EMFF Benthic Impacts Decision Support Tool

User Manual

Version 4.0

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Contents

Please check the online version for the most up to date user manual or get in touch with the helpdesk.

1. Introduction

Bottom trawl fisheries impact sedimentary habitats to various degrees. It is difficult to determine whether a fishery is causing serious or irreversible harm to a habitat objectively. Marine protected areas are areas that protect a range of nationally important, rare or threatened habitats and species.

The Benthic Impacts Tool is a decision support tool and aims to aid the user (typically a regulator) in quantifying the impact of bottom towed fishing activity on sedimentary habitats. The BIT has also been designed to inform adaptive marine protected area management and therefore allows the user to consider various scenarios and their potential impacts on the Relative Benthic Status (from spatial closures, to modified gear types).

Benthic Impacts Tool: Main Aims

Consistent

Evidence-Based

Support

Quantitative Ecological Assessment
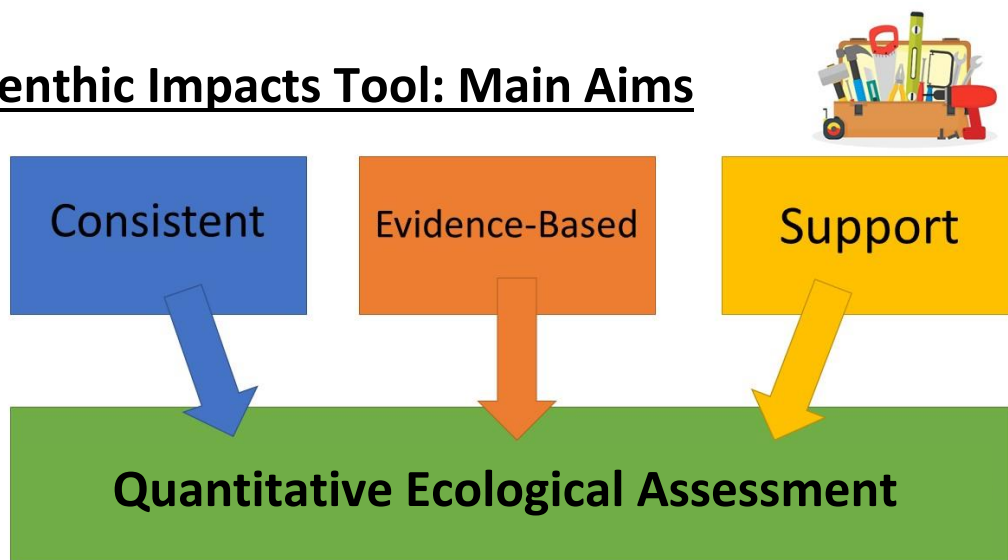
1.1. Tool Overview

Data on the spatial distribution of fishing activity and benthic habitats are used to predict the Relative Benthic Status (RBS) of habitats, and a predicted recovery trajectory over time if fishing were to cease. See the Tool Schematic below, which details the questions the tool is addressing and required data input by the user (essential input is highlighted within a red dashed line box).

Tool Schematic
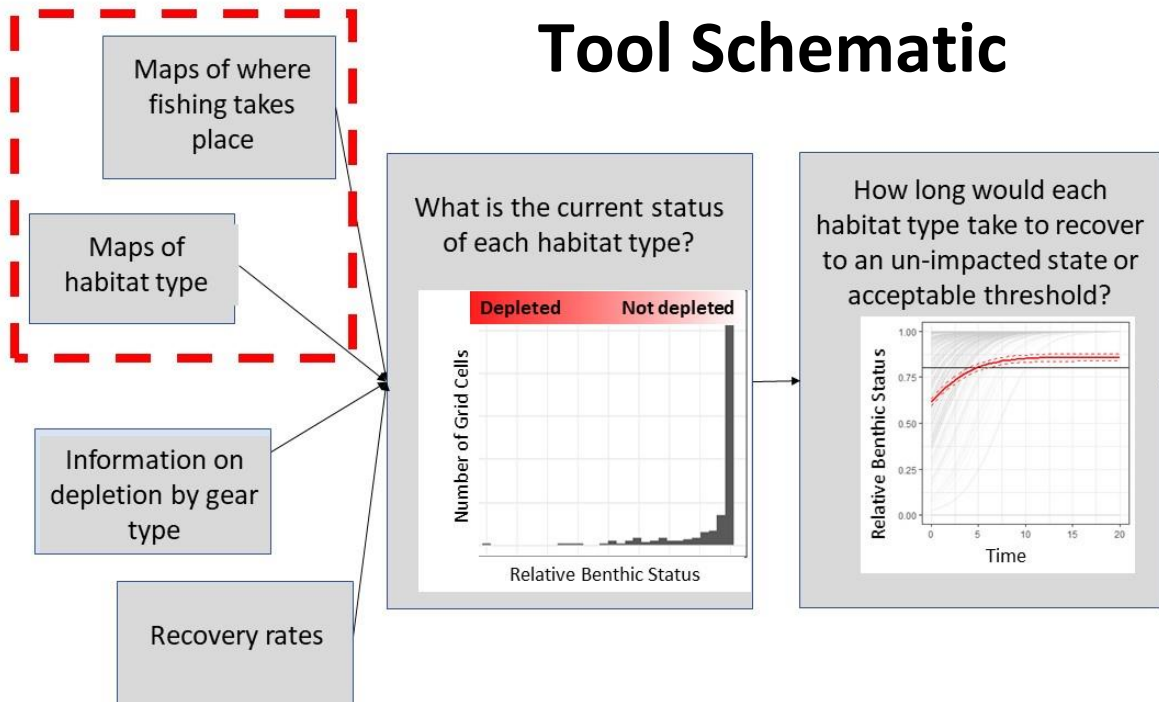
2. The Science – Assessment framework

The Benthic Impacts Tool is based on a wealth of scientific information, which has been published in peer-reviewed journals (Hiddink *et al.*, 2017; Pitcher *et al.*, 2017; Hiddink *et al.*, 2018; Rijnsdorp *et al*., 2018). The method incorporated in the tool has a low demand for data layers, and combines insights based on ecological theory with the most robust available parameter estimates.

In this section, we will highlight the main areas of research that combined together build the framework for this decision support tool. For further information on the science, please contact the helpdesk (section 12) or search for the publications highlighted in the references.
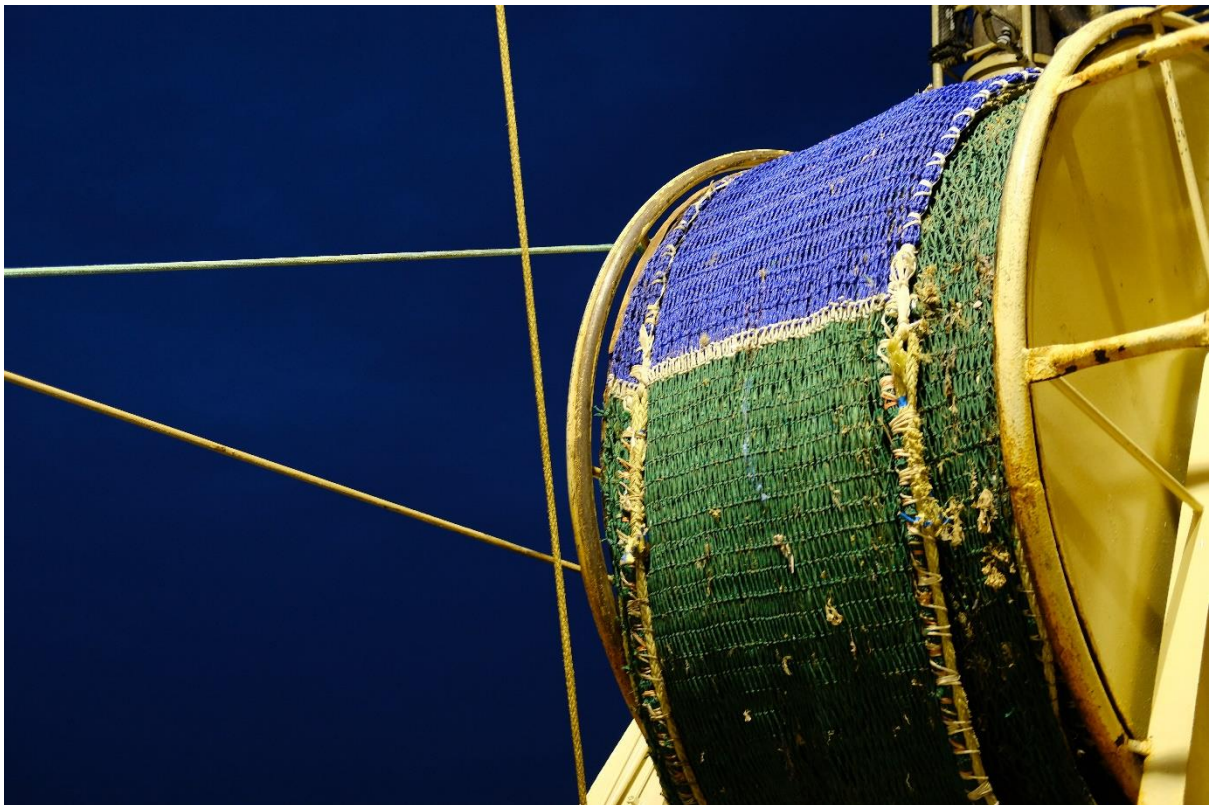
2.1. The Population Model

The Relative Benthic Status (RBS) is defined as the biomass *B* relative to the carrying capacity of the community *K*. RBS is derived by solving the logistic population growth equation for the equilibrium state (Pitcher *et al.*, 2017). The effect of trawling depends on both the trawl mortality (depletion *d*) and the recovery rates (*r*) of the benthic community. In the below example (Fig. 1) trawling occurs once a year, and after trawling recovery of the relative benthic state (RBS) occurs.

