
TeraWatt



- Welcome and Introductions + MASTS
- Project Overview (15 minutes) - Prof. Jon Side
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  WORKSTREAM 1: The Research Questions, and Monitoring Progress towards Project Aims/Deliverables and the Methods Toolbox (Lead Marine Scotland Science - MSS) – Ian Davies

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  WORKSTREAM 3 Sediment Dynamics (Lead Swansea and Strathclyde) – Chris MCaig

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- Industry participation – how can you become involved in the project – what can the project deliver for you! – All
- Summary and Close – Prof. Jon Side

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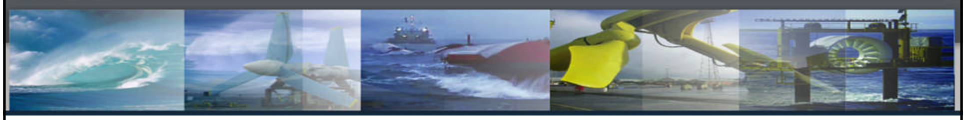
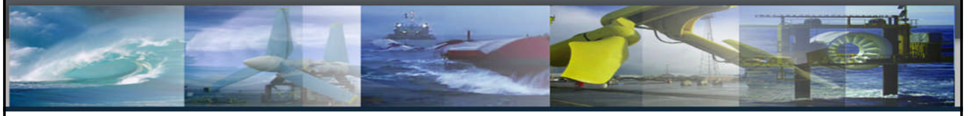


MASTS
Marine Alliance for Science and Technology Scotland

- Combines 700 researchers and the management of marine resources (£66 million annually) from **across Scotland**.
- Strives to ensure that Scottish marine science can remain **internationally competitive**.
- Provides the **academic platform** and **knowledge for marine governance and commerce** to support a Scottish Marine strategy that will **deliver increased value** to the public and private sectors from their investments**.**

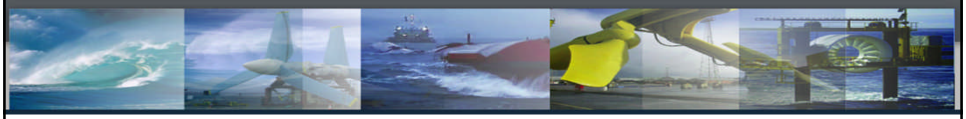
TeraWatt



MASTS

- Ten institutions from Scotland are partners
- A new approach to shared sovereignty
- Shift away from unproductive competition between a large number of small research centres to strong strategic collaboration
- Major cultural change!
- Longer-term structural change!

TeraWatt



MASTS

University of St Andrews
University of Glasgow
University of Stirling
Edinburgh Napier University
Heriot Watt University
University Marine Biological Station Millport
Marine Alliance Science Technology Scotland
eri environmental research institute
marine scotland science
The Scottish Government
University of the Highlands and Islands Lews Castle College
University of Aberdeen
Scottish Association for Marine Science
University of the Highlands and Islands Oilthigh na Gàidhealtachd agus nan Eilean
University of Strathclyde Glasgow
NAFC Marine Centre University of the Highlands and Islands

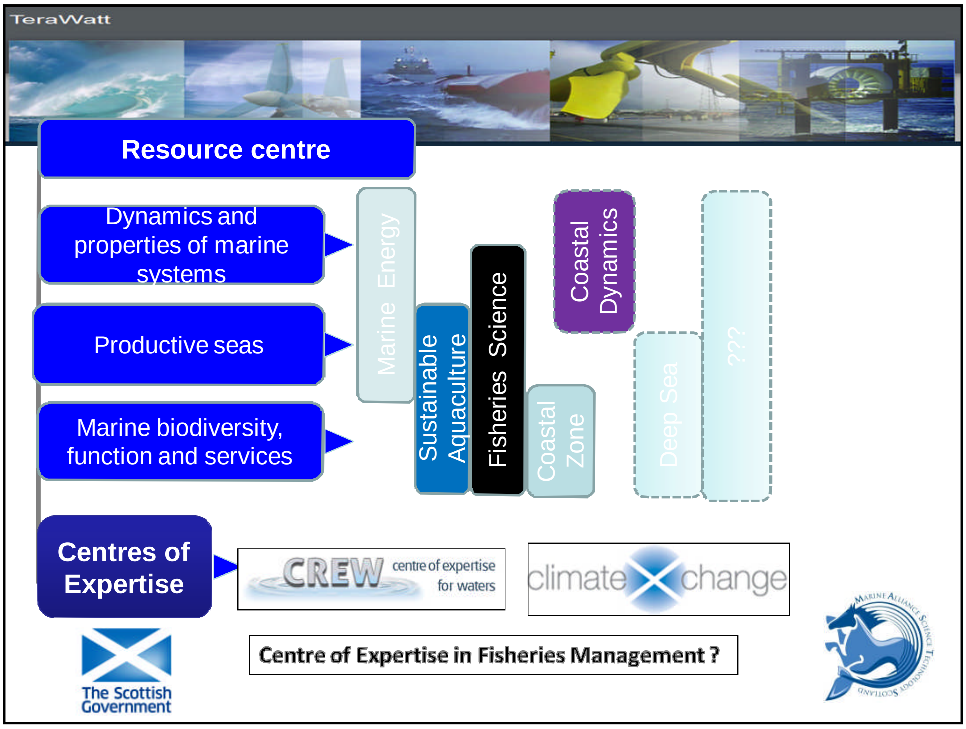
TeraWatt

MASTS

- Directorate established - 2011
- Scottish Funding Council - 7 years funding

Expenditure	
	Total
Existing costs	£25,528,000
New investment from member institutions	£31,985,000
New investment from SFC	£17,859,000
Total	£75,373,000

- *34 new positions*
- *48 PhDs*
- *Infrastructure*
- *Networking*
- *Visiting Fellowships*



