Cyfoeth Naturiol Cymru
Natural Resources Wales

Modelling Sensitivity of Seabed Habitats to Combined Fishing Effects

C. Lush
exeGesIS SDM Ltd

March 2014

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We work for the communities of Wales to protect people and their homes as much as possible from environmental incidents like flooding and pollution. We provide opportunities for people to learn, use and benefit from Wales' natural resources.

We work to support Wales' economy by enabling the sustainable use of natural resources to support jobs and enterprise. We help businesses and developers to understand and consider environmental limits when they make important decisions.

We work to maintain and improve the quality of the environment for everyone and we work towards making the environment and our natural resources more resilient to climate change and other pressures.

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- Maintaining and developing the technical specialist skills of our staff;
- Securing our data and information;
- Having a well-resourced proactive programme of evidence work;
- Continuing to review and add to our evidence to ensure it is fit for the challenges facing us; and
- Communicating our evidence in an open and transparent way.

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1. Crynodeb Gweithredol

Gosododd Cyfoeth Naturiol Cymru (CNC) waith ar gytundeb ag ExeGesIS SDM, i ymchwilio i ganfod a ellid gweithredu, yn ymarferol, y cyfuniad damcaniaethol o sensitifrwydd cynefinoedd i weithgaredd pysgota gwahanol fathau o gêr yn ôl disgrifiad Nisbet et al (2013).

Troswyd t ddamcaniaeth yn fodel. Profwyd y model gan ddefnyddio data gweithgaredd pysgota cyfun, wedi'i gasglu trwy gynllun braenarol FishMap Môn, ar gyfer ardal arbrofol yn cynnwys Traeth Coch a Bae Conwy, er mwyn rhagfynegi sensitifrwydd cynefinoedd. Cyffredinolwyd canlyniadau'r model yn gydrannau 1km, i gyd-fynd â chanlyniadau FishMap Môn, a chrëwyd cyfres o fapiau.

Mae'r prosiect braenarol hwn wedi canfod bod rhagfynegiadau'r model yn ddibynnol ar y data a ddefnyddir i ddiffinio'r cromliniau ymateb cynefin a'r model damcaniaethol a ddefnyddir i amcangyfrif effeithiau cronnol. Y prif gyfyngiad, parthed gwella'r model, oedd diffyg gwybodaeth am effaith y gwahanol olion traed, a synergedd dichonadwy cydrhwng mathau o gêr.

Argymhellwyd y dylid cael asesiadau maes o'r effaith ar wahanol gynefinoedd lle mae'r dwyseddau pysgota yn hysbys o ddata FishMap Môn, er mwyn darparu tystiolaeth i gefnogi sylfaen ddamcaniaethol y model. Caniatâ hyn ddatblygu model cywirach ym mhrosiectau'r dyfodol.

2. Executive Summary

exeGesIS SDM were contracted by Natural Resources Wales (NRW) to undertake a pilot to determine whether the theoretical combination of habitat sensitivity to fishing activity of different gear types as described in Nisbet et al (2013) could be put into practice.

The theory was converted into a model. The model was run using combined fishing activity data, collected through the FishMap Môn pilot project, for a pilot area covering Red Wharf Bay and Conwy Bay to predict the sensitivity of habitats. The outputs from the model were generalised to a 1km resolution to match the FishMap Môn results and a series of maps created.

This pilot project has identified that the model predictions were dependent upon the data used to define the habitat response curves and the theoretical model used to calculate cumulative effects. The main limitation with regard to improving the model was insufficient knowledge of the effect of differing footprints and potential synergy between gear types.

It was recommended that field assessments of the impact on different habitats for known fishing intensities from the FishMap Môn data should be acquired to provide evidence to support the theoretical basis for the model. This will allow a more accurate model to be developed in future projects.

3. Introduction

In November 2013, exeGesIS SDM were contracted by Natural Resources Wales (NRW) to undertake a pilot to determine whether the theoretical combination of habitat sensitivity to fishing activity of different gear types as described in Nisbet et al (2013) could be put into practice. The theory was to be converted into a model and run using combined fishing activity data, collected through the FishMap Mon pilot project, to predict the sensitivity of habitats.

This report outlines the objectives for the pilot project, the datasets used, the analysis undertaken and summarises the results. The discussion identifies the limitations of the current data and approach and provides recommendations for improvements in future projects.

3.1. Aims and objectives

The objective of this pilot project was to determine whether the data on resistance to fishing activity data for each fisheries habitat developed during the NRW habitat sensitivity project (Eno et al., 2013) could be applied to model the impact of cumulative fishing activity on each habitat.

The intention was to develop a methodology to model combined fishing effects and test the methodology using the fishing activity data collected during the FishMap Môn project on two study areas: Red Wharf Bay and Conwy Bay, to determine the feasibility of this approach.

The specific aims for this project were to:

- Calculate footprint versus resistance curves for each fisheries habitat and fishing activity using the revised activity footprints calculated for the FishMap Môn project
- Develop a methodology to model combined fishing effects
- Test the methodology on Red Wharf Bay and Conwy Bay
- Produce an output layer at a 1 km grid resolution
- Produce thematic maps as A4 PDFs

4. Methodology

4.1. Data supplied by Natural Resources Wales (NRW)

4.1.1. Combined seabed habitat

A combined seabed habitat layer was supplied by NRW which contains both intertidal and subtidal habitats.

Intertidal habitats were mapped during the Countryside Council for Wales (CCW) Marine Intertidal Phase 1 Biotope Mapping Survey (Brazier et al., 2002). Data were recorded using the JNCC Biotope Classification (Connor et al., 1997) on 1:5,000 scale maps. Each biotope within the Welsh habitat data was assigned to one of the 31 broad fisheries habitats (see Table 1) using lookup tables produced during the habitat sensitivity project (Hall et al., 2008).

Subtidal habitat data were sourced from the HABMAP project (Robinson et al., 2009). This project used a multi-parameter predictive model to develop seabed biotope maps for the southern Irish Sea. The predictive biotope maps were converted to fisheries habitat maps by grouping biotopes into one of the 31 broad fisheries habitats (see Table 1) from the habitat sensitivity analysis (Hall et al., 2008). The maps were then assessed by experts to assist with validation, and changes to the habitat type were made if evidence suggested that the predicted habitat was incorrect.

Two fields within the supplied data were used for this project:

- *Habitat_Code*
  This field indicates the fisheries habitat for the polygon. In addition to the 31 fisheries habitat codes, this field may also include a habitat code of 32 indicating a mosaic habitat.
- *Dominant_Habitat*
  This field indicates the predominant habitat within the polygon. This field was used instead of the habitat code for mosaic habitats with a habitat code of 32.

Table 1 - List of fisheries habitats assigned to each habitat in the combined seabed habitat layers. Fisheries habitats were taken from (Hall et al., 2008, Eno et al 2013).

Habitat No.	Description
1	Upper shore stable rock - lichens & algal crusts
2	Wave exposed intertidal stable rock
3	Moderately wave exposed intertidal rock
4	Seaweeds mussels on moderately exposed rock
5	Mussels & piddocks on intertidal clay & peat
6	Honeycomb worm reefs
7	Sheltered bedrock, boulders & cobbles
8	Rockpools and overhangs
9	Brown seaweeds, barnacles and fucoids
10	Muddy sands - excluding gaper clams
11	Muds & sands - including gaper clams
12	Intertidal muds
13	Salt marshes
14	Vertical rock with associated species
15	Erect and branching species very slow growing
16	Sand & gravel with long lived bivalves
17	Maerl beds
18	Stable subtidal fine sands
19	Stable subtidal muddy sands, sandy muds & muds
20	Rock with low lying, fast growing faunal turf
21	Rock with erect & branching species
22	Shallow subtidal rock with kelp
23	Kelp and seaweeds on sand scoured rock
24	Dynamic, shallow water fine sands
25	Oyster beds
26	Underboulder & cobbles shallow subtidal community
27	Biogenic reef on sediment
28	Stable spp. rich mixed sediments
29	Unstable coarse sediments - robust fauna
30	Seagrass beds
31	Stable but tideswept, cobbles, pebbles & gravel

4.1.2. Activity intensity layers

A set of detailed intensity level layers were supplied by NRW. These layers were created from survey data collected during the FishMap Môn project and provided a detailed picture of the intensity of fishing activity in the waters around Anglesey.

The FishMap Môn project surveyed commercial, recreational and charter boat fishermen to map the distribution and intensity of fishing activity around Anglesey.

The project liaison officer interviewed 47 commercial fishermen, 26 charter boat operators and over 500 non-commercial fishermen (anglers, bait collectors, mussel gatherers etc). Interviews were undertaken using a specially designed electronic questionnaire that allows fishers to map their fishing locations and input details about their gear types and frequency of fishing. The majority of recreational sea anglers were surveyed using a simplified paper version of the questionnaire.

Each activity was assigned to a gear category based upon the type of equipment used. The gear categories (Table 2) were taken from the habitat sensitivity analysis undertaken by CCW (Hall et al., 2008). For each gear type, the intensity of activity was calculated for each polygon mapped during the project using the formulas from the analysis undertaken by the University of Liverpool (Nisbet et al., 2013).

Table 2 - List of gear categories assigned to each activity in the fishing activity layers. Gear categories were taken from Hall et al. (2008)

Group No.	Description
1	Beam trawls and scallop dredges
2	Rockhopper trawls
3	Oyster/Mussel dredging and Prospecting
4	Demersal trawls
5	Light demersal trawls and seines
6	Hydraulic suction dredges
7	Pelagic trawls, nets and lines
8	Static gear - nets and long lines
9	Static gear - pots
10	Rod and line hand-fishing
11	Casual hand gathering
12	Professional hand gathering
13	Aquaculture - trestles, ground lays & traps
14	Aquaculture - cages & rope cultivation
15a	Foot Access
15b	Vehicular Access

The intensity data for each fisherman was processed using FME to create the detailed intensity level layer for each gear type. Where polygons from individual fishermen overlapped, a single polygon was created in the output layer containing the combined data from the overlapping survey polygons.

Gear categories 2, 4, 6, 13, 14, 15a and 15b were not undertaken by any of the fishermen surveyed during the FishMap Môn project, so these gear categories will not be analysed during this pilot project.

4.1.3. Habitat resistance

Habitat sensitivity and resistance matrices were produced by the CCW fisheries habitat sensitivity project (Eno et al., 2013). These matrices were revised during the FishMap Môn project. The latest version produced in July 2013 was used for this project (see Appendix 9.1).

The matrices indicate the resistance of the habitat (High, Medium, Low or None) to different activity intensities: Heavy, Moderate or Light. Sensitivity to a Single Pass was excluded from the FishMap Môn project as it represents accidental activity that is unlikely to occur. Single Pass has therefore been excluded from this project.

4.1.4. Activity footprint

A methodology was developed by the University of Liverpool to calculate the footprint for each intensity level for each gear type (Nisbet et al., 2013). The calculation was based upon the area in square kilometres (km^2) impacted by a single activity multiplied by the frequency for each intensity level.

The data from the FishMap Môn project indicated that the intensity levels predicted from previous projects (Hall et al., 2008 & Eno et al., 2013) did not fully reflect the actual levels of activity in the waters around Anglesey. The footprint values were therefore revised during the FishMap Mon project (Aron et al., in prep.).

Following initial data processing, it became evident that there was an error in the calculation of footprint per km^2 for particular gear categories in the Nisbet et al. (2013) report when converting footprint per hectare into footprint per km^2. Footprints were calculated based upon intensity levels; therefore the predicted impact for the curve should reflect the intensity level category, however for these gear categories almost all footprint values predicted zero resistance.

The footprint calculations for the following gear types were revised:

Pots

The intensity for pots is based upon the number of pots per hectare lifted daily. As the frequency for pots is based upon a unit area of 1 hectare, the area impacted in m^2 must therefore be divided by the area of a hectare in m^2 i.e. 100 x 100 metres to convert to area impacted in km^2.