This tool uses a model that estimates RBS and its recovery. This model provides an opportunity for quantifying the impacts of bottom towed gear on sedimentary environments. The approach has a low demand for data, and only requires maps of fishing effort and habitat type and their sensitivity. The RBS model parameters quantify the interaction between the gear and seabed biota (i.e. depletion rates, section 2.2) and the recovery dynamics of this biota (i.e. recovery rates, section 2.3-2.4). The depletion rates have been quantified by meta-analysis for typical gear types (i.e. Otter Trawls, Beam Trawls and Dredges) and broadscale sediment types (i.e. Mud, Sand and Gravel), while recovery rates have been estimated in relation to the longevity of benthic biota. Therefore, the Relative Benthic Status of impacted habitats depends on the impact rate (depletion by gear), the recovery rate (of species within habitat) and the exposure to trawling (Pitcher *et al.*, 2017). The outcome of the Benthic Impacts Tool provides an estimate of benthic status relative to an unimpacted habitat baseline (see section 2.8 for the assumptions and limitations posed by the RBS model).

The user can determine the spatial resolution of their data and associated units (in degrees or metres). With this information, a grid is generated within to the same resolution (e.g. a resolution of 0.05° x 0.05° per cell). Values of fishing effort are assigned per grid cell within the area under assessment. An RBS score is calculated per habitat type per grid cell and the distribution of RBS and the mean value per habitat is generated for the assessment. Finally, the recovery trajectories for each habitat if fishing were to cease is estimated.

The following sections (2.2 – 2.4) will break down the above RBS model into the required components.

Relative Benthic Status
RBS = B/K = 1- F d/r

That is,

$$RBS = 1 - \frac{Fishing\ Effort \times Depletion\ Rate}{Recovery\ Rate}$$

Pitcher et al., (2017)
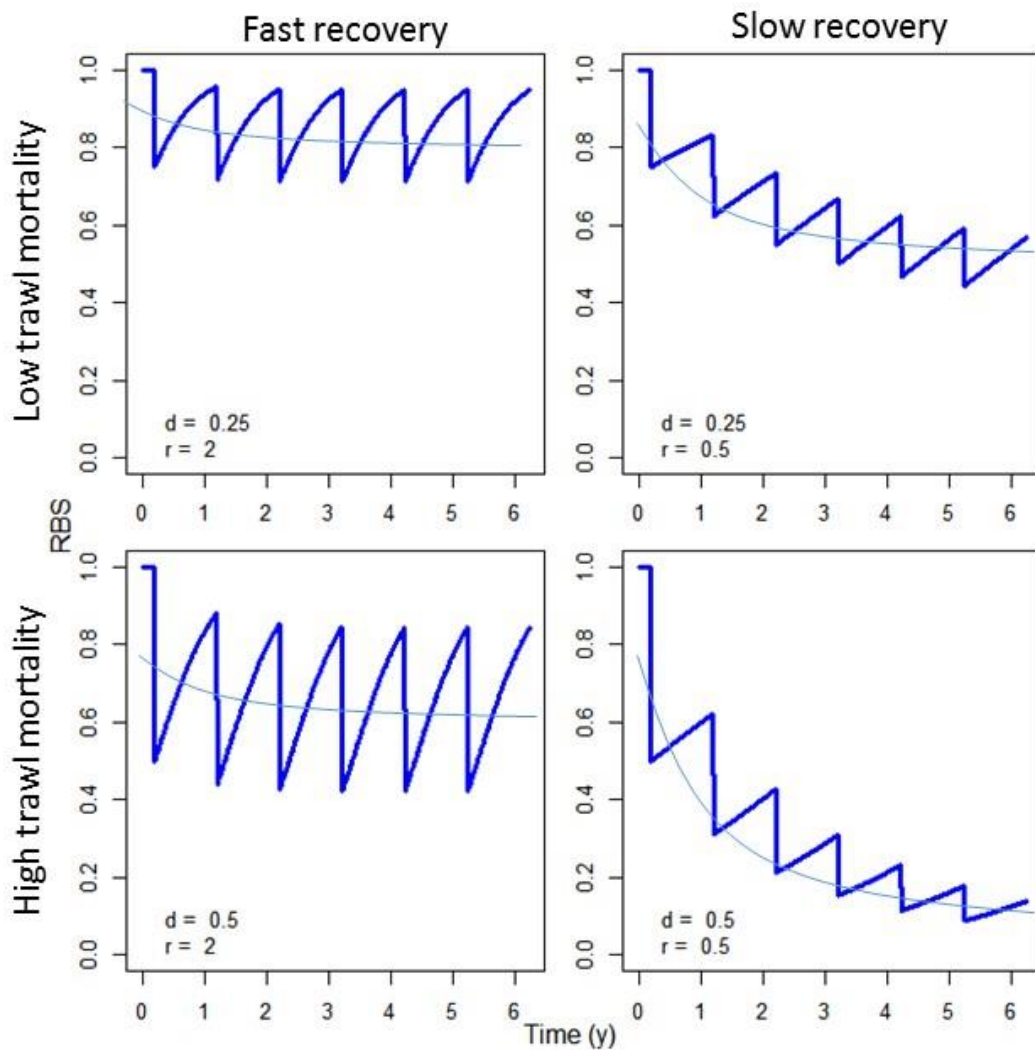
Figure 1. A range of plots to depict what happens to Relative Benthic Status over time based on high/low trawl mortality and fast/slow recovery.

2.2 Depletion

The depletion rate, *d*, relates to the fraction of organisms killed by a trawl pass (Hiddink *et al.,* 2017). Depletion is gear specific, as different gear types have different effects on the seabed (Fig. 2).

HD = hydraulic dredge

TD = towed dredge

BT = beam trawl

OT = otter trawl
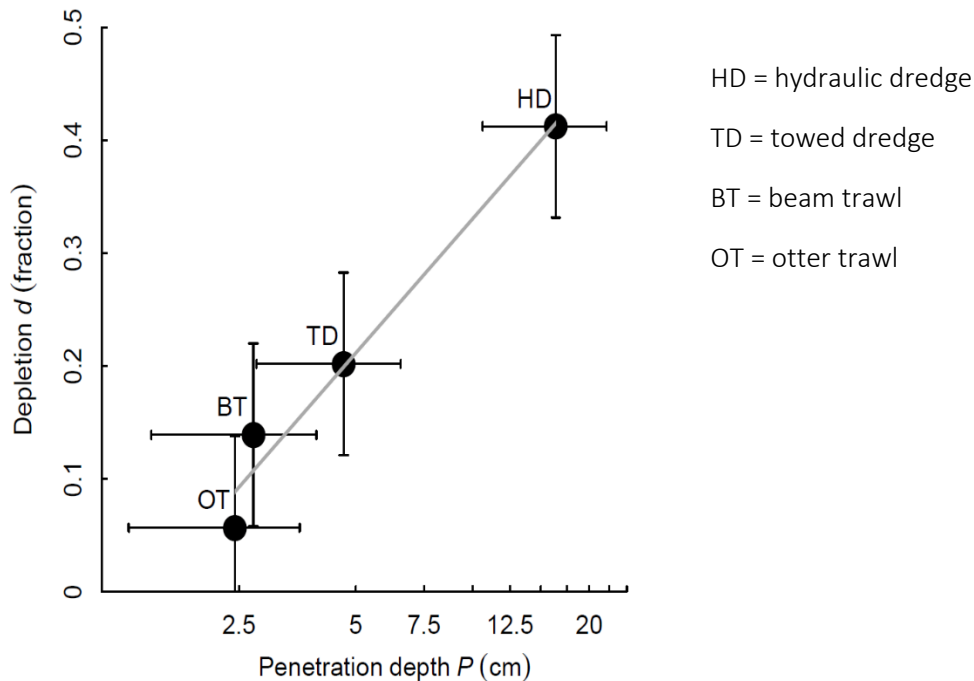
Figure 2. The relationship between the penetration depth (*P*) and depletion (*d*) of macrofaunal community biomass and numbers caused by a single trawl pass for different trawl gears (means ± SD) (Hiddink *et al.*, 2017).

The depletion values are based on multiple meta-analyses which provide a global standard for typical gear types (hydraulic dredge, towed dredge, beam trawl and otter trawl) and simple sediments (mud, sand and gravel) (Hiddink *et al.*, 2018, Scriberras *et al.*, 2018 and Pitcher *et al.*, in prep). The meta-analyses synthesise data from all available (and relevant) trawling studies and provides a systematic review of the current field of evidence to parameterise the RBS model (Hughes *et al.*, 2014). Gears that penetrate deeper into the sediment have a significantly larger impact on the benthic community than those that penetrate less (Scriberras *et al.* 2018). Because the penetration into the sediment depends on the sediment type, depletion is sediment specific, thus in

the Benthic Impacts Tool we offer users the opportunity to define the main sedimentary type of their habitat e.g. mud, sand or gravel (Scriberras *et al*. 2018). As highlighted by Fig. 2, the penetration depth of the gear type positively correlates with the depletion rate of the gear type, therefore the penetration depth acts as a proxy for the depletion rate. The distribution of depletion, *d*, required for parametrising the RBS model is calculated by the method outlined in Hiddink *et al*. (2017) and based on this relationship between penetration depth of gear type and depletion and are already supplied within the Benthic Impacts Tool. Future versions of the Benthic Impacts Tool may allow for the specification of depletion (*d)* values, if robust estimates are obtained by the user or if the penetration depth of the specified gear type is known.