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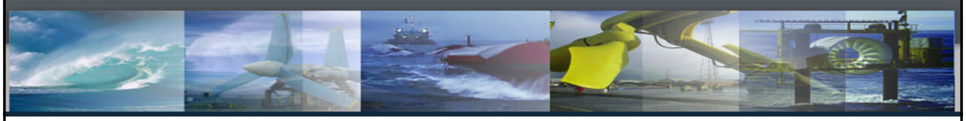
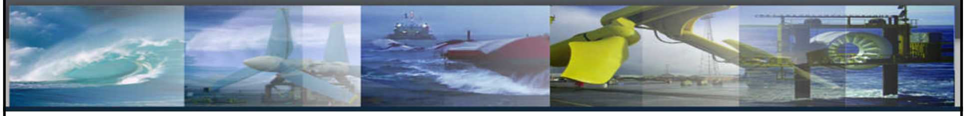


TeraWatt - Project Team - PMC

Jon	**Side**	**Heriot Watt University**
Vengatesan	Venugopal	Edinburgh University
Mike	Bell	Heriot Watt University
Susana	Baston	Heriot Watt University
Arne	Vogler	Lews Castle UHI
Rory	O'Hara Murray	Marine Scotland Science
Ian	Davies	Marine Scotland Science
Alejandro	Gallego	Marine Scotland Science
Mark	James	MASTS
Michael	Burrows	SAMS UHI
Mike	Heath	University of Strathclyde
Chris	McCaig	University of Strathclyde
Harshine	Karunarathna	University of Swansea

TeraWatt



TeraWatt - Project Steering Group

Jon	**Side**	**Heriot Watt University**
Mark	James	MASTS (Chair)
Bill	Ritchie	Independent Scientist
Calum	Miller	Scotrenewables
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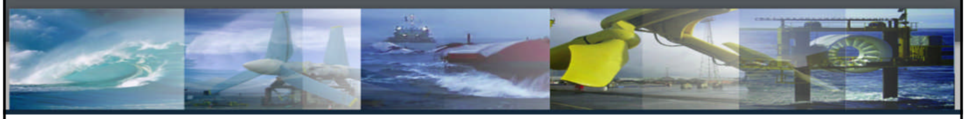
TeraWatt



General Discussion

TeraWatt Website
http://terawatt.weebly.com

TeraWatt – Wave and Tidal Energy Project

The Research Questions and Targets

Rory O'Hara Murray, Marine Scotland Science

The Scottish Government

Marine Scotland is the licensing authority for Marine Renewables

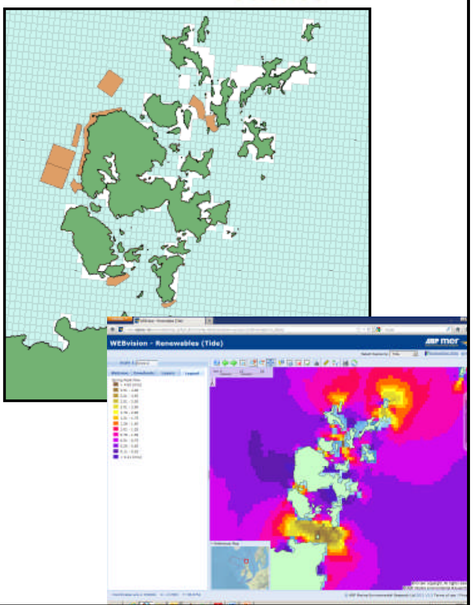
marinescotland science

Renewables Atlas

marinescotland science

What's included for Tide?

- **For springs and neaps:**
  - Tidal range
  - Peak velocity
  - Power
- **Depth, and average tidal power**
- **Resolution approximately 1.8km**
- **Useful for marine spatial planning**
- **Hard to answer questions regarding the consequences of energy removal**
  - Changes to the physical processes
  - Changes to the ecological environment



Research questions & targets

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1. **What is the best way to assess wave and tidal energy resources, and feedbacks on energy extraction, in certain geographical areas?**

2. **What are the physical consequences of wave and tidal energy extraction?**

3. **What are the ecological consequences of wave and tidal energy extraction?**

4. **The development of standard hydrographic modelling methodologies for wave and tidal developments**

1. What is the best way to assess wave and tidal energy resources, and feedbacks on energy extraction, in certain geographical areas?

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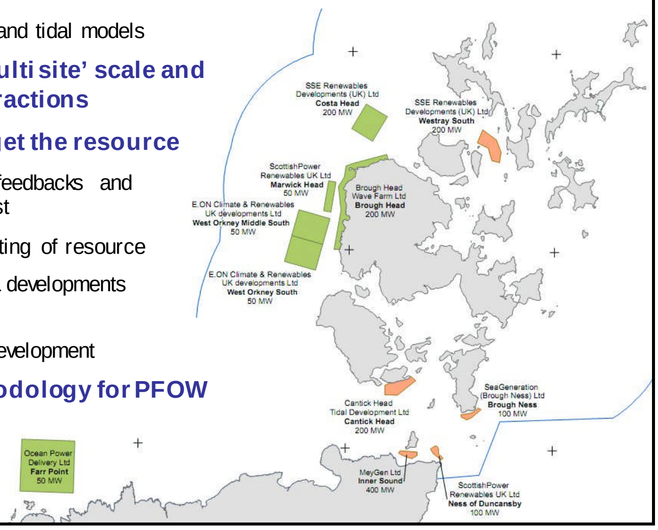
- **PFOW is a complex environment**
  - Coupled wave and tidal models
- **Interested in 'multi site' scale and cumulative interactions**
- **How to best target the resource**
  - What potential feedbacks and interactions exist
  - Intelligent targeting of resource
  - Are the round 1 developments enough?
  - When to stop development
- **Develop a methodology for PFOW**