Footprint per day (km^2) = Footprint of one activity (km^2) * Frequency, where:

- Frequency = Number of pots lifted per day
- Footprint of one activity (km^2) = Area affected by 1 pot ($1.08m^2$) / 10000

The revised footprint per day (km^2) values were:

Light	Moderate	Heavy
0.000216	0.000432	0.000540

Rod and Line

The area impacted for rod and line was adjusted to 1m^2 for a 4 hour visit per person in the final version of the FishMap Môn intensity definitions as shown in Appendix **Error! Reference source not found.** (Natural Resources Wales, 2013).

The intensity for rod and line is based upon the number of people per hectare per week, where a week is 5 days (Nisbet et al., 2013). As the frequency for rod and line is based upon a unit area of 1 hectare, the area impacted in m^2 must therefore be divided by the area of a hectare in m^2 i.e. 100 x 100 metres to convert to area impacted in km^2.

Footprint per day (km^2) = (Footprint of one activity (km^2) * Frequency) / 5 days, where:

- Frequency = Number of people visiting per week
- Footprint of one activity (km^2) = Area affected by a visit (1m^2) / 10000

The revised footprint per day (km^2) values were:

Light	Moderate	Heavy
0.00010	0.00038	0.00040

Hand gathering – Casual and Professional

The intensity for hand gathering is based upon the number of people per hectare per day. As the frequency for hand gathering is based upon a unit area of 1 hectare, the area impacted in m^2 must therefore be divided by the area of a hectare in m^2 i.e. 100 x 100 metres to convert to area impacted in km^2.

Footprint per day (km^2) = Footprint of one activity (km^2) * Frequency, where:

- Frequency = Number of people visiting per day
- Footprint of activity (km^2) = Area of habitat affected by a visit (16m^2 – casual / 50m^2 - professional) / 10000

The revised footprint per day (km^2) values were:

Type	Light	Moderate	Heavy
Casual	0.0032	0.0144	0.0160
Professional	0.0100	0.0450	0.0500

4.2. Pre-processing of input data

4.2.1. Creation of footprint vs resistance table for each habitat

A script was used to convert the resistance values for each habitat / gear combination from the matrix to a flat file format. A second script was then used to combine the daily footprint values with the resistance values to produce a spreadsheet containing the values required for each curve. The spreadsheet was then exported to comma separated value (CSV) format.

4.2.2. Calculation of footprint values based on intensity

The intensity data supplied by NRW were generated using the FishMap Môn project intensity definitions as shown in Appendix **Error! Reference source not found.** (Natural Resources Wales, 2013). These definitions vary in terms of the units used for the output:

- Vessel days within a reference area
- Panels per km^2 per year
- Pots lifted per hectare per day
- People fishing per hectare per week
- People gathering per hectare per day

Each of the intensity values must therefore be converted or recalculated to the footprint per year per km^2 expected for the analysis.

Mobile gears

The intensity for mobile gears, including dredging and trawling, was stated on the FishMap Môn website as the number of vessel days within a specified area. For the majority of these gear categories the reference area was 2.5 by 2.5 nautical miles (nm), however for mussel seed dredging the reference area was $5km^2$.

Of these gear types only mussel dredging (3) and light otter trawl (5a) occur within the pilot area. Footprint per year per km^2 was calculated for a polygon with no overlaps using gear width and length of tow.

Footprint per year per km^2 = Footprint per day (km^2) * No. of days, where:

- Footprint per day (km^2) = Width (km^2) * Length of tow (km) / polygon area (km^2), where:
  - Width (km^2) = (Width of a single gear unit (m) * Number of gear units) / 1000
  - Length of tow (km) = Speed (km/hour) * Tow duration (hours), where:
    - Speed (km/hour) = Speed (knots) * 1.852

The calculated footprint in km^2 for both mussel dredging and light otter trawl were identical to the intensity value in the FishMap Môn data, therefore the intensity value in the data was used for this analysis.

Bottom set nets

The intensity values for bottom set nets are calculated as panels per km^2 per year. For this layer the intensity value could not be converted and had to be recalculated from the raw data.
For each polygon drawn by the fishermen surveyed, the footprint per year (km^2) was calculated using the number of anchors. Each anchor affects $1m^2$ per day.

Footprint per year (km^2) = Footprint per day (km^2) * No. of days, where:

- No. of days = number of days fished
- Footprint per day (km^2) = ((1 m^2 * No. of Anchors)/1000000) / polygon area (km^2)

Potting

The intensity value for pots was calculated as the number of pots per hectare per day. This value was converted to footprint per year.

Footprint per year (km^2) = Footprint per day (km^2) * 365 days, where:
- Footprint per day (km^2) = (1.08 m^2 * Intensity) / 10000

Rod and line

The intensity value for rod and line was calculated as the number of people per hectare per week. This value was converted to footprint per year assuming a 5 day week.

Footprint per year (km^2) = Footprint per day (km^2) * 365 days, where:
- Footprint per day (km^2) = (1 m^2 * (Intensity/5)) / 10000

Hand gathering

The intensity value for hand gathering was calculated as the number of people per hectare per day. This value was converted to footprint per year.

Casual:
Footprint per year (km^2) = Footprint per day (km^2) * 365 days, where:
- Footprint per day (km^2) = (16 m^2 * Intensity) / 10000

Professional:
Footprint per year (km^2) = Footprint per day (km^2) * 365 days, where:
- Footprint per day (km^2) = (50 m^2 * Intensity) / 10000

4.2.3. Creation of combined activity layer

The intensity data for all activities was processed in MapInfo to create a single layer with no overlaps. Footprint columns were added for each gear type and updated with the footprint values for each gear type where the polygon was within the gear intensity layer.

The combined intensity data was split by the habitats and updated with the habitat values where the polygon was within the habitat layer. The data was packed and each row in the resulting layer was given a unique ID. The layer and exported to CSV format.

4.3. Creation of SciPy scripts and data processing

For this project it was decided to use Scientific Python (SciPy) to develop the scripts to fit the curves and process the data. SciPy is an open source coding language which offers built in functions for fitting curves to supplied data.

4.3.1. Curve fitting

Visualisation of graphs showing footprint vs resistance for each habitat and sub-gear combination indicated that none of the relationships were linear. Tests were carried out to identify which groups of equations offered the best visual fit.

Following the tests the following equations were selected to be used to fit curves (Table 3).

Table 3 - Equations used for fitting curves

Equation Name	Formula
Sigmoidal - Gompertz A With Offset	$y = a * \exp(-\exp(b - cx)) + Offset$
Sigmoidal - Gompertz C With Offset	$y = a * \exp(b * \exp(c * x)) + Offset$

Sigmoidal - Hill With Offset	y = ax^b / (c^b + x^b) + Offset
Sigmoidal - Weibull PDF With Offset	y = (a/b) * (x/b)^(a-1.0) * exp(-(x/b)^a) + Offset
Exponential - Exponential With Offset	y = a * exp(bx) + Offset
Exponential - Double Exponential	y = a * exp(bx) + c * exp(dx)
Exponential - Hoerl Transform	y = (bx + c)^a * exp(bx + c)
Exponential - Hoerl Transform With Offset	y = (bx + c)^a * exp(bx + c) + Offset
Exponential - Offset Exponential With Offset	y = a * exp(bx + c) + Offset
Power - Standard Power With Offset	y = a * x^b + Offset

The table of footprint and resistance values (see 4.2.1) was loaded into SciPy. For each habitat and sub-gear type combination the footprint and resistance values were extracted from the table and tested against each of the above equations. For each equation a graph was saved as an image so that the form of the curve could be checked.

The predicted values for each equation were used to calculate the R-squared value and Root Mean Square Error (RMSE) to indicate how well the curve fitted the data. R-squared indicates the degree of correlation between the data and the curve, whilst RMSE calculates the difference between the actual and predicted values. The equation with the best R-squared and RMSE values was selected and the results written to a CSV file.

The best fit curves were visually checked using the graphs. Due to the limited number of data points, in some cases the best curve based on RMSE did not meet the requirements for this project. For example it would be expected that habitats would not recover with increasing intensity, therefore curves which initially descended but ascended to meet the final data point (Figure 1) were replaced.

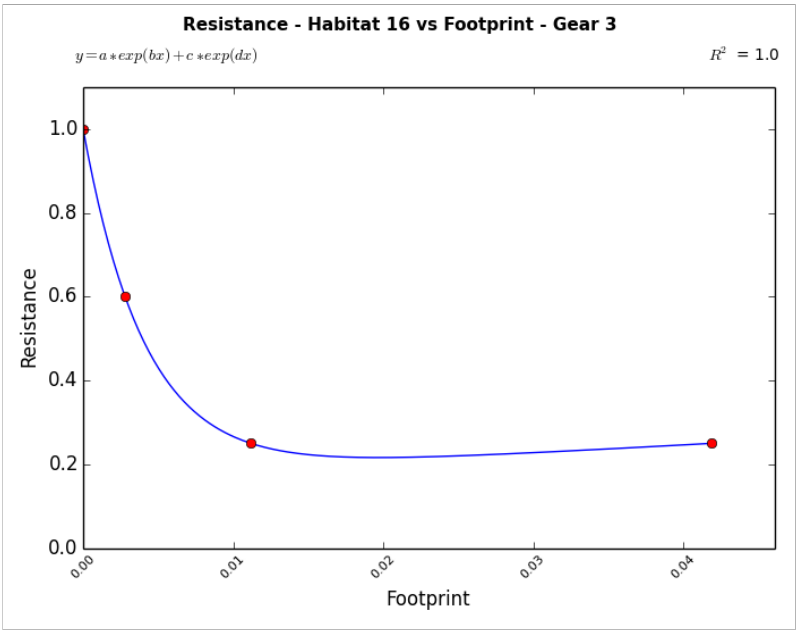

Figure 1 - Example of double exponential plot where best fit curve descends then ascends to meet final data point

In addition, the majority of graphs with data points which were all the same resistance, e.g. MMM, were represented by an exponential function however some were sigmoidal functions with a sudden drop in resistance (Figure 2). These graphs were replaced so that the curves were consistent.

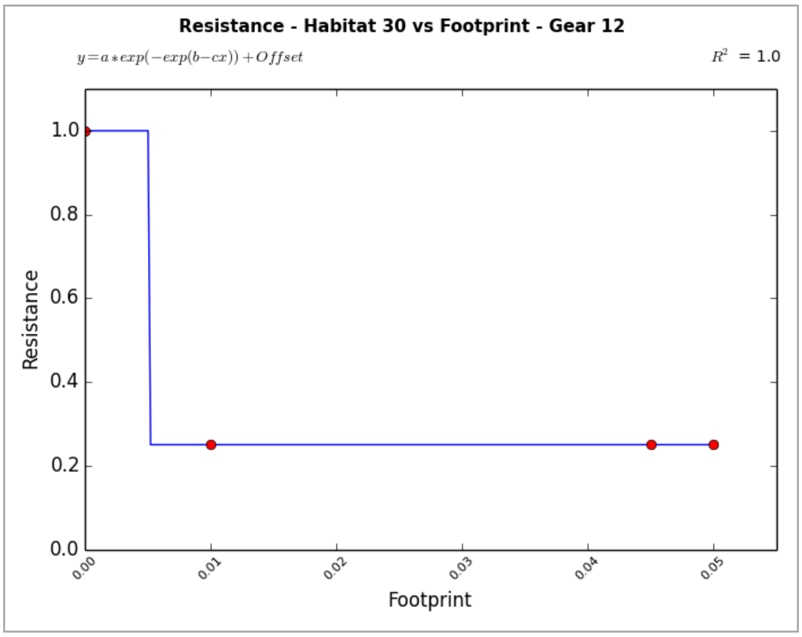

Figure 2 - Example of Gompertz A sigmoidal plot for a habitat with LLL resistance where best fit curve shows sudden drop in resistance

Where the predicted best fit curve was not suitable for the analysis, the equations were ranked by RMSE and the curve with the next lowest RMSE was substituted prior to modelling the reduction in resistance.