2.3 Recovery Rate

The effect of bottom trawling on biota increases with longevity because the recovery rate decreases (Hiddink *et al.*, 2018). The longevity of a species is the maximum potential life span (Hiddink *et al.*, 2018). Bottom trawling impact is x2-3 times greater on long lived species (>10 years) than species living between 1 and 3 years. Recovery is closely related to the inverse of longevity for benthic fauna (Hiddink *et al.*, 2018). Longevity can therefore be considered a suitable proxy for habitat sensitivity and thus the estimated recovery rates for communities (Fig. 3).
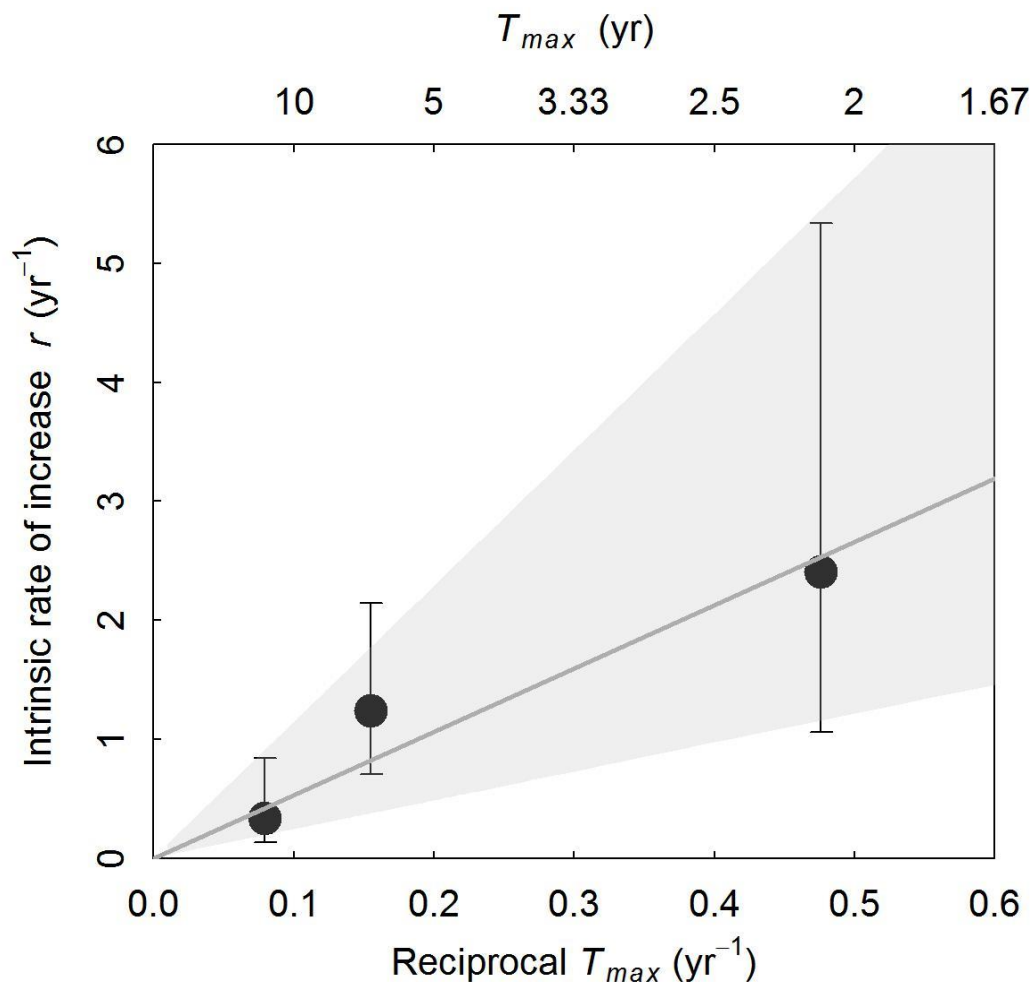

Figure 3. Relationship between *r* and longevity T_{max} estimated from gradient studies (r = 5.31 / longevity, R^2 = 0.96, $F_{1,1}$ = 73.9, P = 0.013).The points and error bars are *r* estimates and their 95% confidence intervals, while the solid line is the fitted regression line. The shaded

areas indicate the regression fits through the upper and lower confidence intervals of the data (upper: r = 11.44 / longevity, lower: r = 2.43 / longevity) (Hiddink *et al.*, 2018).

Information on the longevity distribution of unfished communities within habitats may not always be available. A meta-analysis based on comparative studies of trawling impacts at a global scale highlighted the lower confidence interval estimate of recovery (r) for whole benthic communities, with a typical longevity distribution, to be 0.42 (Hiddink *et al.*, 2017). Therefore, the value 0.42 is used as the default value within the tool for assessments lacking longevity or recovery rate estimates as highlighted in section 2.2 (Hiddink *et al.*, 2017).

We also note that the value(s) obtained for r cannot be modified by the user (in this version or future versions of the Benthic Impacts Tool), as these calculated values are based on the latest peer-reviewed research and deemed as the most appropriate values for use within the Benthic Impacts Tool.

2.4 Longevity

The approach used in this tool relies on estimates of the longevity of species within a community to help determine the sensitivity of the habitat. It is known that species which are long-lived tend to be sensitive to bottom trawling impacts, whilst species which are short lived are more resilient to bottom trawling impacts (Fig. 4 and Hiddink *et al.*, 2018). The response of biota to trawling depends on their population recovery rate, r, also known as the maximum population growth rate. Longevity can be used as a proxy to determine the recovery rate of biota, as recovery and longevity significantly correlate (Fig. 3 and Hiddink *et al.*, 2018). Within the Benthic Impacts Tool there are three options for the user to consider how to determine the estimate of r within the RBS model (see section 6.5 Recovery rates for detail).
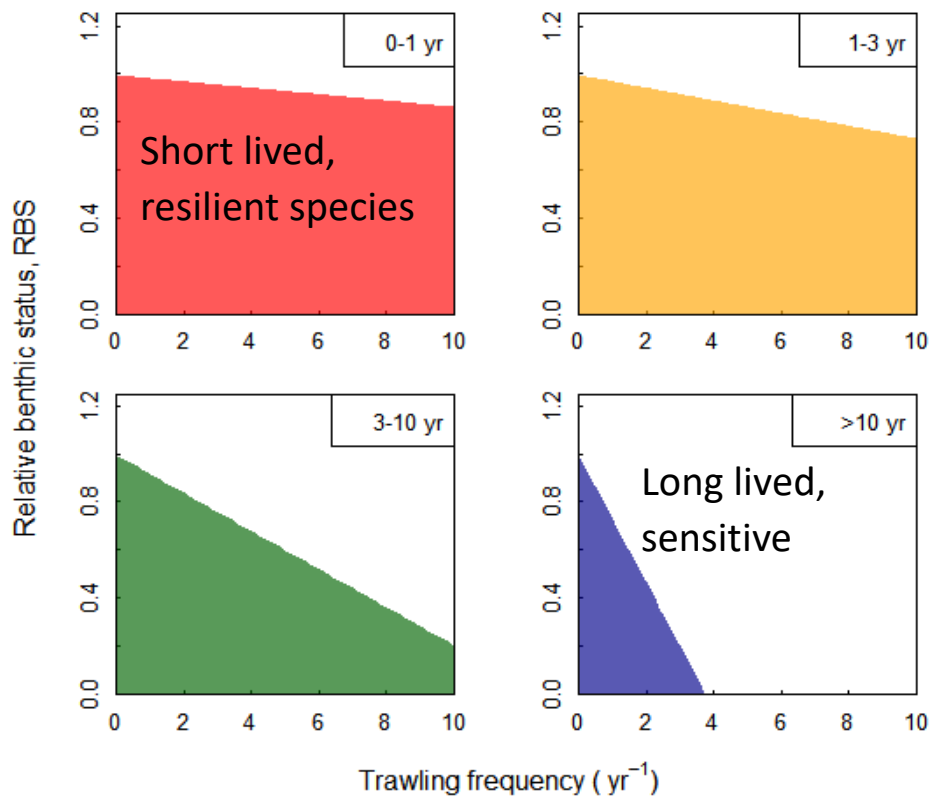
Figure 4. Each plot highlights an age category (<1, 1-3, 3-10 and >10 years) within a community. The Relative Benthic Status decreases as the trawling frequency per year increases, with different rates of change occurring per age category.

2.5 Habitat Sensitivity

The distribution of longevities can then be used to estimate the sensitivity of a habitat to bottom-towed fishing gear. A benthic community with many long-lived species will have a lower mean *r* than a community with many short-lived species and will therefore be more sensitive to the same level of trawling intensity.

The effect of trawling is proportional to the ratio of depletion over recovery, d/r. A lower r will result in a higher impact at the same intensity of trawling. A habitat will be sensitive to trawling if a large fraction of the biomass of the community, in an untrawled community, is made up of long-lived species with a low *r* (Fig. 5a). A habitat will be less sensitive i.e. resilient (Fig. 5b) to trawling if a

large fraction of the biomass of the community, in an untrawled community, is made up of short-lived species with a high *r.*

Figure 5. An example of how the longevity distribution of a benthic community under no trawling pressure affects the response of total community biomass to bottom trawling.

2.6 Assumptions and limitations

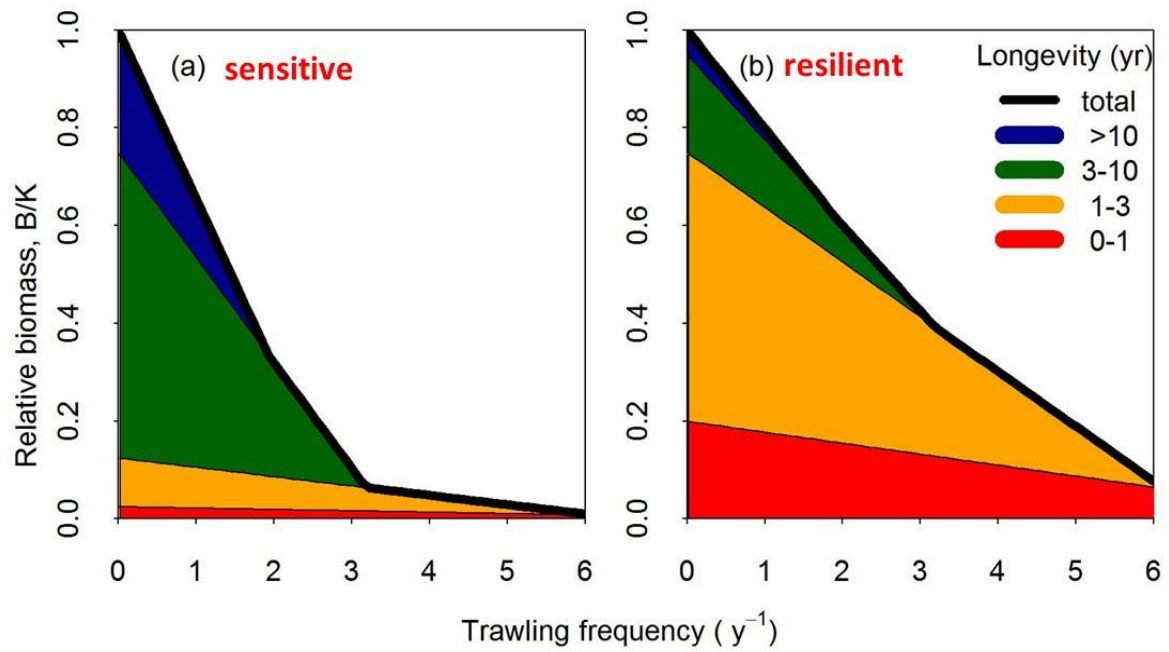The tool outlined in this manual is based on a model, and the outputs are only as good as the inputs (i.e. the data provided, the simplifications, assumptions and parameter estimates used). The logistic population growth model that is used is one of the simplest ecological models developed and is used here exactly because of this simplicity. The simplicity makes the approach transparent and allows the robust estimation of the parameter values. More complex approaches require more data which make complex models less feasible for a general tool intended for global use and with data poor assessments.