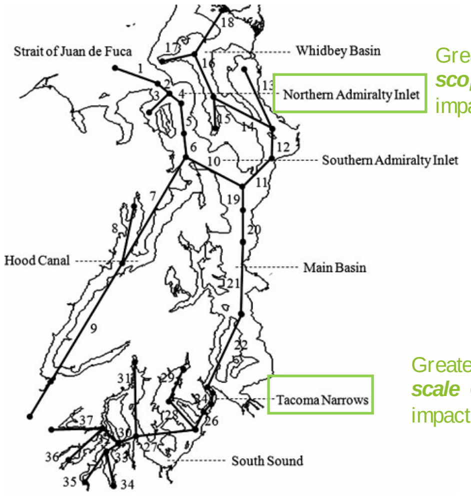
Puget sound 1D modelling example
Polagye et al. 2009

marinescotland science

- Network of 1D channels
- A number of extraction sites considered
- Observed far-field changes to the tide
- Change dependent on magnitude and location of extraction

Implications

- Complicated cumulative effects
- Regional co-ordination and planning important



Greatest *scope* of impact

Greatest *scale* of impact

Puget Sound channel network and coastline (Polagy e et al. 2009)

2. What are the physical consequences of wave and tidal energy extraction?

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- Physical processes include
  - hydrodynamics
  - frontal dynamics
  - sediment transport and bed morphology
  - coastal processes

Model the influence of energy extraction

Couple

- Different scales
  - very close to device / array and the near field
  - **far field**
  - **regional**
- Models need to include these processes
- Cumulativ e consequences on an area, or sites within an area?
- Physical change may limit growth in an area
  - Alteration of resource
  - Other undesirable consequences
  - What is acceptable change? Development of thresholds needed?

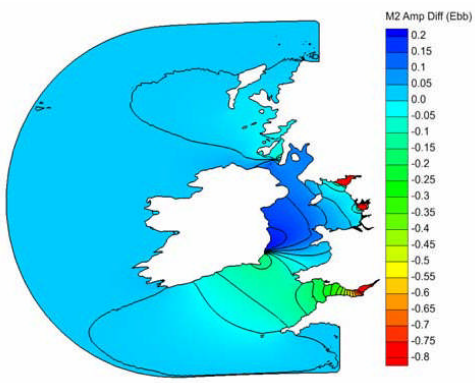
2D modelling of Tidal barrages in the Irish sea Wolf et al. 2009

marinescotland science

- Barrages – Seven, Solway, Morecambe, Mersey, and Dee
- Ebb mode barrages
- M2 tide modelled
- Tidal amplitude, bed shear stress, mixing/stratification, and residuals studied
- Cumulative effects studied

Questions

- To what extent do they interact with each other?
- Are the far field changes due to one development, or a combination?
- Scenario based modelling approach needed



Difference (m) in M2 tidal amplitude due to barrages (Wolf et al. 2009)

3. What are the ecological consequences of wave and tidal energy extraction?

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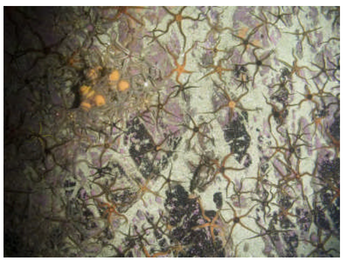
- **Knowledge of baseline biophysical interactions needed**
  - Species and habitats
- **Assessment of the change in physical processes needed**
  - Results from previous questions and work streams
- **Change likely across a range of scales**
  - Near-field
  - Far-field and regional scale
- **Potential impacts**
  - Benthic habitat
  - Disturbance of contaminated sediments
  - Change in intertidal habitat
- **Implications for MSFD and GES**

Physical models → Statistical models of biotopes



Brittlestar bed on moderately wave exposed Circalittoral rock (Moore 2009 SNH commissioned report No.319)

4. The development of standard hydrographic modelling methodologies for wave and tidal developments – a *methods toolbox*

- **An environmental impact assessment is usually required**
- **An assessment of the changes to the physical processes is required**
- **Many approaches taken, including**
  - Literature reviews and conceptual models
  - Computational Fluid Dynamic (CFD) modelling at the device scale
  - 2D hydrodynamic modelling of the array and near-field
- **Guidelines are needed to help developers and the licensing authority decide on the most appropriate approach for a particular project**
  - Methods tool box
- **A better understanding of the scale and scope of expected change on the physical, and ecological, processes is required**

Conclusions

- **Worth while project tacking three important research questions**
- **Questions motivated by a need at the licensing stage**
- **Improve understanding of physical and ecological consequences**
- **Develop tools to aid the licensing procedure**
- **Develop guidelines for developers, licensing authority and wider stakeholder community**

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WORKSTREAM 2: Wave and tidal stream modelling
(Lead Edinburgh University)

Dr Venki Venugopal,

Institute for Energy Systems

WS2.1 : Parameterisation of wave and tidal energy harvesting

WS2.2 : Development of combined wave-tidal energy resource assessment

WS2.3 : Development of combined wave-tidal energy resource harvesting scenarios

WS2.4 : Site-specific fatigue and extreme wave estimation

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WS2.1 Parameterisation of wave and tidal energy harvesting

Definition of key parameters:

- energy harvested by a wave or tidal device
- energy losses due to the device support structure impinging on the flow
- energy losses due to mixing of the wake generated by the device with free-stream flow (tidal only)
- alterations of the flow field due to flow-structure interaction (e.g. waves radiated from a device, or turbulence and vorticity generation in the wake of a device)