4.3.2. Modelling of resistance to combined activity

The exported footprint data for each polygon was used to calculate the impact for each activity for the specified habitat type. Habitat type was taken from the Habitat_Code field except where the habitat was a mosaic (32) in which case the Dominant_Habitat field was substituted. Records were skipped where the habitat value was zero.

For each of the footprint fields where the value was greater than zero, the resistance for that gear type was predicted using the best equation for the relevant habitat / sub-gear combination. The resistance value was then subtracted from 1 to give the impact.

An impact value of -99 was used as a NODATA value to indicate that the record had a footprint but there was not a best fit curve for that habitat / sub-gear combination.

Due to time constraints it was decided at the start of this contract that a simple additive approach would be used to calculate the overall reduction in resistance due to the combined fishing activities. Impact scores greater than zero were therefore added together for all activities within the polygon and subtracted from 1 to give total resistance. If the total impact was greater than 1, resistance was reset to zero.

4.4. Creation of output layers

The derived impact and total resistance data was recombined with the polygon data in MapInfo using the unique ID field to create an output layer showing the raw data.

The data collected during the FishMap Môn project was generalised to a 1 km resolution to protect the anonymity of the people who provided data and any commercial sensitivity regarding the location of fishing activities. It was therefore a requirement for this project to create a generalised 1 km resolution layer so that the outputs could be compared.

A 1 km grid was created in British National Grid as for the FishMap Môn results. Each grid square was updated where the activity polygons intersected the grid square and habitat code was not zero to create the following fields (Table 4).

Table 4 - Fields in Resistance_1km_Grid derived from raw impact data

Field	Description
ActivityArea	The area in hectares affected by fishing activity
MaxResistance	The maximum resistance score within the grid square
MinResistance	The minimum resistance score within the grid square
AvgResistance	The average resistance score within the grid square
WgtAvgResistance	The weighted average resistance score within the grid square

AvgResistance was calculated as a proportional average based upon the area of the activity polygons which intersected the grid square. This value indicates the average resistance of the areas within the grid square which were affected by fishing activity.

WgtAvgResistance was calculated as a proportional average based upon the ratio between areas affected by activity and areas where no activity occurs. This value indicates the average resistance of the entire grid square and was calculated using the following formula:

$$((AvgResistance * ActivityArea) + (1 * (100 – ActivityArea))) / 100$$

Each of the above fields was then classified to create a corresponding resistance category field. The values were classified as follows:

Resistance Score	Resistance Category
1	No impact
>= 0.9 & <1	High
>= 0.6 & <0.9	Medium
> 0 & < 0.6	Low
0	None

Thematic maps were created for the raw data and each of the resistance category columns for the 1km resolution grid. The maps were exported as A4 PDFs.

5. Results

Analysis of the raw data identified that there were 164 polygons where the resulting resistance to combined fishing effects is zero. These polygons tend to cover limited extents and occur where there is level 3 intensity potting and mussel dredging. These areas should be reviewed by NRW staff to determine whether the maximum intensity should be revised for future work.

Each of the following maps was supplied to NRW as A4 PDF documents. Figures 3 - 6 show the generalised resistance for each 1 km grid square using four different methods of calculating the resistance to highlight different aspects of the data.

Figure 3 shows the maximum resistance value for any activity which occurred within each grid square and therefore shows the most optimistic interpretation of the outputs. This calculation only takes into account the resistance score not the area of habitat represented by that score.

Habitat Sensitivity to Combined Fishing Activity Pilot - Maximum Resistance

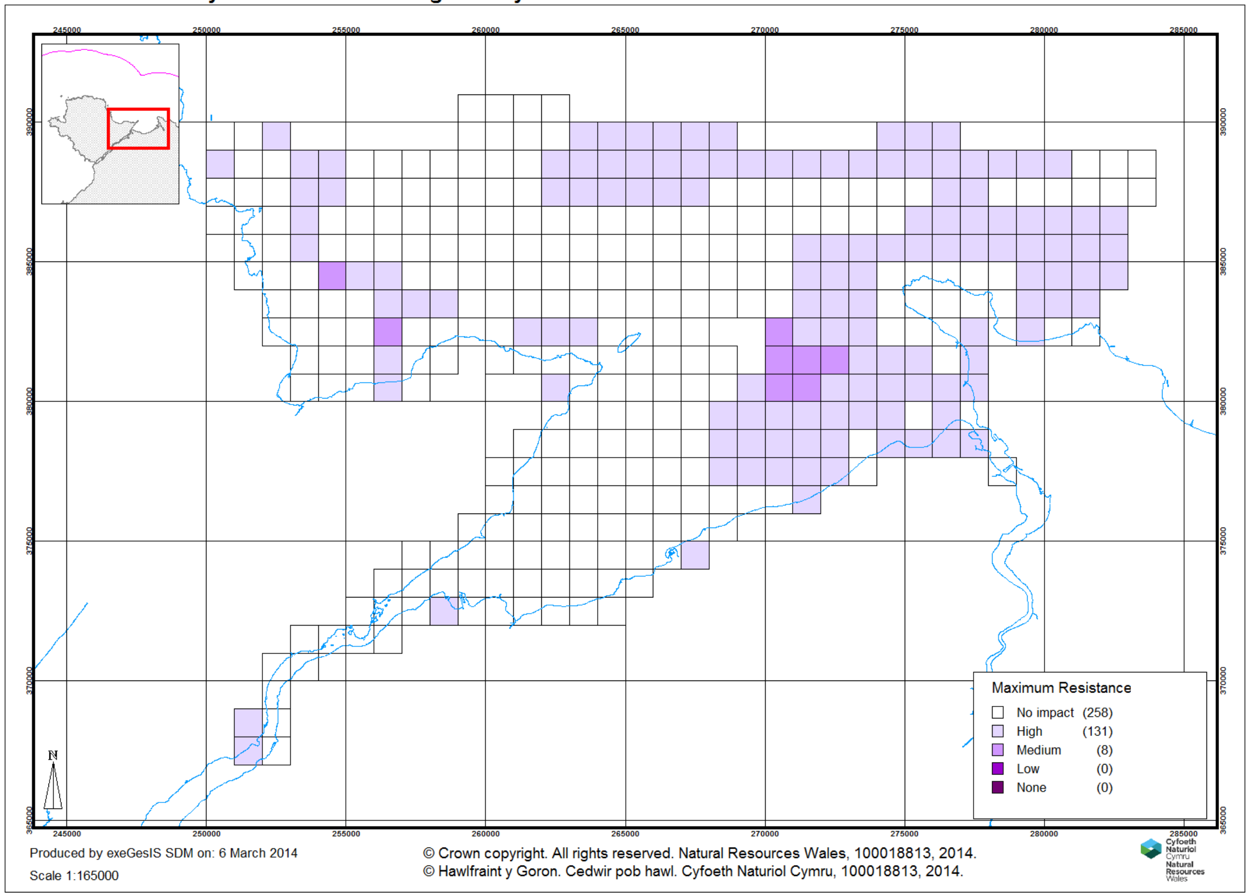

Figure 3 - Map showing maximum resistance for areas affected by activity within each grid square

Figure 4 shows the minimum resistance value for any activity which occurred within each grid square and therefore shows the most pessimistic interpretation of the outputs. This calculation only takes into account the resistance score not the area of habitat represented by that score. Nevertheless it is useful to highlight the grid squares where significant impacts occur.

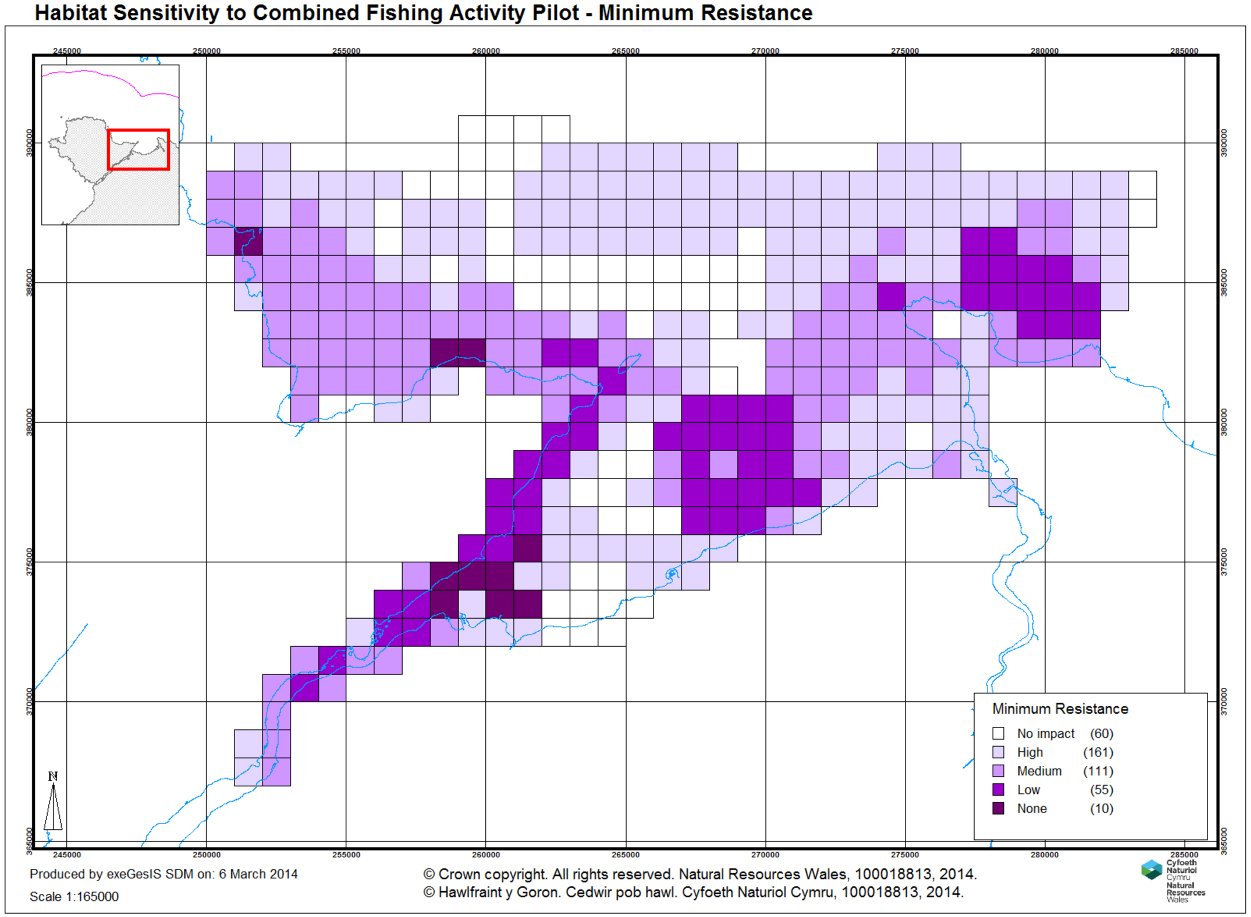

Figure 4 - Map showing minimum resistance for areas affected by activity within each grid square

Figure 5 shows the average resistance value for any activity which occurred within each grid square. The average resistance is calculated as a proportional average based upon polygon area and therefore represents the average impact on habitats affected by fishing activity. This method is a more balanced approach; however it does not take into account areas which have no activity.