The model and the parameter estimates are all based on the latest science and evidence collated. Most of these underlying studies were focused on temperate sedimentary habitats on infauna and epifauna, for towed bottom gears, therefore this tool will provide the most reliable outputs for the same focus.

The approach creates a spatial prediction of fishing impacts but does not include spatial ecological processes. This means that processes like recruitment and dispersal are not included, and that the state of one grid cell does not depend on the grid cells surrounding it. Recruitment and dispersal are not part of the processes explicitly included in the RBS model, which would mean that no recovery could ever occur once RBS = 0. Because this is not realistic, we assume that at least 1% of the carrying capacity remains within the habitat.

The RBS is not a food web model, therefore no effects on higher trophic levels is included. Species interactions such as competition and predation are not explicitly modelled (but are represented in the parameter values estimates). Age structures, size structures and further complex structures are also not explicitly modelled but they do correlate to species biomass and thus are indirectly represented by the RBS model.

The method predicts the relative community biomass, which is the biomass as a fraction of what it would be without bottom trawling. This has the advantage that it is easy to compare between the state of different habitats, and that the data demands of the approach are lower. It does however also mean that in final products, all grid cells will be equally weighted regardless of the amount of

biomass they can support, and areas that can support a high biomass are not given more importance.

The estimated time to recovery provided on the final tab of the Benthic Impacts Tool does not indicate whether the community may recover to the size and age composition associated with no trawling (Hiddink *et al.*, 2019). However, the estimated time to recovery does provide an idea of the recovery of abundance which is likely to correlate with the recovery of important ecosystem processes, such as bioturbation (Hiddink *et al.*, 2019). Full recovery to the pre-trawling age structure is unlikely, especially for habitats that contain some of the longest-lived benthic biota which may live for over 20 years if trawling is allowed to persist in that area (Hiddink *et al.*, 2019).

The parameter values in the tool are currently not applicable to biogenic reef habitats e.g. oyster, mussel beds or reef and rocky habitats – this is purely because we have little scientific evidence of quantitative impact on these habitats and thus a gap in our knowledge. Once this evidence is available, the tool may be modified to accommodate these.

The cell position within the assessment grid is the centre of the cell and assumes that the same value of fishing effort covers the entire cell. This is where data resolution becomes very important. The lower the data resolution, the less precise the RBS model outcomes become. This is most important for very small but heavily fished habitats, where a low habitat resolution map may lead to an underestimate of the trawling impact. We are currently working on sensitivity analyses at Bangor University, where we endeavour to provide evidence for a minimum data standard for the Benthic Impacts Tool in relation to both habitat data and fishing effort data (both of which will be user-based inputs for the tool). This minimum data standard will ensure that the Benthic Impacts Tool will provide a fair and robust opportunity for the best quantitative led evidence.

The RBS model assesses the equilibrium conditions, which assumes that the fishing activity has been continuous over time and does not reflect the reality of peaks and troughs in activity, whether on a yearly or seasonal basis. It is recommended to use several years of fishing effort data, ideally around 5 years.

Considerations for managers and regulators: The model considers direct impacts on biological communities. This is relevant to related conservation objective target attributes such as "Distribution: presence and spatial

distribution of biological communities", but does not provide an indication as to other conservation objective target attributes such as "Structure: sediment composition and distribution".

To conclude, the outcomes of the Relative Benthic Impacts tool reflects the inputs into the tool. Therefore, if poor data quality is input, then the RBS model outcome may also be poor. Therefore, it is important to keep note of the data types and sources when using the Benthic Impacts Tool and the choices made as the user proceeds through the tool, as these will certainly impact the final outcomes. If the Benthic Impacts Tool is used for assessment, both the final outcomes and the user choices should be incorporated as part of the risk assessment and form part of the evaluation of available evidence.

2.7 Frequently Asked Questions

- The model estimates relative total community biomass, how does this relate to seafloor integrity, biodiversity, structure and function?

Community biomass is known to correlate with many ecosystem functions, and when local biomass is decreasing, local biodiversity and species richness will also be declining. Ecosystem processes that benthos provide such as bioturbation, nutrient cycling, and food provisioning for higher trophic levels such as fish and seabirds, are all tightly linked to benthic biomass.

- Some opportunistic species will increase in abundance in response to trawling, how does this approach capture this?

After trawling, smaller, short-lived species may increase in abundance when they are released from competition and predation by the larger, long-lived species. The availability of discards may also provide a food subsidy to some species, although this has been shown to be a very minor fraction of the diet for benthos. Because the species that can increase in abundance are generally small, the total community biomass will largely reflect as loss in the larger species, and an increase in smaller opportunistic species will hardly affect total community biomass. These emergent effects are already incorporated in our parameter estimates as they will have been present in the studies that were used to estimate the parameters.

- How did the underlying studies that provided the input data find unfished areas? Is not all of the seabed already trawled? How do we know what the pristine condition could be like?

Many of the studies that were used went through a careful process of site selection to ensure the true effect of trawling was detected. Unfished areas do occur in all seas, and have been used in many of the studies as 'control' locations. For example, Amoroso et al. (2018) showed that even in the most heavily trawled seas such as the North and Adriatic seas, around 20% of the areas is not trawled. Other studies have included 'control' locations that were infrequently trawled and were a large fraction of the seabed is likely to have been untouched by trawling for many years. Nevertheless, there may have been some loss of the most sensitive fauna since 100s of years ago, and we cannot quantify how much using current methods. As a result, trawl impacts may be underestimated when there is uncertainty on how 'trawl-free' the control

locations have been in the last century. However, managers will need to manage the ecosystem that is currently here, rather than one that might have been there a very long time ago, and this approach does provide the tools to do this.

- How can model outputs be interpreted and be used to assess fisheries management options against conservation objectives?

There are multiple ways of considering the conservation objectives alongside the RBS outputs, for example:

1. *Run through an assessment with the BIT and figure out the best way of achieving an RBS of 80% or 90% per habitat type. Then come up with levels of precaution based on these outputs.*
2. *Run the BIT in reverse i.e. run through an assessment with the BIT, now figure out how much spatial closure or where is best for spatial closure or how much gear modification is necessary to achieve the desired outcome.*

- The main sediment types for depletion are mud, sand and gravel. Is it possible to discriminate between stable sand and dynamic sandy habitats when running an assessment?

There is no way of defining the depletion differences between dynamic and stable sandy habitats at the moment (no clear supportive evidence). However, habitats which are naturally more disturbed, such as dynamic sandbanks, tend to have shorter lived species, whilst long-lived species tend to occupy more stable habitats. The differences between habitats containing long-lived species and short-lived species can therefore be documented in the recovery rates tab, where the user inputs information about the longevity distribution of the community.

3. Technological Requirements

All you need is a computer with an internet connection.

Requirements: 64 MB RAM minimum; 256 MB RAM or higher recommended as the tool deals with the processing of large spatial datasets.

If the assessment area covers an area greater than 100km^2, we do recommend breaking down the area into a smaller size. This will decrease processing time through the tool and prevent memory loss issues with the computer.

The R script behind the Benthic Impacts Tool and associated user manual is available on request. The code will be provided though GitHub. Knowledge of the R software is required for use of this option. Please contact Jan Geert Hiddink (Bangor University) for further information and access.

The Benthic Impacts Tool has been designed to be a web based application and may be made available as such in the future. This user manual is designed to aid the user in the use of the tool as a web-based application. Further details on launching the tool as a web-based application is available on GitHub.

4. Tool Navigation

The tool is divided into 8 tabs which require data input and user interaction. Below is a summary of the role of each tab within the Benthic Impacts Tool, with underlined words indicating the main role of the tab.

Tab 1. Information about the tool, and setting of the working directory.

Tab 2. Fishing effort data is uploaded and checked.

Tab 3. Habitat data, assessment area boundaries and land data (if land is present within the assessment area) is uploaded as shapefiles and a data grid is generated for analysis.

Tab 4. Fishing effort data is converted to swept area ratio (SAR, $year^{-1}$) estimates, which indicate how often a particular area of the seabed is fished per year.

Tab 5. Depletion values are determined for each gear and habitat type.

Tab 6. Recovery rates are estimated from the longevity of species present in each habitat type.

Tab 7. The swept area ratio (SAR, $year^{-1}$) values are combined with the depletion rates for the fishing gear to determine the Relative Benthic Status (RBS) of the seabed in each habitat type. The RBS score indicates to what extent the benthic biota have been affected by fishing [RBS = 1 = natural community, 0 = fishing has resulted in the removal of the original benthic community].