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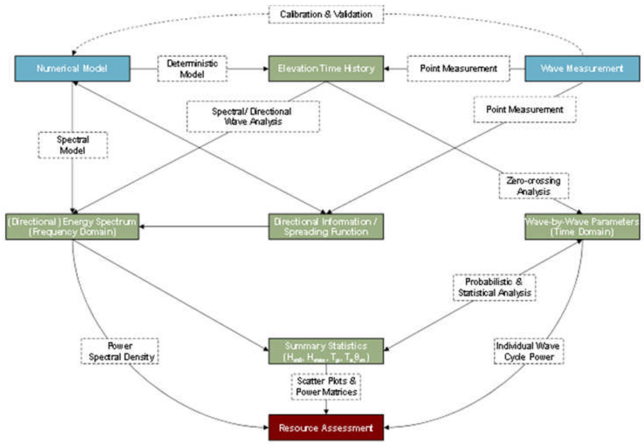
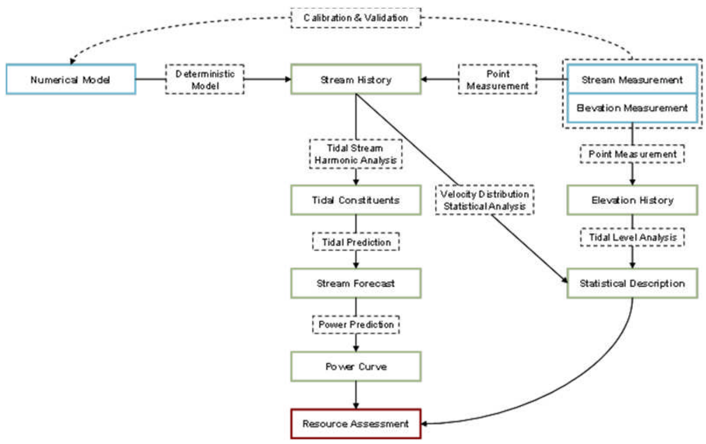
Parameterisation of wave resources



Source: Equimar Protocols

TERAWATT ~ EPSRC GRAND CHALLENGE FUNDING

Parameterisation of tidal resources



Source: Equimar Protocols

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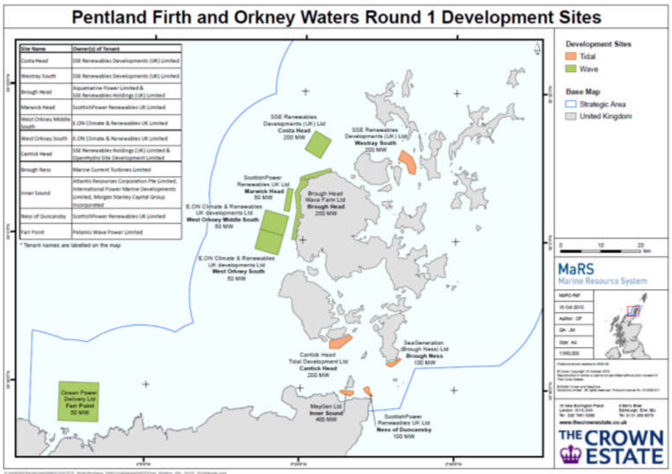
WS2.2 : Development of combined wave-tidal energy resource assessment

Wave-current modelling in finer scale resolution:

- Estimation of theoretical wave/tidal current resource for Pentland Firth and Orkney Waters
- Mike21/3
- Delft 3D
- Model inter-comparison
- Wave buoys/ADCP data from WS1.1 for validation

Leasing and licensing



In the Pentland Firth Orkney Waters Round One, The Crown Estate granted options for leases for up to 1.6GW of marine capacity.

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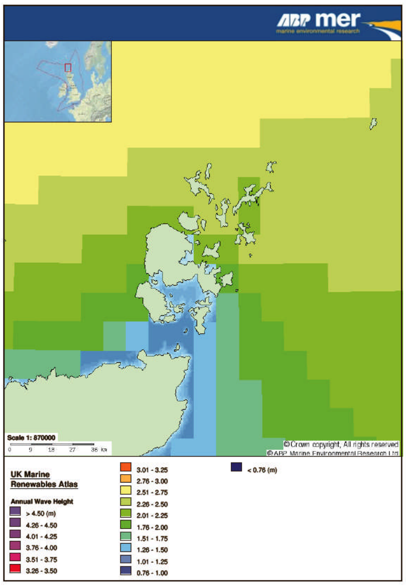
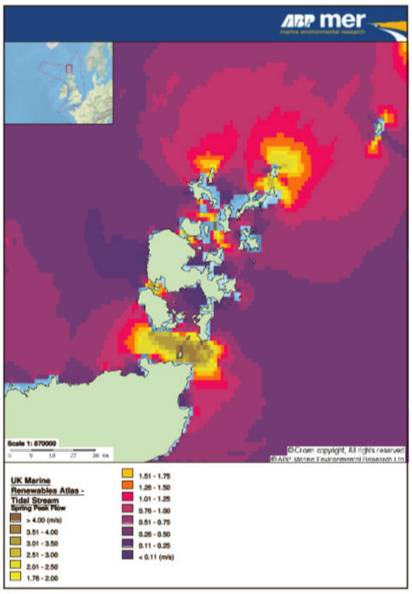
WS2.2 : Development of combined wave-tidal energy resource assessment





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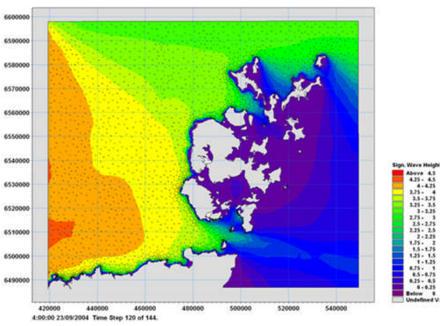
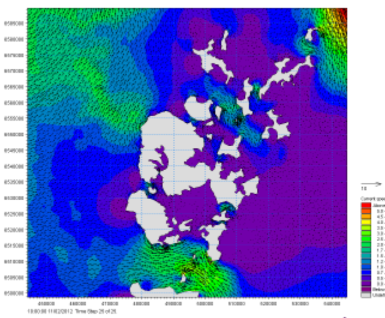
WS2.2 : Development of combined wave-tidal energy resource assessment



Wave resource



Tidal resource

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WS2.3 : Development of combined wave-tidal energy resource harvesting scenarios

Impact of energy harvesting on regional, local and fine scale hydrodynamics

- hypothetical energy converters
- assessment of individual and cumulative impact of developments
- Impact of build order on potential resources
- examine altered flow physics
- assessment of mean and extreme variability
- impact on neighbouring wave/tidal climate
- impact on one type of array (eg., nearshore) on another type (coastal)
- output of assessment, model results will feed into WS3 and WS4.