Habitat Sensitivity to Combined Fishing Activity Pilot - Average Resistance

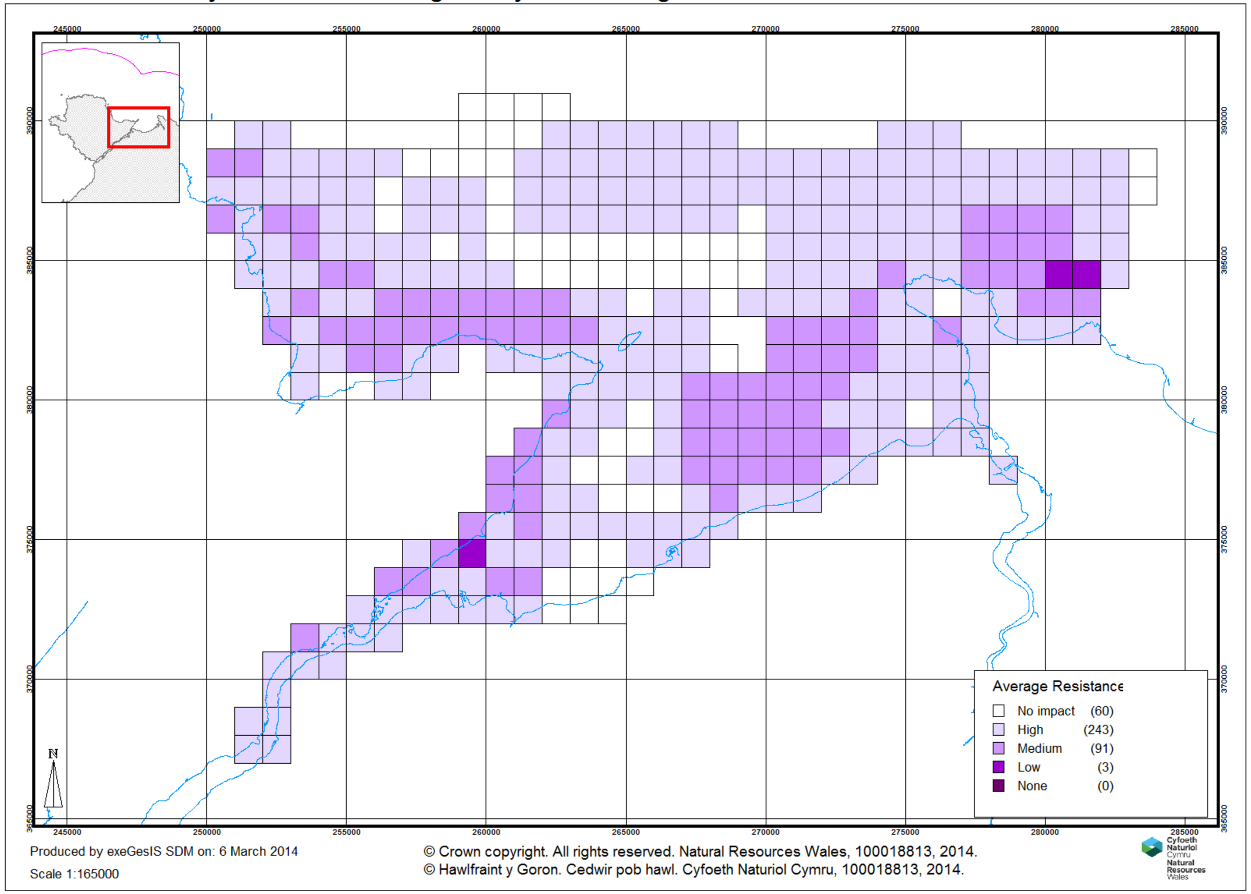

Figure 5 - Map showing average resistance for areas affected by activity within each grid square

Figure 6 shows the weighted average resistance value for each grid square. The weighted average resistance is calculated as a proportional average between the average resistance of areas affected by activity and the resistance i.e. 1 of areas where no activity occurs. This method is therefore the best overview in terms of representing average resistance for the seabed as a whole.

Habitat Sensitivity to Combined Fishing Activity Pilot - Weighted Average Resistance

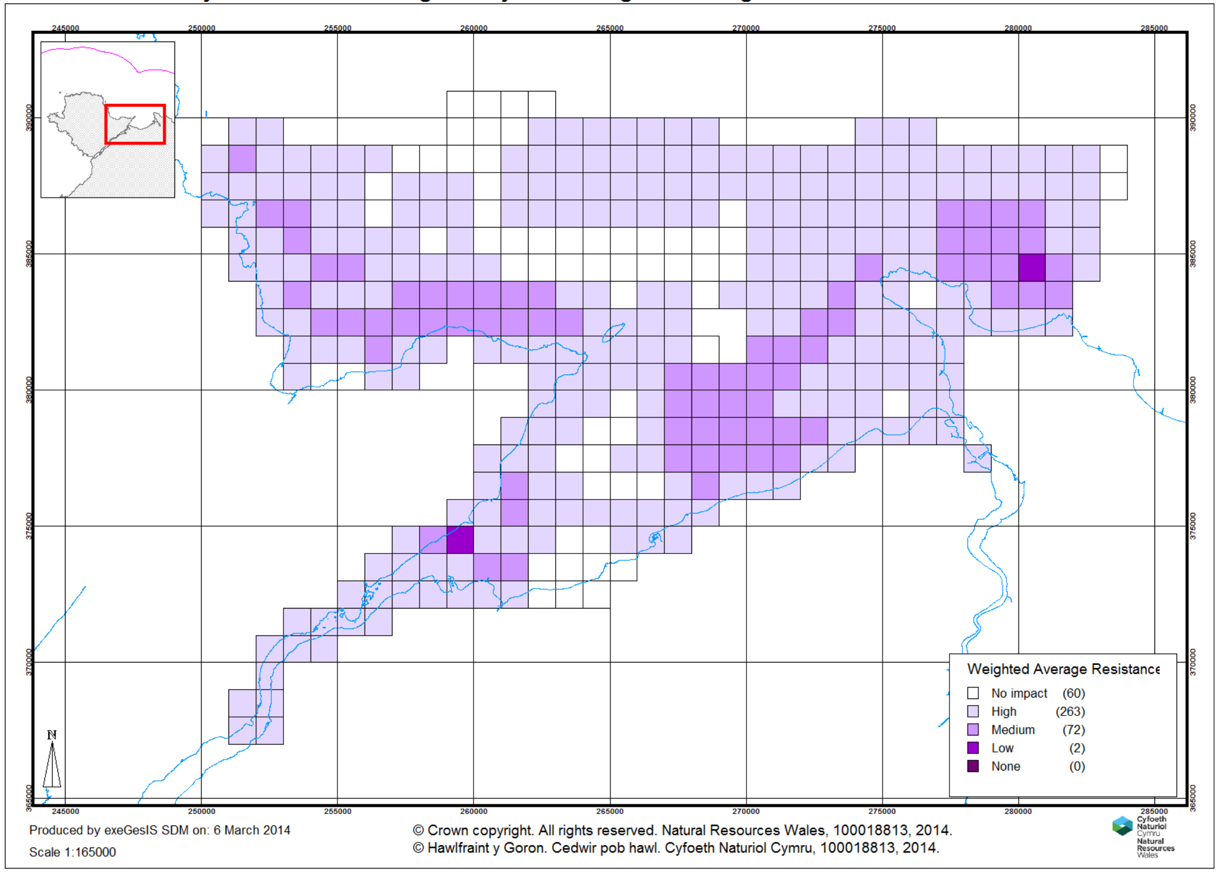

Figure 6 - Map showing weighted average resistance for areas affected by activity within each grid square

6. Discussion

6.1. Issues with the methodology

6.1.1. Fitting curves to minimal data

For each of the graphs only 4 data points were available representing the habitat resistance to no activity and heavy, moderate and light intensity activity.

This is the minimum number of data points to which the majority of curves can be fitted and represents noiseless data therefore most equations tested were an exact fit to the data i.e. R-squared = 1.

Additional data should be collected via field survey to quantify the habitat impact of different activity footprints. This would require survey points, and possible samples, to be taken where particular habitats intersect activities with a known footprint from the FishMap Môn data. The reduction in resistance for each survey point could be added to the analysis and would provide the basis for determining which of the possible curves most accurately represented the actual habitat response to increased activity.

6.1.2. Fitting curves to HHM or MML data for gears 8-11

Some of the best fit curves for gears 8 – 11 were not a good fit for the data. This occurred where the habitat has a resistance pattern of HHM or MML due to a minor change in footprint resulting in a change in resistance as shown in Figure 7 and Figure 8.

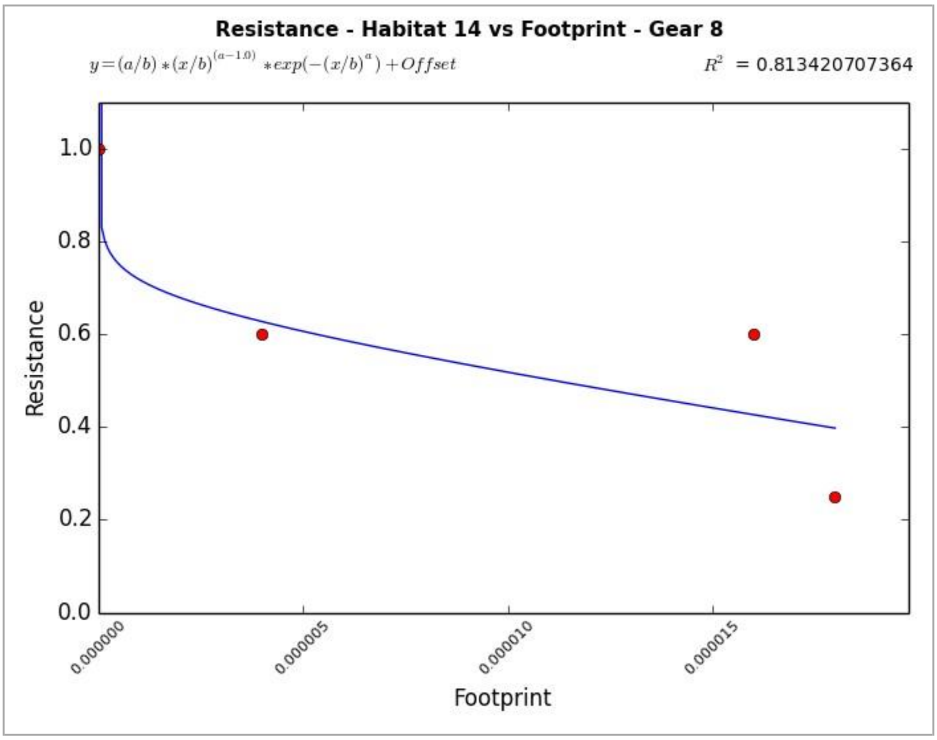

Figure 7 - Example of Weibull PDF sigmoidal curve for MML pattern data for gear 8 (nets)

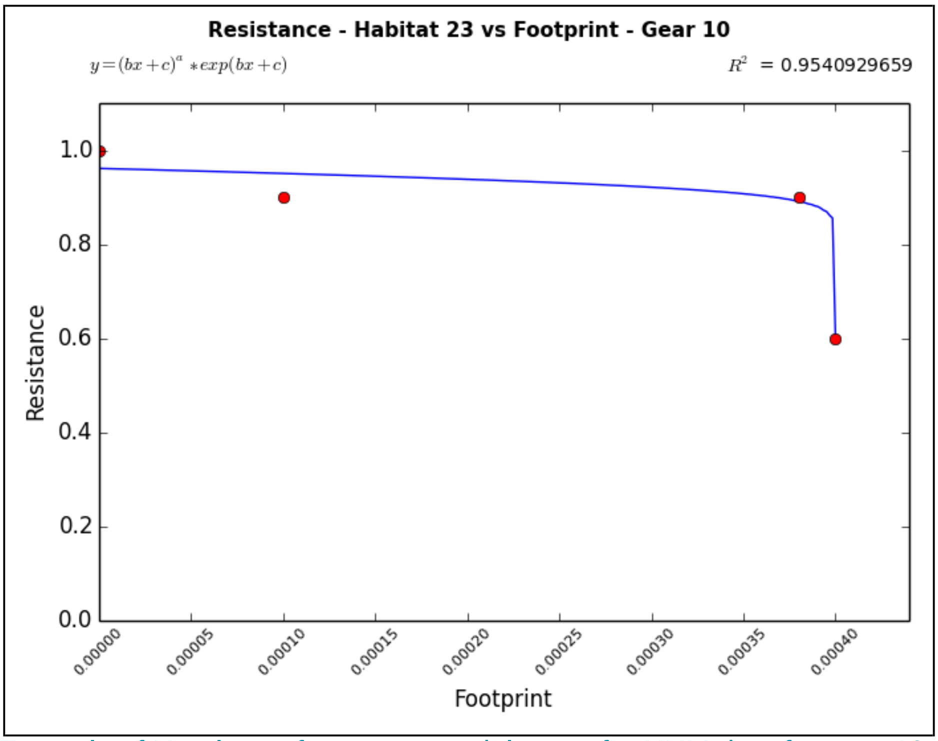

Figure 8 - Example of Hoerl transform exponential curve for HHM data for gear 10 (rod & line)

None of the equations tested were a good fit for this scenario. An alternative approach which would provide the best fit for this data would be to calculate a curve for each section of the graph. The example shown in Figure 9 uses multiple exponential curves.