Tab 8. The recovery trajectory for each habitat type can then be predicted from the current RBS (Relative Benthic Status) and the recovery rate.
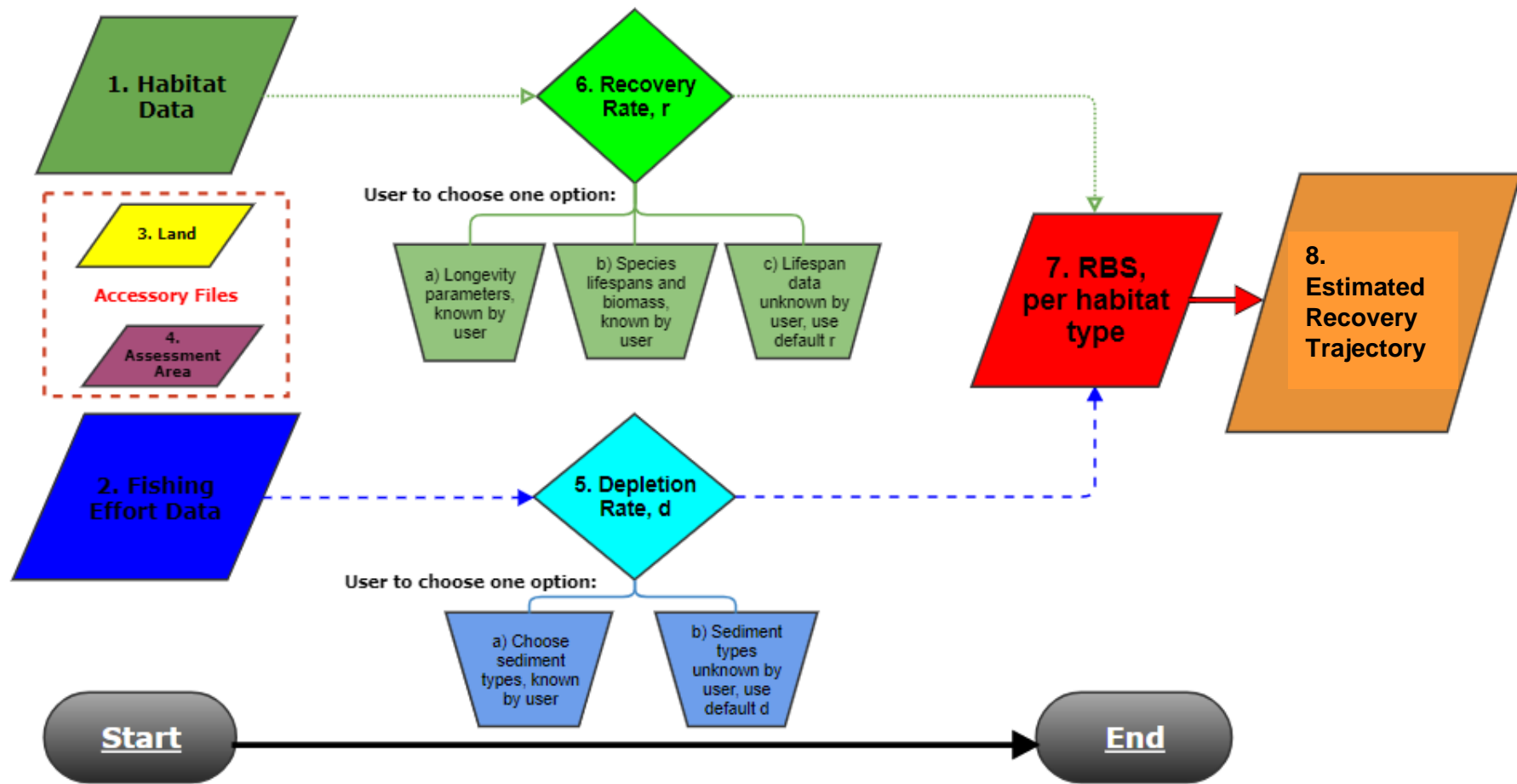
Figure 6. A flowchart highlighting the user input (1 – 4), user interactions (5 and 6) and user output (7 and 8) of the Benthic Impacts Tool.

5. Data requirements

The minimum data requirements include:
1. Fishing effort data
2. Habitat data

For improved confidence in the output, also include:

3. Species longevity data

or

4. Species longevity distribution parameters

All spatial data files should be processed to the same spatial resolution and same projection. The recommended projection for processing through the Benthic Impacts Tool is WGS 84.

See the 'Data Format' in section 6 for advice on formatting your data.

6. Data Format

6.1 Fishing Effort Data (mandatory)

6.1.1 What is fishing effort?

In the Benthic Impacts Tool, fishing effort is the Swept Area Ratio (SAR, year^{-1}). The swept area (km^2) of a fishing vessel depends on the gear swept width and the tow speeds, and this is the value required for the Tool input. The Swept Area Ratio (SAR, year^{-1}) is then calculated by the Tool itself, and this is calculated as the total swept area per grid cell divided by the grid cell area. At the moment, the Benthic Impacts Tool requires fishing effort data to be aggregated to the resolution of 0.05°. Future versions of the Tool will allow the user to specify a resolution and also input unaggregated data.

6.1.2 Why do we need it?

We need the fishing effort data in order to calculate the impact the fishing activity is having on the benthic communities. The Swept Area (km^2) calculation gives an easy format to assess using square grid cells which are comparable over time and space.

6.1.3 Which gear types can be processed through the Benthic Impacts Tool?

When using the first version of the Benthic Impacts Tool, the following general gear types may be considered for assessment: hydraulic dredge (HMD), towed dredge (DRB), beam trawl (TBB), otter trawl (OT) and seine netting (SEINE). They must follow the abbreviated naming convention as highlighted in brackets after each gear type. This is important for the Tool to be able to recognise the gear type chosen and associate the required depletion data to this gear type. The tool supports a single-gear assessment approach or a multi-gear assessment approach. The multi-gear assessment approach will consider the fishing activity and depletion values for all gear types, leading to combined impact outputs. Another functionality of the tool is to allow the input of modified gear types. In order to input modified gear type values, the depletion for the new gear type needs to be calculated first (see section 2.2 on depletion to learn how to calculate this, or use the Seafish Fishing Gear Impacts Tool for gear modification calculations). Gear modifications can also be considered by the tool.

6.1.4 How do I process gear modification through the Benthic Impacts Tool?

In order to process a gear modification, additional data needs to be added to the tool on the depletion tab. If depletion for gear type is known, a .csv file will need to be uploaded on the depletion tab (Task 14c / 17), which outlines the gear type and depletion value for gear type. If multiple gears are being considered, then all gear types and their depletion values will need to be included in the .csv file. Below is an example of a .csv file. The column headings must be the same as stated below (i.e. "d.gear" for the depletion value and "gear" for the gear type).

	A	B	C
1	d.gear	gear	
2	0.2	DRB	
3	0.2	HMD	
4	0.06	OT	
5	0.14	TBB	
6	0.7	GEAR_MOD	
7			
8			

d.gear: Depletion value (fraction in cm)

gear: The fishing gear. This can be any name but must match the gear type from the fishing effort input file.

If further information about the penetration depth of the modified gear type is available, then another .csv file may be uploaded (TASK 14b/17). This dataset will refer to the penetration depth per gear type and per sediment type (mud, sand and gravel). See below for an example. The column headings must be the same as stated below (i.e. "gear_type" for gear type, "habitat_cat" for sediment and "mean_pd" for the mean penetration depth in cm).

	A	B	C	D
1	gear_type	habitat_cat	mean_pd	
2	GEAR_MOD	mud	60	
3	GEAR_MOD	sand	43	
4	GEAR_MOD	gravel	45	
5	TBB	mud	3	
6	TBB	sand	2	
7	TBB	gravel	3	
8	DRB	mud	7	
9	DRB	sand	5	
10	DRB	gravel	6	
11	HMD	mud	23	
12	HMD	sand	23	
13	HMD	gravel	23	
14	SEINE	mud	1.99	
15	SEINE	sand	1.01	
16	SEINE	gravel	1.83	
17				

gear_type: The fishing gear. This can be any name but must match the gear type from the fishing effort input file.

habitat_cat: Sediment type tested for gear penetration (i.e. mud, sand or gravel)

mean_pd: The mean penetration depth (cm) for associated gear and sediment type.

6.1.5   What data is suitable?

The fishing effort data currently requires pre-processing before being used in the tool. The tool reads .csv files of fishing effort, with the aggregation chosen during file input for either aggregated or unaggregated data. If data is unaggregated, we recommend an aggregation of 0.05° x 0.05° (as followed by ICES methodologies). The tool allows the user to choose between metres or degrees – the choice behind this will depend on whether the data format is in degrees or meters and the location of the assessment area. It is critical to ensure that all data input into the tool is of the same units and resolution (this is for both fishing effort and habitat data). If the assessment area is found in polar regions, we do recommend the use of metres over degrees, as 1° of latitude is of a different length depending on latitudinal location. Vessel monitoring system data or GPS tracker data of fishing vessels can be pre-processed to the Benthic Impacts Tool data requirements. This .csv file should only contain points that represent fishing activity (i.e. no steaming activity). It must contain the

following column headings, formatted in the same way (i.e. use of capitals and underscores). Example:

	A	B	C	D	E
1	Latitude	Longitude	AreaSwept	Gear	
2	50.325	0.025	16.35349658	TBB	
3	50.325	0.075	17.75144175	TBB	
4	50.375	0.025	21.88457425	TBB	
5	50.375	0.075	17.74218583	TBB	
6	50.325	0.125	5.331364582	TBB	
7	50.375	0.125	20.15903646	TBB	

Latitude: The latitude of the data point (in degrees, °)

Longitude: The longitude of the data point (in degrees, °)

AreaSwept: The area swept by that fishing point (i.e. speed x gear width x duration, in km^2)

Gear: The fishing gear (e.g. TBB, DRB, OT, HMD, SEINE)

NB. When working with coordinates please use decimal degrees (with no use of commas).

6.1.6   How to deal with different fishing gear types?

The tool can process a single gear type assessment or an in-combination gear type assessment. If multiple gear types are considered, each data point (i.e. row) in the fishing effort dataset needs to be associated to a single gear type.

6.1.7   How to obtain fishing effort data?

SAR can be calculated using vessel monitoring system data, AIS or GPS tracker data. Your local fisheries authority or fisheries manager representative may be able to supply the required fishing effort data. For example, in England (UK) you may contact the Marine Management Organisation (MMO) or your local Inshore Fisheries and Conservation Authority (IFCA).