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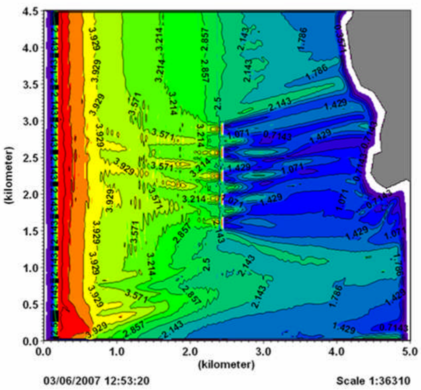
WS2.3 : Development of combined wave-tidal energy resource harvesting scenarios



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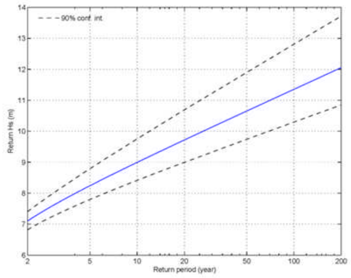
WS2.4 : Site-specific fatigue and extreme wave estimation by numerical wave simulation

Methodology for extremes:

- ERA-40 data for extremes estimation at grid points
- Mike21 for estimating conditions at specific sites
- Guidelines and uncertainty quantification



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marine scotland

University of Strathclyde Glasgow

University of the Highlands and Islands
Oilthigh na Gàidhealtachd agus nan Eilean

Swansea University
Prifysgol Abertawe

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Thank you

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WORKSTREAM 3 Sediment Dynamics

WS3.1 Modelling seabed sediment transport and geomorphology

WS3.2 Modelling changes in accretion/erosion of the coastline

WS3.3 Modelling large scale suspended sediment distributions

University of Swansea & University of Strathclyde

WS3 deliverables

- DW3.1. Spatial distribution of local net sediment transport pathways predicted for energy extraction scenarios
- DW3.2. Spatial distribution of net bedload sediment transport rates at tide-averaged scale
- DW3.3. Spatial distribution maps of bathymetry and coastline change
- DW3.4. Fully parameterised statistical model to predict SPM profiles
- DW3.5. Spatial distribution maps of the predicted impact of energy extraction scenarios in SPM concentrations for use in **WS4**

WS3.1 Modelling seabed sediment transport and geomorphology
WS3.2 Modelling changes in accretion/erosion of the coastline

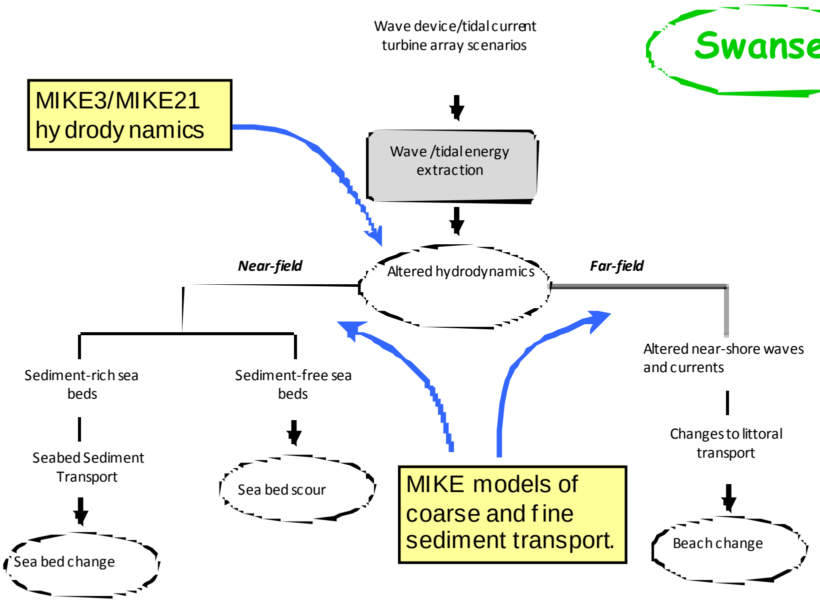
The task involves research into Hydrodynamics and their effects on Morphodynamics…

Swansea

- Hydrodynamics
  - Tides and waves
  - Wave-current interaction
  - Device interaction
  - Near-bed velocities
- Morphodynamics
  - Fine/coarse/mixed sediment
  - Sediment mapping
  - Bed change/bed scour

WS3.1 Modelling seabed sediment transport and geomorphology
WS3.2 Modelling changes in accretion/erosion of the coastline

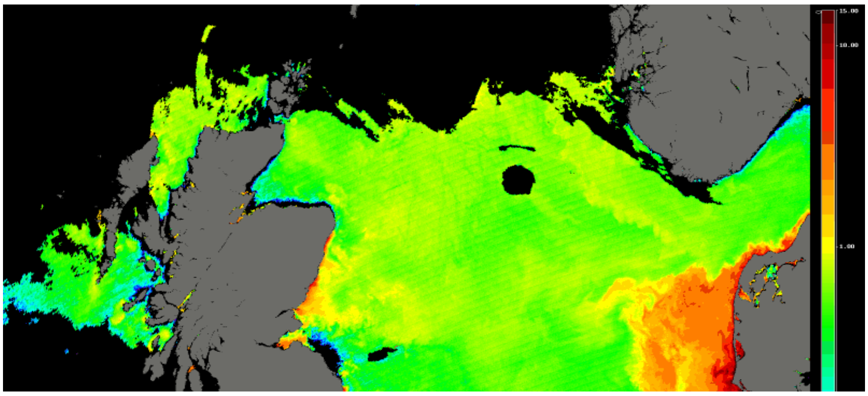
Swansea



WS3.3 Modelling large scale suspended sediment distributions

Strathclyde

Turbidity varies considerably over the North Sea due to a variety of factors
What will be the effect of installing wave and tidal devices?