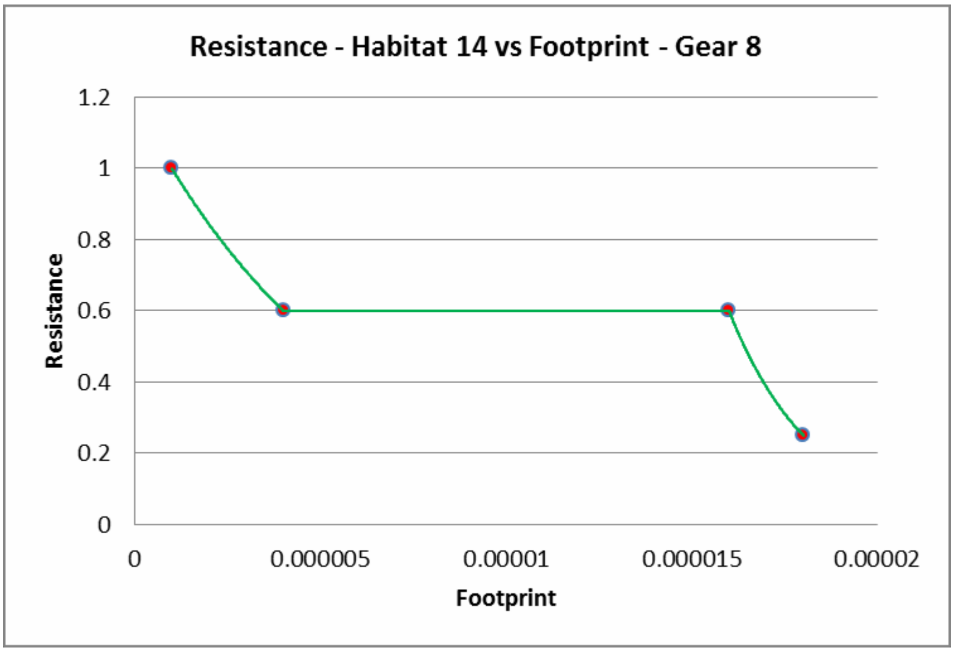

Figure 9 - Example of multiple curves for MML data for gear 8 (nets)

This approach would require additional logic in the code to determine whether the footprint value would be categorised as Light, Moderate or Heavy; and therefore apply the appropriate equation for each section of the graph.

6.2. Potential improvements to the methodology

The methodology chosen for modelling the cumulative impact of fishing activities could be improved. Two possible methods for improving the model were discussed at the interim meeting as outlined below.

6.2.1. Iteratively calculating reduction in resistance

For the majority of habitats, resistance to fishing activity tends to a greater initial reduction in response to fishing activity, followed by more moderate reduction. This varies depending on the habitat as identified in previous work (Hall et al., 2008 & Eno et al. 2013).

The methodology could therefore be improved by iteratively calculating the reduction in resistance. The impact for each activity which occurs within the polygon could be calculated.
The fishing activities could then be ordered in terms of impact on the habitat. This could be either from least impact to greatest impact or vice-versa.

Ordering from least impact to greatest impact is more likely to ensure that the cumulative impact of all fishing activities is considered, whilst ordering from greatest impact to least impact will ensure that the impact of the most damaging activity is not underestimated. Both approaches could be valid and should therefore be tested to determine the optimum approach.

The process used to calculate the cumulative reduction in resistance is shown in Figure 10.

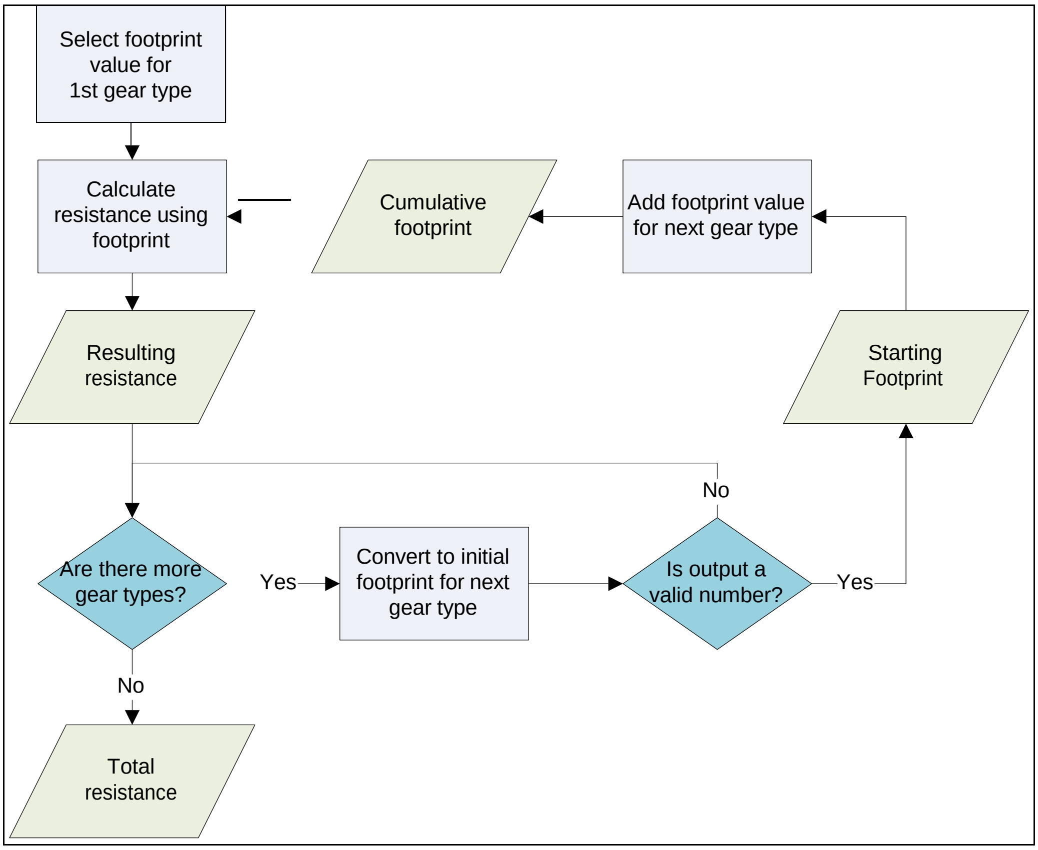

Figure 10 - Flowchart showing how resistance would be calculated using an iterative process

An iterative process uses the resulting resistance from each stage to calculate the cumulative footprint for the next gear type as the combination of previous impacts plus the additional footprint for each gear.

In order to calculate the cumulative footprint, the resulting resistance must be converted to a footprint value for the current gear type. It therefore requires the equation used to describe relationship between footprint and resistance to be inverted. For the majority of equations used for this project, an inverse equation can be derived. The exception is the double exponential equation which does not have a mathematical inverse. It would therefore be necessary to find an alternative equation for the habitat / sub-gear combinations where the double exponential was the best fit.

Due to the differences in how the habitat responds to each gear, the inverse equation may return a value which is not a number for the specified resistance value. This would occur where the cumulative resistance to preceding fishing activity is already below the curve for the graph.
For example, if resistance was 0.72 but the resistance response for the next gear was HHH, it would be impossible to predict a footprint. In this instance, it would be assumed that since resistance was already below the minimum value for the curve that the additional activity would have no additional impact on the habitat, therefore this gear type would be skipped.

6.2.2. Standardising for gear types with similar footprints

Standardisation could be applied to gear types which have the same habitat response and use the same frequency distribution to define intensity but differ in the size of the daily footprint.

For example, all forms of trawling (gear types 1c, 2, 4, 5a and 5b) have an intensity pattern of 12, 48 and 180 days per year but different footprints.

The data for different forms of trawling could therefore be standardised by dividing by the daily footprint and added together to give a total number of days. A curve could therefore be generated for resistance versus number of days and used to calculate reduction in resistance for total number of days trawling.

6.3. Recommendations for future work

In order to permit the assessment of the cumulative impacts of fishing activity additional data must be collected on the impacts of individual fishing activities and areas where multiple fishing activities occur in order to expand the available knowledge on how different fishing types which occur in the same location interact.

In many complex systems, synergy will cause the cumulative effects to either be diminished or exaggerated. Synergy could exist between fishing activities due to the differing gear types used which affect the seabed in a variety of ways. This would affect the theoretical model which would need to be applied to assess the cumulative effects of new fishing activities in a particular area.

Additional data would potentially allow a multivariate statistical analysis of the interaction between different gear types which could identify synergies and allow a suitable modelling approach to be developed.

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  - Kirsty Lindenbaum
  - Bryn Jones
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9. Appendices

9.1. Resistance Matrix for FishMap Môn – July 2013

The following abbreviations have been used in the table:

- Resilience: H – High, M – Medium, L – Low
- Resistance: H – High, M – Medium, L – Low, N – None
- Confidence: H – High, M – Moderate, L – Low

Sensitivity and confidence are also shown by colour:

Sensitivity:

Intensity	Sensitivity
1. Low	
2. Medium	
3. High	

Confidence:

Confidence	Colour
1. Low	
2. Moderate	
3. High	

		1a King Scallops				1b Queen Scallops			
		Intensity				Intensity			
Habitat	**Resilience (recover-ability)**	Level 1	Level 2	Level 3	Confidence assessment	Level 1	Level 2	Level 3	Confidence assessment
1. Up. shore stable rock-lichens + algal crusts	**L**								
2. Wave exposed intertidal stable rock	**M**								
3. Mod. wave exposed intertidal rock	**M**								
4. Seaweeds+mussels on mod. exposed rock	**M**								
5. Mussels + Piddocks on intertidal clay + peat	**L**	L	N	N	H	L	N	N	H
6. Honeycomb worm reefs	**L**	N	N	N	H	N	N	N	H
7. Sheltered bedrock boulders + cobbles	**L**				H				H
8. Rockpools and overhangs	**M**								
9. Brown seaweeds, barnacles +fucoids	**M**								
10. Muddy sands - excl. gaper clams	**M**	M	M	L	H	M	M	L	H
11. Muds + sands - incl. gaper clams	**L**	N	N	N	H	N	N	N	H
12. Intertidal muds	**M**	M	M	L	H	M	M	L	H
13. Salt marshes	**L**								
14. Vertical rock with associated spp.	**L**								
15. Erect+branching spp very slow growing	**N**								
16. Sand+gravel with long lived bivalves	**L**	L	L	N	H	L	L	N	H
17. Maerl beds	**N**	L	L	N	H	L	L	N	H
18. Stable subtidal fine sands	**L**	M	M	L	H	M	M	L	H
19. Stable muddy sands sandy muds + muds	**L**	M	L	L	H	M	L	L	H
20. Rock with low-lying fast growing faunal turf	**M**								
21. Rock with erect + branching spp	**M**								
22. Shallow subtidal rock with kelp	**M**								
23. Kelp+ seaweeds on sand scoured rock	**M**	L	L	N	H	L	L	N	H
24. Dynamic, shallow water fine sands	**M**	H	M	M	H	H	M	M	H
25. Oyster beds	**N**	N	N	N	H	N	N	N	H
26. Under-boulder+cobb. shallow subtidal comm.	**L**								
27. Biogenic reef on sediment	**L**								
28. Stable spp. Rich mixed sediments	**M**	L	N	N	H	L	N	N	H
29. Unstable coarse sediments - robust fauna	**H**	H	H	M	H	H	H	M	H
30. Seagrass beds	**L**	L	N	N	H	L	N	N	H
31. Stable but tide swept cobbles, pebbles + gravel	**M**	M	L	N	H	M	L	N	H