6.1.8   How to process VMS data?

We recommend processing and cleaning the VMS and logbook data through the R statistical programming software, where the package "vmstools" has been developed for this purpose (http://nielshintzen.github.io/vmstools/). Please get in touch with the Helpdesk for further instructions on processing the VMS data where an R script has already been generated for processing and cleaning fishing effort data.

6.2 Assessment Area Shapefile (mandatory)

A shapefile is a vector data storage format for storing the location, shape and attributes of geographic features. This includes a set of related files. The Assessment Area shapefile (e.g. named 'Assessment_Area') should outline your assessment area as a polygon (this will more than likely be the Marine Protected Area of interest). This will allow the tool to ensure all analysis occurs within this assessment area. Within Version 1.0 of the Benthic Impacts Tool, the Assessment Area shapefile is a mandatory upload. The Assessment Area shapefile can be generated within a Geographic Information Systems (GIS) software such as ArcMap or QGIS (many others are available). Using the GIS software, draw around the Assessment Area of interest and save this as a shapefile. The Assessment Area shapefile will allow the Benthic Impacts Tool to trim down all the other data inputs to ensure that only the area of interest is considered within the assessment. We are only interested in the assessment area, as large datasets or shapefiles increase the processing time of the Benthic Impacts Tool (this can vary between computers). Ensuring that all datasets are focused on the Assessment Area is therefore highly recommended.

6.3 Land or Spatial Closure Shapefile (not mandatory)

The Land or Spatial Closure shapefile (e.g. called 'Island') should highlight any land within the assessment area or nearby or highlight the spatial closure desired as a polygon. This will allow the Benthic Impacts Tool to remove areas of unnecessary analysis and therefore potentially reduce processing time (similar to the Assessment Area shapefile above). There are many websites that offer free land shapefiles, such as: https://www.diva-gis.org/gdata .

6.4.　Habitat Data Shapefile (mandatory)

6.4.1. What is habitat data?

A shapefile is a vector data storage format for storing the location, shape and attributes of geographic features. This includes a set of related files. The shapefile should provide an outline of habitat types within your area of assessment, this may range in resolution from basic sedimentary descriptors (e.g. sand, mud, gravel) to more complex descriptors (e.g. muddy sand). However, it is recommended to use the best resolution data available.

6.4.2. What data is suitable?

The benthic habitat under assessment should correspond to at least one of the below habitat characteristics:

1. Substratum – sediment type (e.g. hard substrate)
2. Geomorphology – seafloor topography (e.g. flat rocky terrace)
3. Biota – characteristic flora or fauna groups (e.g. kelp dominated seagrass bed and mixed epifauna).

6.4.3. Why do we need it?

The habitat data is required as the Benthic Impacts Tool assessment is undertaken per habitat type. That is, an RBS score and recovery trajectory score is calculated per habitat type.

6.4.4. How do we decide on the best habitat data to use?

Using a coarse scale habitat type will likely give a higher RBS score than a finely described habitat type, as the area is likely to be larger for the coarse scale habitat type and therefore diluting the impact of fishing across a broader area (Fig. 7 highlights how RBS may change depending on the resolution of the habitat data used). We do recommend the use of the highest resolution habitat data available, as this will ensure that each habitat is represented, and a more detailed analysis of fishing impact is obtained. At Bangor University, we are currently undertaking a sensitivity analysis, which will highlight a minimum standard of habitat data resolution required for using the Benthic Impacts Tool and should be available towards the end of 2020.
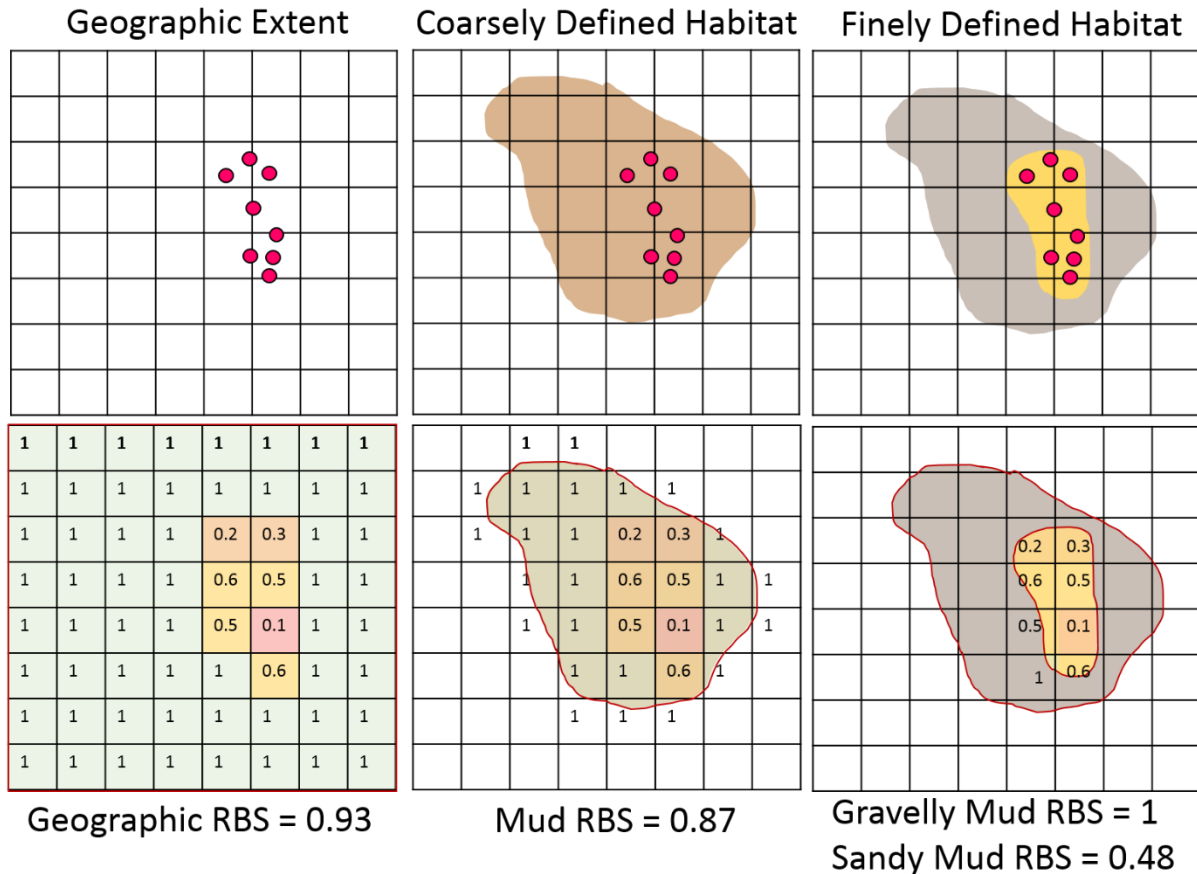
Figure 7. Schematic highlighting how RBS values may change depending on the resolution (from coarse to fine) of habitat data processed through the Benthic Impacts Tool.

6.4.5. Is the Benthic Impacts Tool suitable for the assessment of VMEs?

The Benthic Impacts Tool is not compatible for the assessment of Vulnerable Marine Ecosystems (VMEs) as the research to support decision making in this area is lacking. Therefore, we recommend the removal of VMEs from the assessment process when using the Benthic Impacts Tool.

6.4.6. How to obtain habitat data?

Please contact your local environmental management authority, who may have shapefiles of habitat available for local seascapes. In England (UK), the Environment Agency, Natural England or the relevant Inshore Fisheries and Conservation Authorities may have the required data.

6.4.7. How to process the habitat data?

Not much processing of the habitat data is required. For the tool to recognise different habitat types, please rename the habitat types column to "RCS" by either using ArcMap (or other GIS software) or R (or other programming

software). RCS is the name used for habitat types within the Benthic Impacts Tool for a habitat to be recognised, in later versions of the Tool we will allow a user to define the name of the habitat types column. We also recommend that you cut the habitat shapefile to the appropriate size of your assessment area (this will reduce overall processing time within the tool).

Below is an example map, highlighting the data input into the tool.
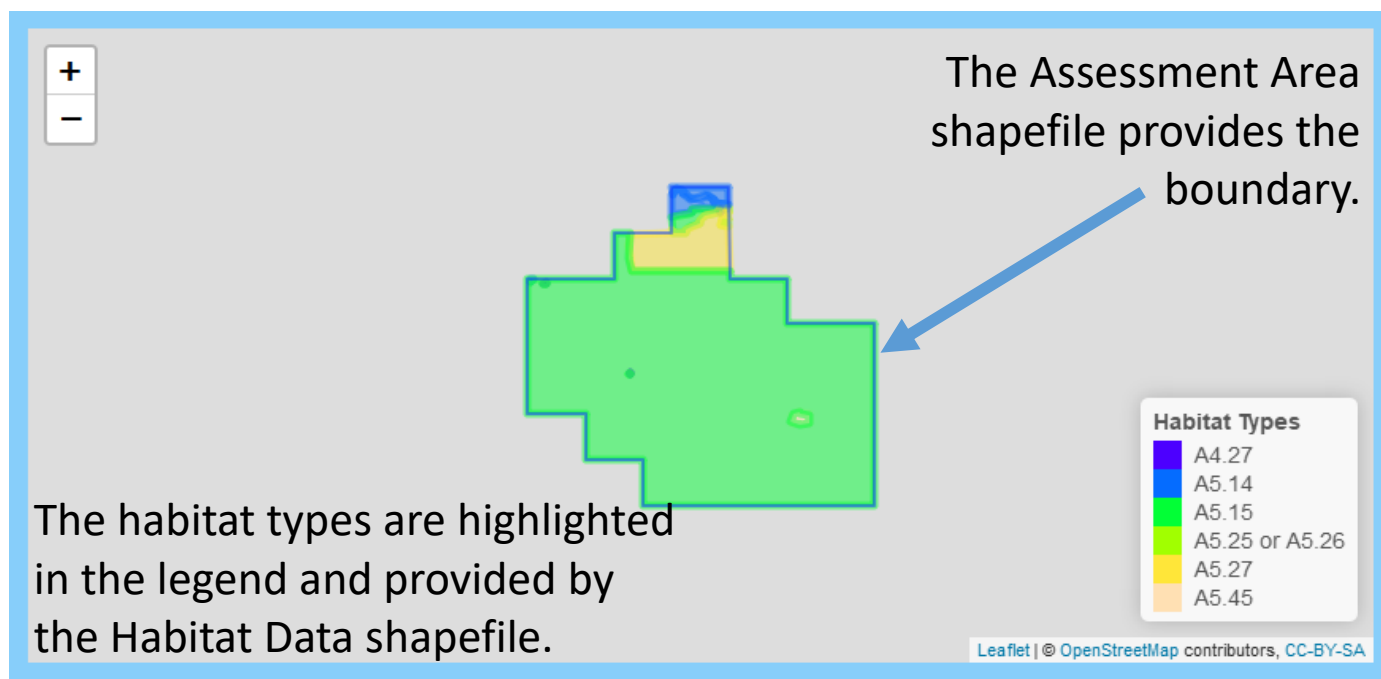
6.5.   Recovery rates (not mandatory)

There are three options for the user to choose from to determine recovery rates within the Benthic Impacts Tool.