MODIS Aqua image 22 March 2012, processed using Strathclyde algorithm to give suspended sediment in $g.m^{-3}$

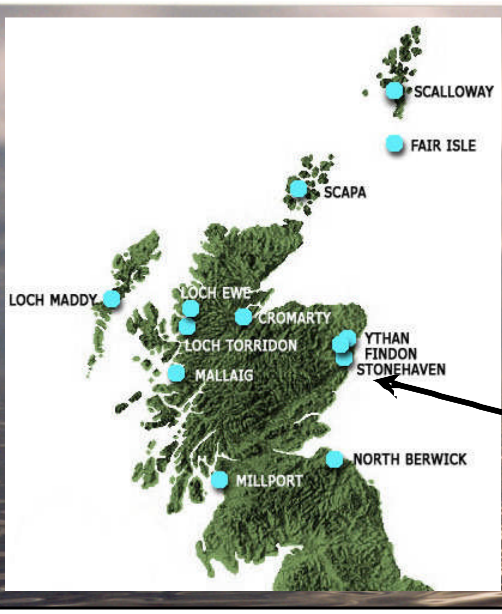
WS3.3 Modelling large scale suspended sediment distributions

Strathclyde

Starting from a large dataset of turbidity measurements at Stonehaven, NE Scotland.

- Stage 1: set up MIKE21 for Stonehaven.
- Stage 2: one dimensional (vertical) statistical model of temporal dynamics of SPM at given altitudes above the seabed at Stonehaven – explanatory variables: seabed depth, salinity, tidal velocity, wave characteristics.
- Stage 3: Critically evaluate MIKE suspended sediment model results against observed data.
- Stage 4: Apply the statistical model in a variety of locations – pulling in seabed sediment types. Compare against satellite data.
- Stage 5: Test effects of altering tidal velocities for simulated SPM.

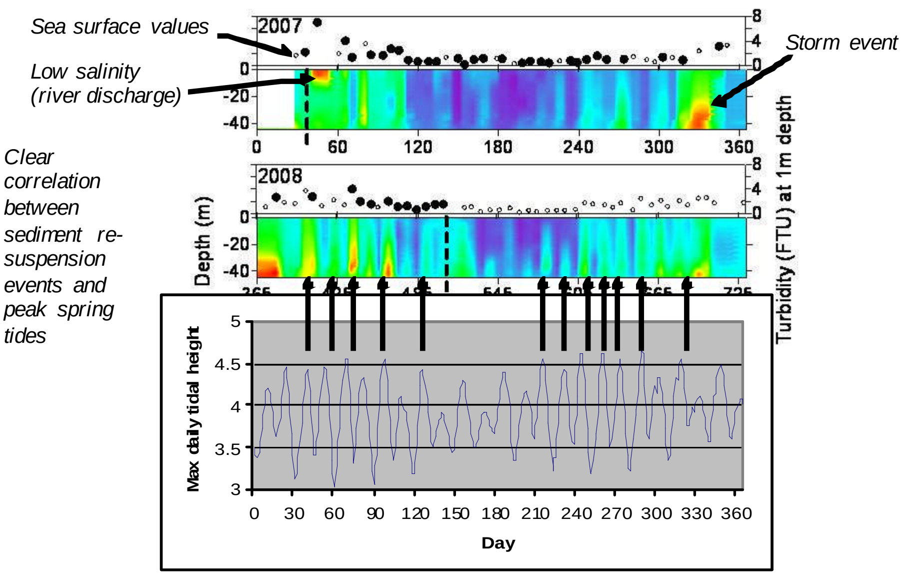
MSS monitoring of Scottish Inshore waters



Stonehaven monitoring site (5km offshore)

- **Weekly hydrographic and plankton sampling since 1997**
- **Weekly turbidity profiles since 2007**

3 years of weekly turbidity profiles



Why do we care about turbidity?

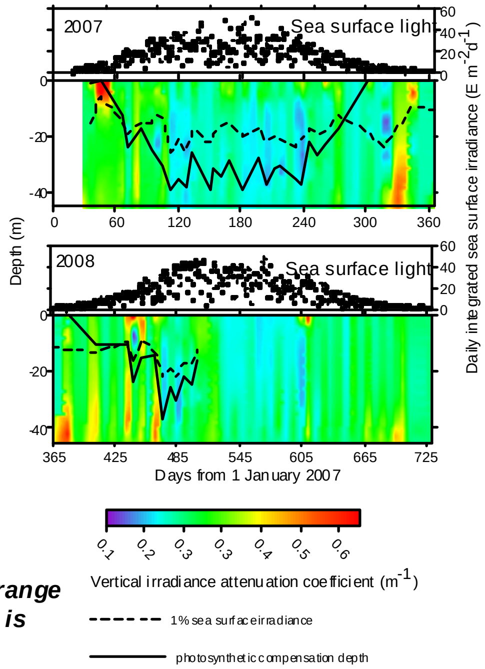
Attenuation of light available for photosynthesis…

Color scale – light attenuation coefficient – correlated with turbidity

Solid line – depth at which phytoplankton photosynthisis rate = respiration rate (no net production)

Dashed line – depth at which light intensity is 1% of sea surface value.

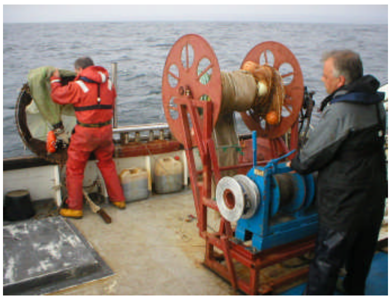
Turbidity events reduce the depth range over which net primary production is possible



Questions ?