		1c Beam Trawls				2 Rock Hopper			
		Intensity				**Intensity**			
Habitat	**Resilience (recover-ability)**	Level 1	Level 2	Level 3	Confidence assessment	Level 1	Level 2	Level 3	Confidence assessment
1. Up. shore stable rock-lichens + algal crusts	**L**								
2. Wave exposed intertidal stable rock	**M**								
3. Mod. wave exposed intertidal rock	**M**								
4. Seaweeds+mussels on mod. exposed rock	**M**								
5. Mussels + Piddocks on intertidal clay + peat	**L**	M	L	N	H				
6. Honeycomb worm reefs	**L**	N	N	N	H	N	N	N	M
7. Sheltered bedrock boulders + cobbles	**L**				H				
8. Rockpools and overhangs	**M**								
9. Brown seaweeds, barnacles +fucoids	**M**								
10. Muddy sands - excl. gaper clams	**M**	M	M	L	H				
11. Muds + sands - incl. gaper clams	**L**	N	N	N	H				
12. Intertidal muds	**M**	M	M	L	H				
13. Salt marshes	**L**								
14. Vertical rock with associated spp.	**L**								
15. Erect+branching spp very slowgrowing	**N**					L	L	L	M
16. Sand+gravel with long lived bivalves	**L**	L	L	N	H	L	L	L	M
17. Maerl beds	**N**	L	L	N	H	L	L	L	M
18. Stable subtidal fine sands	**L**	M	M	L	H				
19. Stable muddy sands sandy muds + muds	**L**	M	L	L	H				
20. Rock with low-lying fast growing faunal turf	**M**					M	L	L	M
21. Rock with erect + branching spp	**M**					L	L	L	M
22. Shallow subtidal rock with kelp	**M**					M	L	L	M
23. Kelp+ seaweeds on sand scoured rock	**M**	L	L	N	H	M	L	L	M
24. Dynamic, shallow water fine sands	**M**	H	M	M	H				
25. Oyster beds	**N**	N	N	N	H				
26. Under-boulder+cobb. shallow subtidal comm.	**L**					L	L	L	M
27. Biogenic reef on sediment	**L**	L	L	L	H	L	L	L	M
28. Stable spp. Rich mixed sediments	**M**	L	L	N	H	L	L	L	M
29. Unstable coarse sediments - robust fauna	**H**	H	H	H	H	H	H	H	M
30. Seagrass beds	**L**	L	L	N	H				M
31. Stable but tide swept cobbles, pebbles + gravel	**M**	H	M	L	H	M	L	L	M

Habitat	Resilience (recover-ability)	(3) Oyster/Mussel dredging and Prospecting: Intensity Level 1	Level 2	Level 3	Confidence assessment	4 Demersal Trawls: Intensity Level 1	Level 2	Level 3	Confidence assessment
1. Up. shore stable rock-lichens + algal crusts	L								
2. Wave exposed intertidal stable rock	M								
3. Mod. wave exposed intertidal rock	M								
4. Seaweeds+mussels on mod. exposed rock	M								
5. Mussels + Piddocks on intertidal clay + peat	L	N	N	N	L				
6. Honeycomb worm reefs	L	N	N	N	L				
7. Sheltered bedrock boulders + cobbles	L				L				
8. Rockpools and overhangs	M								
9. Brown seaweeds, barnacles +fucoids	M								
10. Muddy sands - excl. gaper clams	M	M	M	L	L	H	M	L	H
11. Muds + sands - incl. gaper clams	L	N	N	N	L	H	M	L	H
12. Intertidal muds	M	M	M	L	L	H	M	L	H
13. Salt marshes	L								
14. Vertical rock with associated spp.	L								
15. Erect+branching spp very slowgrowing	N	L	L	L	L				
16. Sand+gravel with long lived bivalves	L	M	L	L	L	M	L	L	H
17. Maerl beds	N	L	L	L	L	L	L	L	H
18. Stable subtidal fine sands	L	M	M	L	L	H	M	M	H
19. Stable muddy sands sandy muds + muds	L	M	M	L	L	M	L	L	H
20. Rock with low-lying fast growing faunal turf	M	L	L	L	L				
21. Rock with erect + branching spp	M	L	L	L	L				
22. Shallow subtidal rock with kelp	M				L				
23. Kelp+ seaweeds on sand scoured rock	M	L	L	L	L	L	L	L	H
24. Dynamic, shallow water fine sands	M	H	H	H	L	H	M	M	H
25. Oyster beds	N	N	N	N	L	L	L	L	H
26. Under-boulder+cobb. shallow subtidal comm.	L				L				H
27. Biogenic reef on sediment	L	L	L	L	L	L	L	L	H
28. Stable spp. Rich mixed sediments	M	L	L	L	L	L	L	L	H
29. Unstable coarse sediments - robust fauna	H	H	H	H	L	H	H	H	H
30. Seagrass beds	L	L	L	L	L	L	L	L	H
31. Stable but tide swept cobbles, pebbles + gravel	M	M	L	L	L	H	M	M	H

		(5a) Light demersal trawls and seines				(5b) Light Beam Trawls			
		Intensity				Intensity			
Habitat	**Resilience (recover-ability)**	Level 1	Level 2	Level 3	Confidence assessment	Level 1	Level 2	Level 3	Confidence assessment
1. Up. shore stable rock-lichens + algal crusts	**L**								
2. Wave exposed intertidal stable rock	**M**								
3. Mod. wave exposed intertidal rock	**M**								
4. Seaweeds+mussels on mod. exposed rock	**M**								
5. Mussels + Piddocks on intertidal clay + peat	**L**								
6. Honeycomb worm reefs	**L**	M	M	M	H	M	M	M	H
7. Sheltered bedrock boulders + cobbles	**L**								
8. Rockpools and overhangs	**M**								
9. Brown seaweeds, barnacles +fucoids	**M**								
10. Muddy sands - excl. gaper clams	**M**	M	M	M	H	M	M	M	H
11. Muds + sands - incl. gaper clams	**L**	M	M	M	H	M	M	M	H
12. Intertidal muds	**M**	H	H	H	H	H	H	H	H
13. Salt marshes	**L**								
14. Vertical rock with associated spp.	**L**								
15. Erect+branching spp very slowgrowing	**N**								
16. Sand+gravel with long lived bivalves	**L**	M	M	M	H	H	M	L	H
17. Maerl beds	**N**	L	L	L	H	L	L	L	H
18. Stable subtidal fine sands	**L**	M	M	M	H	H	H	M	H
19. Stable muddy sands sandy muds + muds	**L**	H	H	M	H	H	H	M	H
20. Rock with low-lying fast growing faunal turf	**M**								
21. Rock with erect + branching spp	**M**								
22. Shallow subtidal rock with kelp	**M**								
23. Kelp+ seaweeds on sand scoured rock	**M**	M	L	L	H	M	L	L	H
24. Dynamic, shallow water fine sands	**M**	H	H	M	H	H	H	M	H
25. Oyster beds	**N**	L	L	L	H	N	N	N	H
26. Under-boulder+cobb. shallow subtidal comm.	**L**				H				H
27. Biogenic reef on sediment	**L**	L	L	L	H	L	L	L	H
28. Stable spp. Rich mixed sediments	**M**	M	M	L	H	M	M	L	H
29. Unstable coarse sediments - robust fauna	**H**	H	H	H	H	H	H	H	H
30. Seagrass beds	**L**	L	L	L	H	L	L	L	H
31. Stable but tide swept cobbles, pebbles + gravel	**M**	H	H	M	H	H	M	M	H

		(6) Hydraulic suction dredges				(8) Static gear- nets and long lines			
		Intensity				**Intensity**			
Habitat	**Resilience (recover-ability)**	Level 1	Level 2	Level 3	Confidence assessment	Level 1	Level 2	Level 3	Confidence assessment
1. Up. shore stable rock-lichens + algal crusts	**L**								
2. Wave exposed intertidal stable rock	**M**								
3. Mod. wave exposed intertidal rock	**M**								
4. Seaweeds+mussels on mod. exposed rock	**M**								
5. Mussels + Piddocks on intertidal clay + peat	**L**					H	H	H	M
6. Honeycomb worm reefs	**L**					H	H	M	M
7. Sheltered bedrock boulders + cobbles	**L**								
8. Rockpools and overhangs	**M**								
9. Brown seaweeds, barnacles +fucoids	**M**					H	H	H	M
10. Muddy sands - excl. gaper clams	**M**					H	H	H	M
11. Muds + sands - incl. gaper clams	**L**					H	H	H	M
12. Intertidal muds	**M**					H	H	H	M
13. Salt marshes	**L**					H	H	H	M
14. Vertical rock with associated spp.	**L**					M	M	L	M
15. Erect+branching spp very slowgrowing	**N**					L	L	L	M
16. Sand+gravel with long lived bivalves	**L**	H	M	L	H	H	H	H	M
17. Maerl beds	**N**	L	L	L	H	H	M	M	M
18. Stable subtidal fine sands	**L**	H	H	M	H	H	H	H	M
19. Stable muddy sands sandy muds + muds	**L**	H	H	M	H	H	H	H	M
20. Rock with low-lying fast growing faunal turf	**M**					H	M	M	M
21. Rock with erect + branching spp	**M**					L	L	L	M
22. Shallow subtidal rock with kelp	**M**					H	H	M	M
23. Kelp+ seaweeds on sand scoured rock	**M**	M	L	L	H	H	H	M	M
24. Dynamic, shallow water fine sands	**M**	H	H	M	H	H	H	H	M
25. Oyster beds	**N**	N	N	N	H	H	H	H	M
26. Under-boulder+cobb. shallow subtidal comm.	**L**					H	H	H	M
27. Biogenic reef on sediment	**L**					H	H	H	M
28. Stable spp. Rich mixed sediments	**M**	M	L	L	H	H	H	H	M
29. Unstable coarse sediments - robust fauna	**H**					H	H	H	M
30. Seagrass beds	**L**	L	L	L	H	M	L	L	M
31. Stable but tide swept cobbles, pebbles + gravel	**M**	H	M	M	H	H	H	H	M

Habitat	Resilience (recover-ability)	(9) Static gear -pots Intensity Level 1	Level 2	Level 3	Confidence assessment	(10) Rod and line hand-fishing Intensity Level 1	Level 2	Level 3	Confidence assessment
1. Up. shore stable rock-lichens + algal crusts	**L**								
2. Wave exposed intertidal stable rock	**M**								
3. Mod. wave exposed intertidal rock	**M**								
4. Seaweeds+mussels on mod. exposed rock	**M**					H	H	M	L
5. Mussels + Piddocks on intertidal clay + peat	**L**					H	H	M	L
6. Honeycomb worm reefs	**L**	M	M	M	M	H	H	H	L
7. Sheltered bedrock boulders + cobbles	**L**					H	H	H	L
8. Rockpools and overhangs	**M**					H	H	H	L
9. Brown seaweeds, barnacles +fucoids	**M**	H	H	H	M	H	H	H	L
10. Muddy sands - excl. gaper clams	**M**					H	H	H	L
11. Muds + sands - incl. gaper clams	**L**					H	H	H	L
12. Intertidal muds	**M**					H	H	H	L
13. Salt marshes	**L**								
14. Vertical rock with associated spp.	**L**	M	L	L	M	H	M	L	H
15. Erect+branching spp very slowgrowing	**N**	H	M	M	M	H	M	L	H
16. Sand+gravel with long lived bivalves	**L**	H	H	H	M	H	H	H	L
17. Maerl beds	**N**	H	M	L	H	H	H	M	L
18. Stable subtidal fine sands	**L**	H	H	H	M	H	H	H	L
19. Stable muddy sands sandy muds + muds	**L**	H	H	H	M	H	H	H	L
20. Rock with low-lying fast growing faunal turf	**M**	H	H	M	H	H	H	M	L
21. Rock with erect + branching spp	**M**	H	M	M	H	H	M	L	H
22. Shallow subtidal rock with kelp	**M**	H	H	M	H	H	M	L	H
23. Kelp+ seaweeds on sand scoured rock	**M**	H	H	H	H	H	H	M	M
24. Dynamic, shallow water fine sands	**M**	H	H	H	M	H	H	H	L
25. Oyster beds	**N**	H	H	M	M	H	H	H	L
26. Under-boulder+cobb. shallow subtidal comm.	**L**	H	H	M	M	H	H	M	L
27. Biogenic reef on sediment	**L**	H	H	M	M	H	H	M	L
28. Stable spp. Rich mixed sediments	**M**	H	H	M	M	H	H	H	L
29. Unstable coarse sediments - robust fauna	**H**	H	H	H	M	H	H	H	L
30. Seagrass beds	**L**	M	M	L	M	H	H	M	L
31. Stable but tide swept cobbles, pebbles + gravel	**M**	H	H	H	M	H	H	H	L