6.5.1. Input longevity distribution parameters

The first option requires the user to provide the longevity distribution per habitat type within the area under assessment based on a logistical regression of the cumulative biomass distribution by log(longevity) for each habitat using the approach in Rijnsdorp *et al*. (2018). This logistic regression will provide estimates of the slope m and intercept b, which together describe the longevity-biomass distribution for the community, and these m and b values can be entered in the tool in the table for the first longevity option within the Benthic Impacts Tool. This approach requires a sophisticated analysis of extensive benthic sample data that needs to include areas of no or low bottom trawling effort but will yield to most accurate assessment of the impact of trawling on the seabed.

6.5.2. Input species data

The second longevity option calculates the longevity distribution for the user and requires a dataset to be uploaded as a .csv file. This dataset should contain the habitat name, species name, species longevity (in years) and the proportion of biomass per species. This data should be obtained from benthic samples at unfished stations that represent an undisturbed state. An example is below. The dataset can be written in Microsoft Excel and saved as a .csv file or by any other method for making .csv files. This dataset is then processed (as above) for the user without further user processing required. This option requires similar data to the first option, but requires data from unfished stations, which can be difficult to obtain. It is also recommended to disregard the target species from this list of species (even if it is part of the community) as the biomass and distribution of these species are likely heavily impacted by fishing activity.

An existing database of species longevities exists at this link: https://datadryad.org/stash/dataset/doi:10.5061/dryad.426658h

For species longevities not included in the above database, consider looking through further peer-reviewed and published literature.

Table 2. Example dataset including heading names and layout of longevity data upload. Please do not include units or spaces between the heading titles, the species longevity column needs to be in years and the proportion of biomass as a fraction between 0 and 1.

HabitatName	SpeciesName	SpeciesLongevity	ProportionOfBiomass
A5.14	species 1	4	0.05
A5.14	species 2	6	0.2
A5.14	species 3	15	0.30
A5.14	species 4	25	0.4
A5.14	species 5	40	0.05
A5.25	species 6	2	0.6
A5.26	species 7	7	0.4
A5.45	species 8	4	0.02
A5.45	species 9	1	0.98
A4.27	species 10	5	0.59
A4.27	species 11	14	0.41
A5.27	species 12	56	0.1
A5.27	species 13	20	0.9
A5.15	species 14	1	0.99
A5.15	species 15	23	0.01

6.5.3. Use a default setting

The third option is for the user that does not have access to benthic species longevity and biomass data within their assessment area. The tool has an inbuilt precautionary value for the species recovery rate which is the value of r = 0.42. This value has been calculated as the lower confidence interval estimate of r for an average benthic community, regardless of habitat or location, from Hiddink et al (2017). This is based on a global meta-analysis and based on all available experimental and comparative data on benthic impacts of trawling and is therefore likely to be very precautionary for most benthic habitats but may not be appropriate for some of the more sensitive habitats. See section 2.4 on Recovery Rates for further information about how these are calculated.

Species Longevity Data (see science section for rationale, click on hyperlink)

7. Data Downloads

Data is available for download from the Benthic Impacts Tool. Maps will automatically generate as .png files within the working directory chosen by the user. Here is a list of maps downloaded and the filename given to these (change filenames as required outside the tool): a map of the habitat data types (filename: habitat_map1.png), a map of Swept Area Ratio calculated for the assessment area (SAR_map1.png) and a map of Relative Benthic Status calculated for the assessment area (RBS_map1.png).

The downloading of plots will be controlled by the user. The user may choose to download a plot my checking the box on the appropriate tab e.g.   ☒

If the checkbox is checked, then ensure that a filename is given to the plot to be downloaded. Then search for this file in the working directory folder that was highlighted at the beginning of the tool processing.

8. Quick Starter Guide

Checklist

☐ TASK 1 – Create a data folder

☐ TASK 2 - Set working directory (Tab 1)

☐ TASK 3 – Upload fishing effort (Tab 2)

☐ TASK 4 – Do you have multiple gear types? (Tab 2)

☐ Task 5 – Choose a gear type to assess (Tab 2)

☐ TASK 6 – Upload Assessment Area Shapefile (Tab 3)

☐ Task 7 – Do you have a land shapefile? (Tab 3)

    a) If yes, upload land shapefile,

    b) If no, proceed to **Task 8**

☐ TASK 8 – Upload habitat Shapefile (Tab 3)

☐ TASK 9 – Choose between metres and degrees (Tab 3)

☐ TASK 10 - Choose grid cell size (Tab 3)

☐ TASK 11 – Tell the tool how many years of fishing activity data you have (Tab 4) to calculate SAR

☐ TASK 12 – Choose the gear type associated with your fishing effort data (Tab 5)

☐ TASK 13 – Associate sediment data or not (Tab 5):

    a) Input sediment type data (if known)

    b) Leave blank if not known (default will be used)

☐ TASK 14 – Do you have a gear type modification?

a) Standard or modified gear type? If modified, continue to b) and c)

b) Input gear modification file for gear, sediment time and penetration depth

c) Input gear modification file for gear and average depletion

☐ TASK 15 – Choose method for calculating recovery rates (Tab 6)

a) Input known model parameters

b) Upload species longevity data

c) Choose default recovery value

☐ TASK 16 – click to calculate RBS (Tab 7)

☐ TASK 17 – click to calculate recovery time (Tab 8)

9. Example Assessment

Before you start using the tool, make sure that a data folder is ready.

Important Considerations

1. Have all the desired data in one folder,
2. Give each file an easy to remember name e.g. habitat_data , assessment_area, species_longevity_data *etc*

See section 6 on how to [format the data](#) to ensure compatibility with the tool.

9.1Tab 1 – Information

The first tab of the tool gives a brief overview of the tool, including a list of key references and collaborations. On this tab the user will set their working directory.

Click on the 'Click to set working directory...' button and choose the folder which has all of your data files required for processing within the tool.
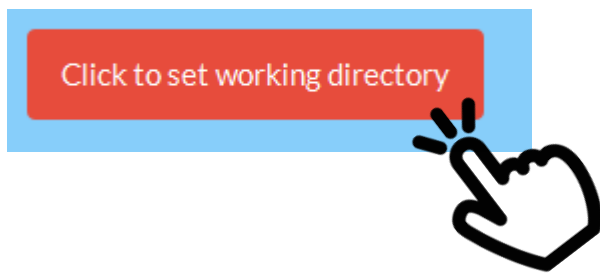
N.B. The selection window may pop up behind the tool, so please minimise the tool and have a look for the pop up if it does not appear upon clicking.

9.2 Tab 2 – Effort Data

The second tab of the tool is for loading fishing effort data.

Again, click on the 'Browse...' button to look for the required file.
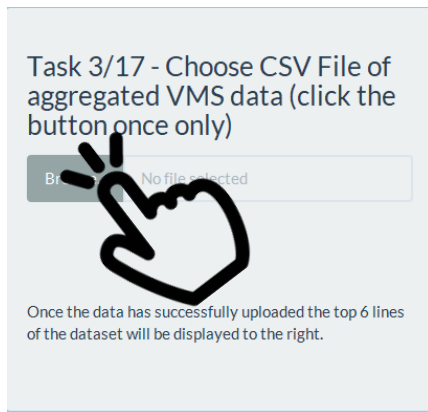
Once the file has been uploaded, the top 6 lines of the dataset will be displayed, and the upload complete icon will appear.

Here, you may also highlight if this assessment is for multiple gear types or a single gear type.