TeraWatt Workstream 4

Ecological Consequences of wave and tidal energy extraction (Lead Heriot-Watt University and SAMS – Jon Side and Mike Burrows)

TeraWatt WS 4 Ecological consequences

WATER MOVEMENTS:

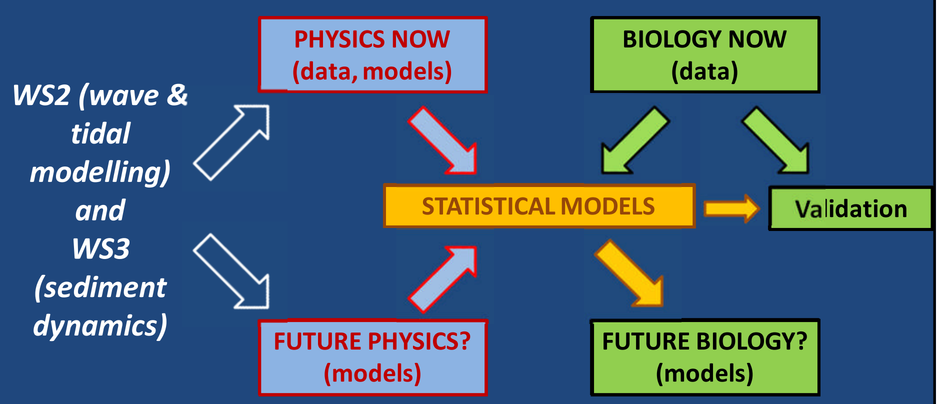
1. A resource for energy extraction
2. Important ecological factors determining the distribution and abundance of marine organisms
3. Energy extraction has consequences for water movements
4. How might this affect marine organisms?

TeraWatt WS 4
Ecological consequences

OBJECTIVES:

- Produce methodologies for statistical models that will enable benthic biotope characterization, using given physical parameters and outputs from workstreams 2 and 3
- Illustrate and validate with field data
- Demonstrate what changes in these may occur as a consequence of various energy extraction scenarios
- Evaluate other potential ecological effects

TeraWatt WS 4
Ecological consequences

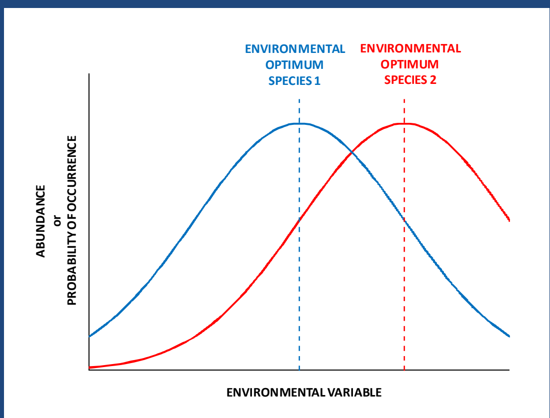


TeraWatt WS 4
Ecological consequences

MODELLING THE BIOLOGY:

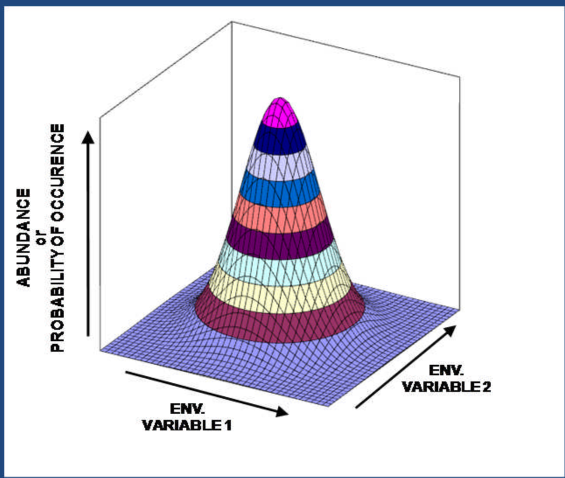
- Spatially referenced survey data and biological records provide information on incidence, presence / absence or abundance of species or biotopes at given locations
- TeraWatt models and external data provide information on the physical environment at those locations
- Statistical models (MAXENT, GAM, CVA) provide a description of habitat
- Projection of the statistical models onto GIS data layers for current conditions provides biological baseline
- Projection of the statistical models onto GIS data layers for modelled future conditions provides indication of possible biological change

TeraWatt WS 4
Ecological consequences



- Abundance or probability of occurrence of a species varies in relation to environmental conditions
- Optimum conditions exist along any given environmental gradient
- Changes in environment are likely to lead to long-term changes in species abundance or incidence

TeraWatt WS 4
Ecological consequences



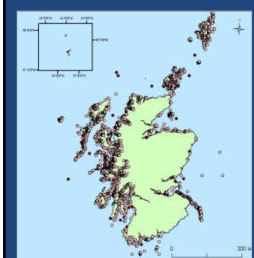
- Abundance or probability of occurrence of a species varies in relation to environmental conditions
- Optimum conditions exist along any given environmental gradient
- Changes in environment are likely to lead to long-term changes in species abundance or incidence
- Multiple environmental gradients exist
- Statistical models are used to describe these relationships

TeraWatt WS 4
Ecological consequences

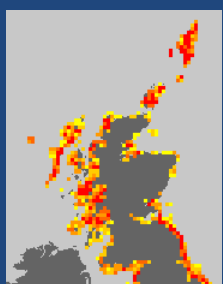
Statistical models will use:

- Existing data on marine species / biotope incidence and abundance
- Existing environmental data layers
- New data on hydrodynamics, generated by TeraWatt

Scottish bryozoan records

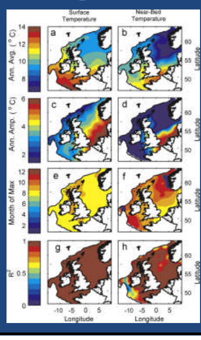


MNCR sites

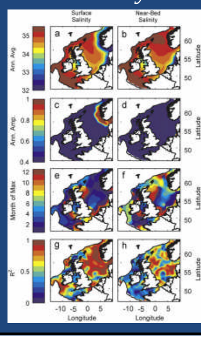


Berx & Hughes (2009)