Habitat	Resilience (recover-ability)	(11) Casual hand gathering				(12) Professional hand gathering			
		Intensity				Intensity			
		Level 1	Level 2	Level 3	Confidence assessment	Level 1	Level 2	Level 3	Confidence assessment
1. Up. shore stable rock-lichens + algal crusts	**L**								
2. Wave exposed intertidal stable rock	**M**	H	M	M	L	H	M	L	L
3. Mod. wave exposed intertidal rock	**M**	H	M	M	H	H	M	L	H
4. Seaweeds+mussels on mod. exposed rock	**M**	H	M	M	H	H	M	L	H
5. Mussels + Piddocks on intertidal clay + peat	**L**	H	M	M	L	H	M	L	L
6. Honeycomb worm reefs	**L**	M	L	L	L	M	L	L	L
7. Sheltered bedrock boulders + cobbles	**L**	M	M	M	H	M	M	M	H
8. Rockpools and overhangs	**M**	H	M	M	H	H	M	M	H
9. Brown seaweeds, barnacles +fucoids	**M**	H	M	L	H	M	L	L	H
10. Muddy sands - excl. gaper clams	**M**	H	H	M	H	H	M	L	H
11. Muds + sands - incl. gaper clams	**L**	H	M	L	H	M	L	L	H
12. Intertidal muds	**M**	H	M	L	H	M	L	L	H
13. Salt marshes	**L**	H	H	H	H	M	L	L	H
14. Vertical rock with associated spp.	**L**								
15. Erect+branching spp very slowgrowing	**N**								
16. Sand+gravel with long lived bivalves	**L**								
17. Maerl beds	**N**								
18. Stable subtidal fine sands	**L**								
19. Stable muddy sands sandy muds + muds	**L**								
20. Rock with low-lying fast growing faunal turf	**M**								
21. Rock with erect + branching spp	**M**								
22. Shallow subtidal rock with kelp	**M**								
23. Kelp+ seaweeds on sand scoured rock	**M**								
24. Dynamic, shallow water fine sands	**M**								
25. Oyster beds	**N**								
26. Under-boulder+cobb. shallow subtidal comm.	**L**	H	H	M	M	H	M	L	M
27. Biogenic reef on sediment	**L**	H	H	M	M	H	M	L	M
28. Stable spp. Rich mixed sediments	**M**	H	M	L	M	H	L	L	M
29. Unstable coarse sediments - robust fauna	**H**	H	H	H	M	H	H	H	M
30. Seagrass beds	**L**	H	H	M	M	L	L	L	M
31. Stable but tide swept cobbles, pebbles + gravel	**M**								

Habitat	Resilience (recover-ability)	(13) Aquaculture- trestles, ground lays+ traps				(14) Aquaculture- cages + rope cultivation			
		Intensity				Intensity			
		Level 1	Level 2	Level 3	Confidence assessment	Level 1	Level 2	Level 3	Confidence assessment
1. Up. shore stable rock-lichens + algal crusts	**L**								
2. Wave exposed intertidal stable rock	**M**								
3. Mod. wave exposed intertidal rock	**M**								
4. Seaweeds+mussels on mod. exposed rock	**M**								
5. Mussels + Piddocks on intertidal clay + peat	**L**	H	H	M	M				
6. Honeycomb worm reefs	**L**	M	L	L	M	M	M	L	L
7. Sheltered bedrock boulders + cobbles	**L**	M	M	M	M				
8. Rockpools and overhangs	**M**								
9. Brown seaweeds, barnacles +fucoids	**M**	M	N	N	M				
10. Muddy sands - excl. gaper clams	**M**	M	M	M	M				
11. Muds + sands - incl. gaper clams	**L**	M	M	M	M				
12. Intertidal muds	**M**	M	M	M	M				
13. Salt marshes	**L**								
14. Vertical rock with associated spp.	**L**					H	H	H	
15. Erect+branching spp very slowgrowing	**N**					M	M	L	L
16. Sand+gravel with long lived bivalves	**L**	H	M	L	M	M	M	L	H
17. Maerl beds	**N**				M	M	M	L	H
18. Stable subtidal fine sands	**L**	H	M	L	M	M	M	L	H
19. Stable muddy sands sandy muds + muds	**L**	H	M	L	M	M	M	L	H
20. Rock with low-lying fast growing faunal turf	**M**					M	M	L	H
21. Rock with erect + branching spp	**M**					M	M	L	H
22. Shallow subtidal rock with kelp	**M**								
23. Kelp+ seaweeds on sand scoured rock	**M**					M	M	L	H
24. Dynamic, shallow water fine sands	**M**	H	H	M	M	M	M	L	H
25. Oyster beds	**N**								
26. Under-boulder+cobb. shallow subtidal comm.	**L**								
27. Biogenic reef on sediment	**L**	M	L	L	M	M	M	L	
28. Stable spp. Rich mixed sediments	**M**	H	M	L	M	M	M	L	H
29. Unstable coarse sediments - robust fauna	**H**	M	M	L	M	L	L	L	H
30. Seagrass beds	**L**	M	M	L	M	M	M	L	
31. Stable but tide swept cobbles, pebbles + gravel	**M**	H	H	M	M	H	H	M	H

		(15a) Foot Access			(15b) Vehicular Access		
		Intensity			Intensity		
Habitat	**Resilience (recover-ability)**	Level 1	Level 2	Level 3	Level 1	Level 2	Level 3
1. Up. shore stable rock-lichens + algal crusts	**L**	M	L	L			
2. Wave exposed intertidal stable rock	**M**	M	M	L			
3. Mod. wave exposed intertidal rock	**M**	M	L	L			
4. Seaweeds+mussels on mod. exposed rock	**M**	M	L	L	M	L	L
5. Mussels + Piddocks on intertidal clay + peat	**L**	M	M	M	M	N	N
6. Honeycomb worm reefs	**L**	M	M	L	M	N	N
7. Sheltered bedrock boulders + cobbles	**L**	M	M	L	M	L	L
8. Rockpools and overhangs	**M**	M	M	M			
9. Brown seaweeds, barnacles +fucoids	**M**	M	M	M	M	M	L
10. Muddy sands - excl. gaper clams	**M**	M	M	L	M	L	L
11. Muds + sands - incl. gaper clams	**L**	M	M	L	M	L	L
12. Intertidal muds	**M**	M	M	L	M	L	L
13. Salt marshes	**L**	M	M	M	L	L	L
14. Vertical rock with associated spp.	**L**						
15. Erect+branching spp very slowgrowing	**N**						
16. Sand+gravel with long lived bivalves	**L**						
17. Maerl beds	**N**						
18. Stable subtidal fine sands	**L**	H	H	H	H	H	H
19. Stable muddy sands sandy muds + muds	**L**	H	H	H	M	M	M
20. Rock with low-lying fast growing faunal turf	**M**	H	H	H			
21. Rock with erect + branching spp	**M**	M	M	M	L	L	L
22. Shallow subtidal rock with kelp	**M**	M	M	M			
23. Kelp+ seaweeds on sand scoured rock	**M**	H	H	H			
24. Dynamic, shallow water fine sands	**M**	H	H	H			
25. Oyster beds	**N**	M	L	L	N	N	N
26. Under-boulder+cobb. shallow subtidal comm.	**L**	M	M	M	M	L	L
27. Biogenic reef on sediment	**L**	M	M	M	M	L	L
28. Stable spp. Rich mixed sediments	**M**	M	L	L	L	L	L
29. Unstable coarse sediments - robust fauna	**H**	H	H	H	H	H	H
30. Seagrass beds	**L**	M	M	L	L	L	L
31. Stable but tide swept cobbles, pebbles + gravel	**M**						

9.2. FishMap Môn Project Fishing Intensity Definitions

The intensity definitions for the FishMap Môn project were based upon Hall et al. (2008) and Tyler-Walters and Arnold (2008).

9.2.1. Fishing Activities (Gear Types)

Type	Description
1	Beam trawls and scallop dredging
2	Rockhopper trawls
3	Oyster/mussel dredging and prospecting (several orders excluded)
4	Demersal trawls
5	Light demersal trawls and seines
6	Hydraulic suction dredges
7	Pelagic trawls, drift nets and hook and line fishing (with no seabed contact)
8	Static gear – nets and long lines
9	Static gear - pots
10	Rod-and-line fishing
11	Hand gathering, casual
12	Hand gathering, professional
13	Aquaculture and intertidal traps
14	Aquaculture cage and rope cultivation
15a	Access to and across the foreshore/intertidal - foot access
15b	Access to and across the foreshore/intertidal - vehicle access

9.2.2. Gear Type 1 a, b and c

TYPE	GEAR	NO DREDGES OR BEAMS	GEAR WIDTH (m)	TOTAL GEAR WIDTH (m)	SPEED (knots)	SPEED (km/h)	TOTAL TIME/DAY GEAR IN CONTACT WITH SEA BOTTOM (h)	DAILY FOOTPRINT (km^2) No overlap assumed a priori among tows
1a	Scallop (kings)	10	0.85	8.5	3	5.55	15	0.71
1b	Scallop (queens)	16	0.76	12.2	3	5.55	9	0.61
1c	Beam trawling	2 beams	6	12	3	5.55	12 (6 tows*2hrs)	0.80

TYPE	GEAR	SEASON (months)	INTENSITY LEVELS OF FISHING ACTIVITY (vessel-days per year)		
			Level 1	Level 2	Level 3
1a	Scallop (kings)	6	6 - 12	24 - 48	90
1b	Scallop (queens)	12	12 - 24	48 – 96	365
1c	Beam trawling	4	6 - 12	24 - 48	180

N.B Level 3 intensity for king scallop dredging has been changed from 5.9 to 3
Levels 1x and 2x represent the intensities between the ranges for which sensitivity assessments were undertaken.

TYPE	GEAR	DAILY FOOTPRINT, km^2	SEASON (months)	INTENSITY LEVELS OF FISHING ACTIVITY (footprint in km^2 over a year per km^2, based on number of vessel-days in a 2.5 nm by 2.5 nm area and reference daily footprint)				
				Level 1	Level 1 x	Level 2	Level 2 x	Level 3
1a	Scallop dredging (kings)	0.71	6	0.20 – 0.40	0.4 - 0.8	0.80 – 1.6	1.6 – 3.0	3.0
1b	Scallop dredging (queens)	0.61	12	0.35 – 0.70	0.7 – 1.35	1.35 – 2.7	2.7 – 10.2	10.2
1c	Beam trawling	0.80	12	0.22 – 0.45	0.45 – 0.89	0.89 – 1.78	1.78 – 6.69	6.69

9.2.3. Gear Type 2 - Rockhopper Trawls

TYPE	GEAR	NO DREDGES OR BEAMS	GEAR WIDTH (m)	TOTAL GEAR WIDTH (m)	SPEED (knots)	SPEED (km/h)	TOTAL TIME/DAY GEAR IN CONTACT WITH SEA BOTTOM (h)	DAILY FOOTPRINT (km^2) No overlap assumed a priori among tows
2	ROCK-HOPPER TRAWLS	TWIN RIG	50	100	2.8	5.18	20	10.36

SEASON (months)	INTENSITY LEVELS OF FISHING ACTIVITY Number of Days		
	Level 1	Level 2	Level 3
6	6 - 12	24 – 48	180

TYPE	GEAR	DAILY FOOTPRINT, km^2	SEASON (months)	INTENSITY LEVELS OF FISHING ACTIVITY (footprint in km^2 over a year per km^2, based on number of vessel-days in a 2.5 nm by 2.5 nm area and reference daily footprint)				
				Level 1	Level 1 x	Level 2	Level 2 x	Level 3
2	ROCKHOPPER TRAWLS	10.36	6	0.30 – 0.60	0.6 – 1.25	1.25 – 2.5	2.5 – 9.3	9.3

9.2.4. Gear Type 3 – Mussel Seed Dredging

TYPE	GEAR	NO DREDGES or BEAMS	GEAR WIDTH (m)	TOTAL GEAR WIDTH (m)	SPEED (knots)	SPEED (km/h)	TOTAL TIME/DAY GEAR IN CONTACT WITH SEA BOTTOM (h)	DAILY FOOTPRINT (km^2) No overlap assumed a priori among tows
3	Mussel dredging (not applicable to oyster dredging)	4	3	12	3	5.55	2.5	0.17

SEASON (months)	INTENSITY LEVELS OF FISHING ACTIVITY Number of Days		
	Level 1	Level 2	Level 3
3	3 - 6	12 - 24	90

N.B. Blue represents the revised $5km^2$ reference area. The old reference area was $21.5km^2$.