Temperature

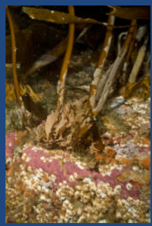


Salinity



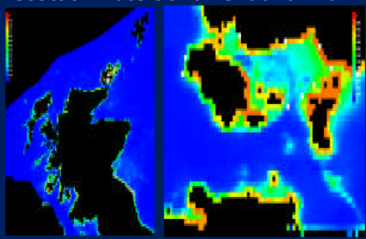
TeraWatt WS 4
Ecological consequences

Alcyonidium hirsutum

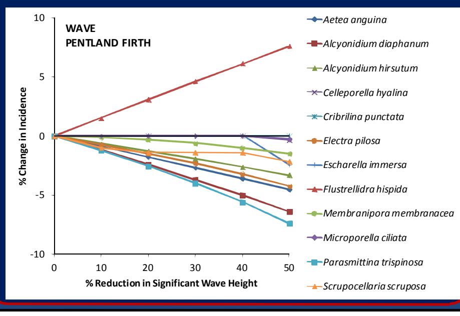


Statistical models:
- This example is Maximum Entropy modelling of bryozoan species incidence in Scottish waters
- Wave and tidal data taken from DTI Atlas
- TeraWatt will (1) generate more realistic hydrodynamic data, and (2) provide realistic energy extraction scenarios

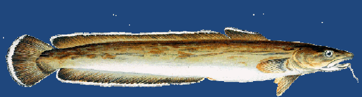
MAXENT models of distribution for marine bryozoan distribution in Scottish waters and Pentland Firth



Projected changes after energy extraction

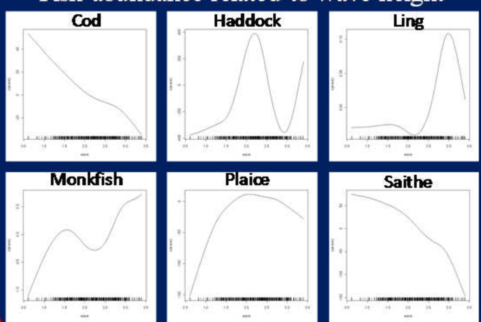


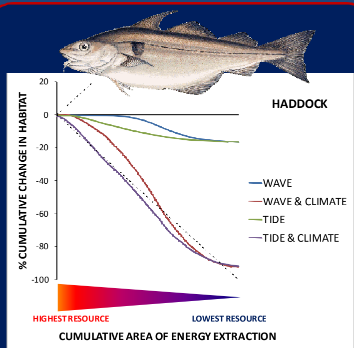
TeraWatt WS 4
Ecological consequences



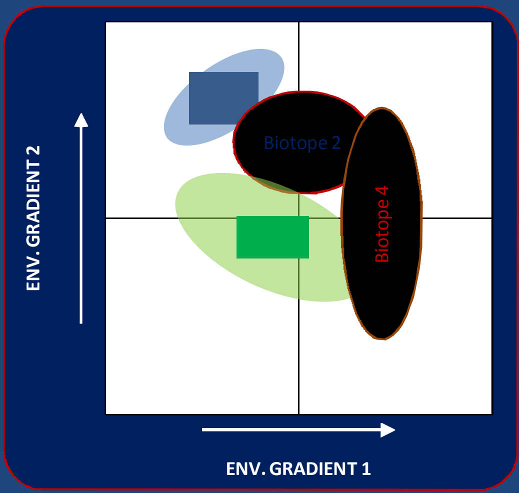
Statistical models:
- This example is GAM modelling of fish survey (IBTS) data
- Projections are used to assess possible changes in habitat from wave and tidal energy extraction

Fish abundance related to wave height



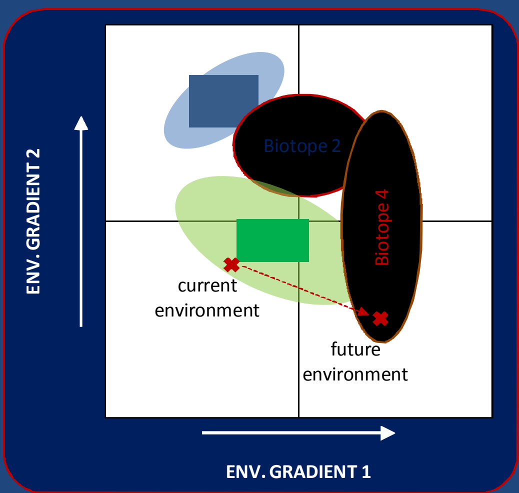


TeraWatt WS 4
Ecological consequences



Statistical models:
- Biotopes will be considered as well as species
- We will use multivariate techniques (e.g. CVA) to describe how biotopes occur in environmental 'space'

TeraWatt WS 4
Ecological consequences



Statistical models:
- Biotopes will be considered as well as species
- We will use multivariate techniques (e.g. CVA) to describe how biotopes occur in environmental 'space'
- Projections of how environmental conditions might change will allow us to predict future biotopes

TeraWatt WS 4
Ecological consequences

OUTCOMES:

- Large-scale changes in the distribution and abundance of marine species and biotopes in response to wave and tidal energy extraction – is this an issue?
- Information and toolbox for:
  - regulators involved in marine planning and consenting processes
  - further research considering wave and tidal energy extraction as part of a bigger picture

TeraWatt WS 4
Ecological consequences

TASKS:

- WS4.1 Statistical modelling for benthic biotope characterization
- WS4.2 Model validation
- WS4.3 Model re-runs with extraction of hydrokinetic energy
- WS4.4 Extended studies of ecological change

TeraWatt WS 4
Ecological consequences

DELIVERABLES:

- DW4.1. Validated statistical models for benthic biotope characterization
- DW4.2. Probabilistic outputs of change in benthic biotopes from various energy extraction scenarios
- DW4.3. Methods description for such assessments and means of incorporation / development in other regional and shelf-wide models