TYPE	GEAR	DAILY FOOTPRINT, km^2	SEASON (months)	INTENSITY LEVELS OF FISHING ACTIVITY (footprint in km^2 over a year per km^2, based on number of vessel-days in a 5km² area and reference daily footprint)				
				Level 1	Level 1 x	Level 2	Level 2 x	Level 3
3	Mussel seed 21.5km² ref	0.17	3	0.02 – 0.05	0.05 – 0.10	0.10 – 0.20	0.2 – 0.7	> 0.70
3	Mussel seed 5km² ref	0.17	3	0.1 – 0.2	0.2 – 0.4	0.4 – 0.8	0.8 – 3	> 3

9.2.5. Gear Type 4 - Otter Trawling

TYPE	GEAR	NO DREDGES or BEAMS	GEAR WIDTH (m)	TOTAL GEAR WIDTH (m)	SPEED (knots)	SPEED (km/h)	TOTAL TIME/DAY GEAR IN CONTACT WITH SEA BOTTOM (h)	DAILY FOOTPRINT (km^2) No overlap assumed a priori among tows
4	Otter trawling	Twin rig	50	100	2.8	5.18	20	10.36

SEASON (months)	INTENSITY LEVELS OF FISHING ACTIVITY Number of Days		
	Level 1	Level 2	Level 3
6	6 – 12	24 - 48	180

TYPE	GEAR	DAILY FOOTPRINT, km^2	SEASON (months)	Intensity levels of fishing activity (footprint in km^2 over a year per km^2, based on number of vessel-days in a 2.5 nm by 2.5 nm area and reference daily footprint)				
				Level 1	Level 1 x	Level 2	Level 2 x	Level 3
4	Otter trawling	10.36	6	0.30 – 0.60	0.6 – 1.25	1.25 – 2.5	2.5 – 9.3	9.3

9.2.6. Gear Type 5a and b – Light Trawling

Light Otter Trawl - Total width of gear has increased from 11.5m to 30m. This is considered as the spread from door to doors for a typical net size of 11m wide and ~18m long. Everything else in the gear configuration is the same.

TYPE	GEAR	NO DREDGES or BEAMS	GEAR WIDTH (m)	TOTAL GEAR WIDTH (m)	SPEED (knots)	SPEED (km/h)	TOTAL TIME/DAY GEAR IN CONTACT WITH SEA BOTTOM (h)	DAILY FOOTPRINT (km^2) No overlap assumed a priori among tows
5a	Light otter	Single rig	30	30	2	3.70	7.5	0.83
5b	Light beam		3	3	2	3.70	8	0.09

N.B. Light Otter Trawl daily footprint increased from $0.3km^2$ a day to $0.83km^2$ a day

	INTENSITY LEVELS OF FISHING ACTIVITY Number of Days		
	Level 1	Level 2	Level 3
Final changes	6 – 12	24 - 48	180

Same number of days for both 5a and 5b.

TYPE	GEAR	DAILY FOOTPRINT, km^2	SEASON (months)	INTENSITY LEVELS OF FISHING ACTIVITY (footprint in km^2 over a year per km^2, based on number of vessel-days in a 2.5 nm by 2.5 nm area and reference daily footprint)				
				Level 1	Gap	Level 2	Gap	Level 3
5a	Light otter	0.83	12	0.23 – 0.46	0.46 – 0.93	0.93 – 1.85	1.85 – 6.95	> 6.95
5b	Light beam	0.09	4	0.02 – 0.05	0.05 – 0.1	0.1 – 0.2	0.2 – 0.75	0.75

9.2.7. Gear Types 6 and 7

These gear types were not applicable to the project.

9.2.8. Gear Type 8 - Nets and long-lines

Nets have been recorded as lines and polygons.

Intensity levels

Intensity	New definitions
3	> 15 panels in an area of 2.5 nm by 2.5 nm, fished daily
2	2 – 15 panels in 2.5 nm by 2.5 nm area, fished daily
1	< 2 panel, in 2.5 nm by 2.5 nm area, fished daily

1 panel = 100 m length

Intensity	Definition in a 1km^2 area fished daily	Definition in a 1km^2 area fished in a year
3	>0.69 panels	>254.6 panels
2	0.09 - 0.69 panels	33.9 – 254.6 panels
1	0.09 panels	<33.9 panels

Assumptions used in assessing sensitivity to these levels of activity:

- Standard panel length is 100m
- Impact from the net as well as the anchors is assessed
- 1 square metre patch impacted per anchor
- All activities assumed to use same size/weight anchors
- For each anchor a standard admiralty pattern anchor assumed (10 kg max weight as precautionary)

9.2.9. Gear Type 9 – Pots

Intensity levels

Intensity	Frequency / density of fishing activity (Hall et al definition)	Total pots lifted in a year per ha by any number of fishermen ("pot-days")	Footprint area over a year
3	> 5 pots / ha (i.e. 100m by 100m), lifted daily	> 1825	>0.1825 ha in a year/ ha (18% of the area)
2	2-5 pots / ha, lifted daily	730 – 1825	0.0730 – 0.1825 ha in a year/ ha (7 to 18%)
1	< 2 pots / ha, lifted daily	<= 730	0.0730 ha in a year/ ha (7% of the area)

Assumptions used in assessing sensitivity to these levels of activity:

- Each pot on a line assumed to impact 1 square meter and each line to have two anchors, each also impacting 1 square metre.

Type 8 pots (fixed) to be moved into type 9.

9.2.10. Gear Type 10 – Rod-and-line hand fishing (includes natural bait fishing)

Intensity levels

Level	Definitions per week	Definition per year	Percentage coverage
3	>20 people fishing per hectare per week	1040 people per hectare per year = 1040m^2 impact	> 0.104
2	6 -19 people fishing per hectare per week	312 – 1040 people per hectare per year =312 – 1040m^2 impact	0.031 – 0.104
1	< 5 people fishing per hectare per week	< 312 people per hectare per year 52 – 312m^2 impact	< 0.031

Total angler-days per year computed on the basis of 52 weeks/year (the activity has no seasonal aspect and intensities look at the cumulative activity of any number of anglers in an area).

Assumptions used in assessing sensitivity to these levels of activity:

- 1 person's visit equals 4 hours
- Each person casting 4 times an hour (16 times per visit)
- Each 4hr visit affecting 1 square metre on the seabed
- Main impact associated with weights on lines, also hooks and snagging of lines

All data recorded as points, these need to be attributed to polygons drawn (RSA shape file: M:\GIS_Users\Michela_B\Reference layers\RSA_sites\RSA_Sites_Casting)
Two shape files were drawn – one where fishermen stand and the other where they would cast. Where they would cast should be used for the RSA analysis and points attributed to these polygons

No of persons visit x avg fishing time = total fishing time at a site through the year.
Add up every person's total time at a particular site
Then divide by 4 to get metre squared impact over the year
Then divide by polygon casting area

9.2.11. Gear Type 11 – Hand gathering, casual (does not include access) and Gear Type 12 – Hand gathering, professional (does not include access)

Level	Definitions
Gear Type 11	
3	>10 people fishing per hectare. Large number of individuals mainly concentrated in one area, with the activity occurring daily
2	3-10 people fishing per hectare per day
1	< 3 people fishing per hectare per day
Single visit	Single visit in a year
Gear Type 12	
3	>10 people fishing per hectare often using vehicles. Large number of individuals mainly concentrated in one area, with the activity occurring daily
2	3-10 people fishing per hectare per day
1	< 3 people fishing per hectare per day
Single visit	Single visit in a year

Assumptions used in assessing sensitivity to these levels of activity:

- Three different gathering activities are considered: cockle raking, winkle and mussel picking and lug/rag worm digging. Sensitivity is assessed against the most impacting activity that can occur on each habitat (digging > raking > picking).

  Cockle raking:
  Gear Type 11, Casual
  One individual rakes and sorts a 1m by 2m area in a 15 min window
  → 16 square metres raked in a 2 hour visit per day per person

  Gear Type 12, Professional
  One individual rakes and sorts a 1m by 2m area in a 10 minute window
  → 50 square metres raked in a 5 hour visit per day per person

  Season: 8 months (Sep 1 – Apr 28)

  Lug/Rag worm digging
  Type 11, Casual - each person typically digs 5 sq metres in 2 hr
  Type 12, Professional - each person typically digs 15 sq metres in 5 hr

  The worst case scenario that would occur on the habitat is used, i.e. fork digging rather than pumping.

  Season: year-round

	Area covered / year / person	<3 people / day	3-10 people / day	>10 people / day
Casual (2hr) 5m2/day	1825	5475/10000 = 0.55	0.55 – 1.83	18250/10000 = 1.83
Professional (5hr) 15m2/day	5475	16425/10000 = 1.64	1.64 – 5.48	54750/10000 = 5.48

Winkle picking
Area covered on a tide: 200 m^2
Professional (200m^2 in 5 hr)
200m * 365 = 73000m^2

Level 1	Level 2	Level 3
<3 people per day = 219000	219000 - 730000	> 10 people per day = 730000
219000/10000 = 21.9	21.9 - 73	730000/10000 = 73

9.2.12. Gear Type 15a and 15 b – Foot and Vehicle Access

Level	Foot access	Vehicle access
3	Access by >10 people per hectare per day. Large numbers of individuals mainly concentrated in one area	Access by more than two 4x4s (or SUVs) or a mixture of SUV and ATVs per hectare per day. Several vehicles access the area as a group.
2	Access by 3-9 people per hectare per day	Access by a single 4x4 (or SUV) or several ATVs per hectare per day
1	Access by 1-2 people per hectare per day	Access by one – two trail bikes or ATVs per hectare per day
Single visit	Access on a single occasion	Access on a single occasion

The intensity scales above equate each individual to two passes (to and from fishing site).

9.3. Data Archive Appendix

Data outputs associated with this project are archived as project 444, media 1485 on server–based storage at Natural Resources Wales.

The data archive contains:

[A] The final report in Microsoft Word and Adobe PDF formats.

[B] A CSV file containing the resistance and footprint data converted to flat file format used to calculate the curves

[C] A CSV file containing the formula and calculated coefficients for each curve

[D] A full set of best plot images produced in JPEG format showing:

- Original data points (red circles)
- Calculated best fit line (blue line)
- Equation of best fit line
- R-squared value

[E] GIS layers and workspace in MapInfo format on which the maps in the report are based:

- Resistance_1km.tab contains the processed data generalised to a 1km resolution.
- Resistance.wor contains the generalised data thematically mapped by the resistance category.

Metadata for this project is publicly accessible through Natural Resources Wales' Library Catalogue http://194.83.155.90/olibcgi by searching 'Dataset Titles'. The metadata is held as record no 115626.

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