Below, is the table output:
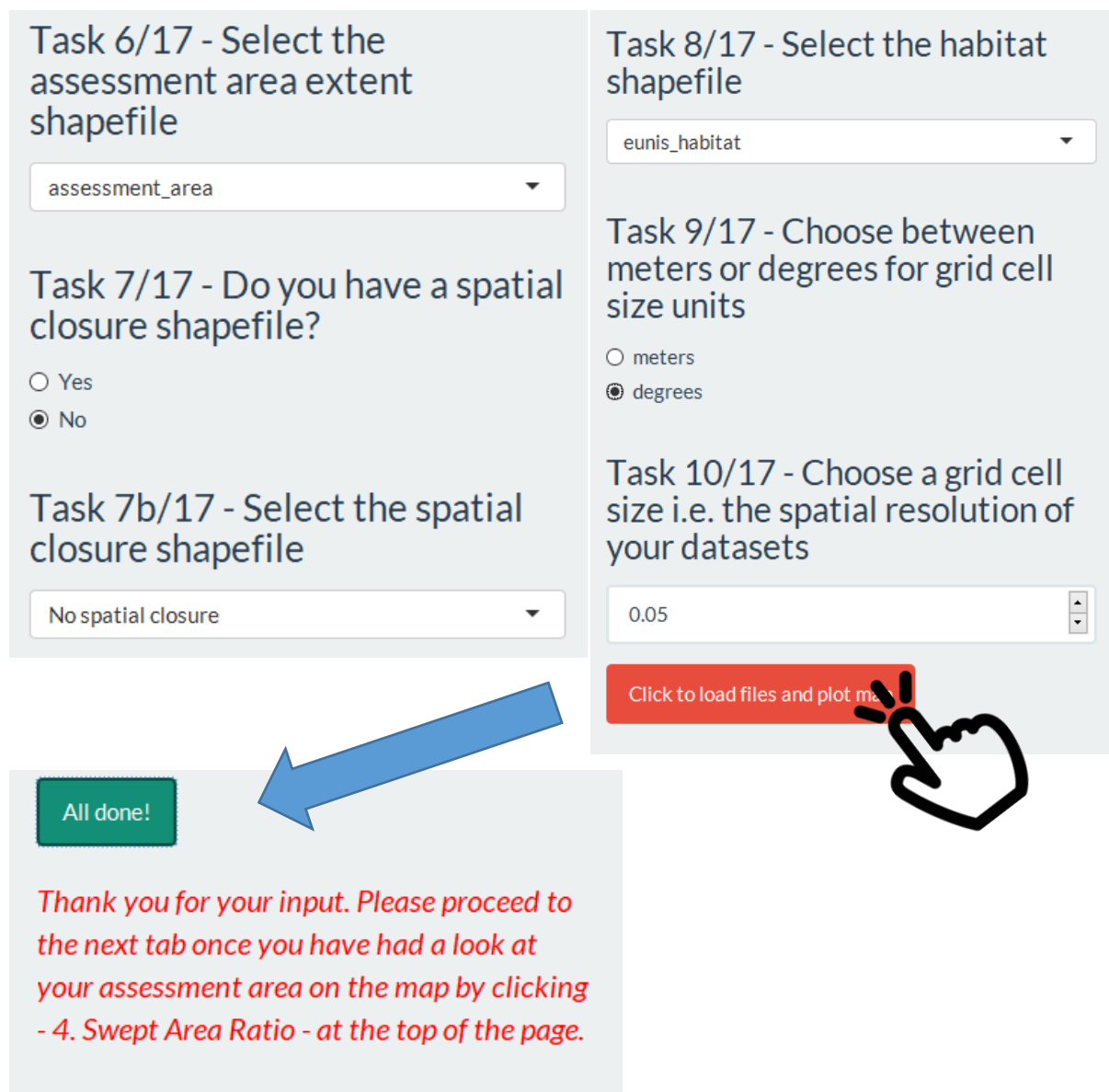
Navigate to next tab...

9.3 Tab 3 – Habitat Data

The third tab of the tool is for loading habitat, the spatial closure and the assessment area (e.g. Marine Protected Area) shapefiles. You may also indicate whether you would like to work in degrees or meters here and choose the spatial resolution of your data (we recommend the ICES standard of 0.05° if unsure).Click on the 'Click to load...' button once you have chosen the correct files from the dropdown boxes.

Task 6/17 - Select the assessment area extent shapefile

assessment_area ▼

Task 7/17 - Do you have a spatial closure shapefile?

○ Yes
◉ No

Task 7b/17 - Select the spatial closure shapefile

No spatial closure ▼

Task 8/17 - Select the habitat shapefile

eunis_habitat ▼

Task 9/17 - Choose between meters or degrees for grid cell size units

○ meters
◉ degrees

Task 10/17 - Choose a grid cell size i.e. the spatial resolution of your datasets

0.05

Click to load files and plot map

All done!

Thank you for your input. Please proceed to the next tab once you have had a look at your assessment area on the map by clicking - 4. Swept Area Ratio - at the top of the page.

The output will show an interactive map of the area of interest, highlighting the habitat types and the assessment area.

9.4 Tab 3 – Habitat Data continued

Map output:
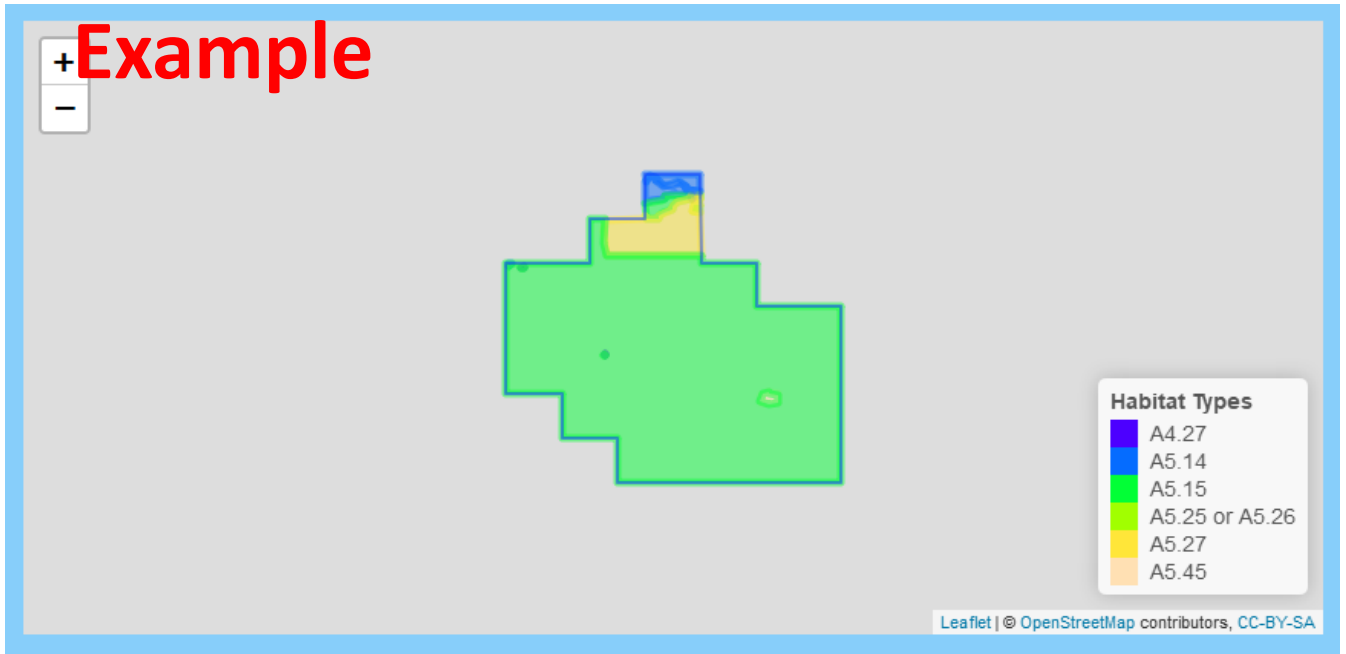
This is an interactive map, so feel free to navigate! Zoom in and out and click on various habitats for their names. This output is based on the three shapefiles (habitat, land, assessment area) which have just been uploaded into the tool.

The map will also have been saved to your working directory folder as "hab_map1.png". Please navigate to this folder to rename the file an appropriate name, this is critically important if you are running multiple assessments as the file refresh with every run of the tool if the filename is not changed.

Navigate to next tab…

9.5 Tab 4 – Swept Area Ratio (SAR, year^{-1})

The fourth tab of the tool calculates the Swept Area Ratio (SAR, year^{-1}) based on the number of years of fishing activity occurring in the assessment area.


Modify the number of years as appropriate, then click the 'Click to calculate…' button.

The SAR map will automatically be saved to your working directory as "SAR_map1.png". Please navigate to this folder and rename the file, as previously explained.

The histogram is an optional plot to download here. Add a filename and check the box to save the histogram to the working directory (i.e. your data folder).

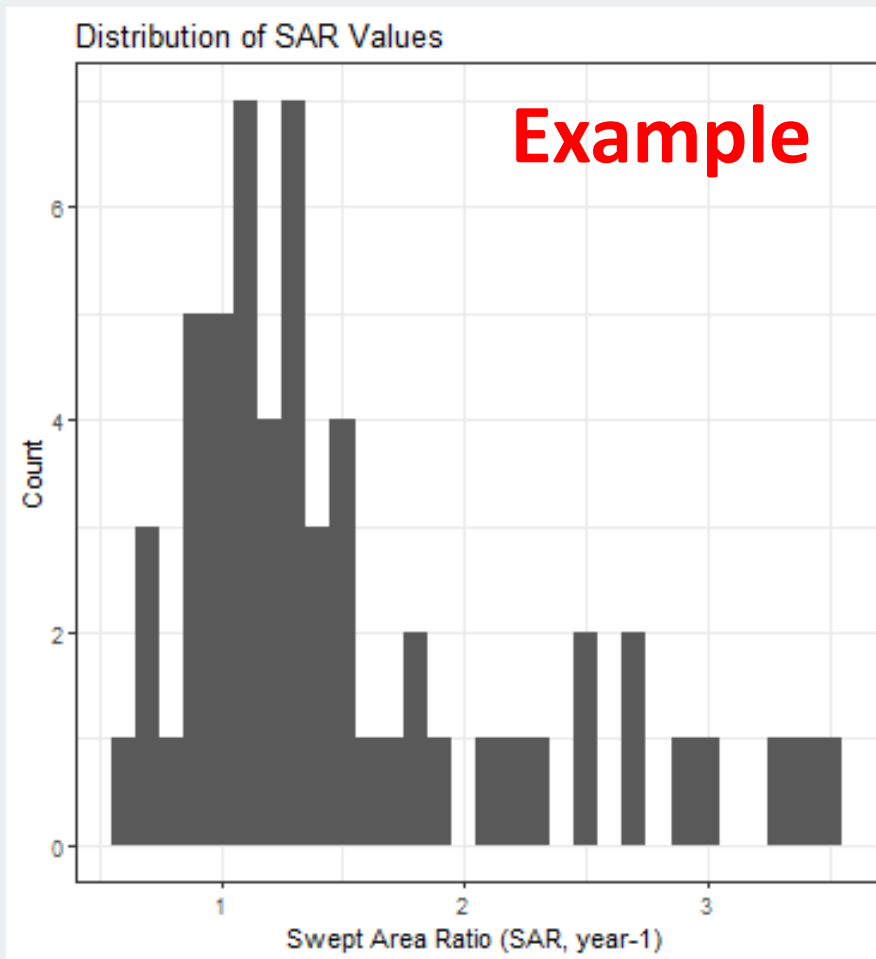The output will include a map of SAR for the assessment area…
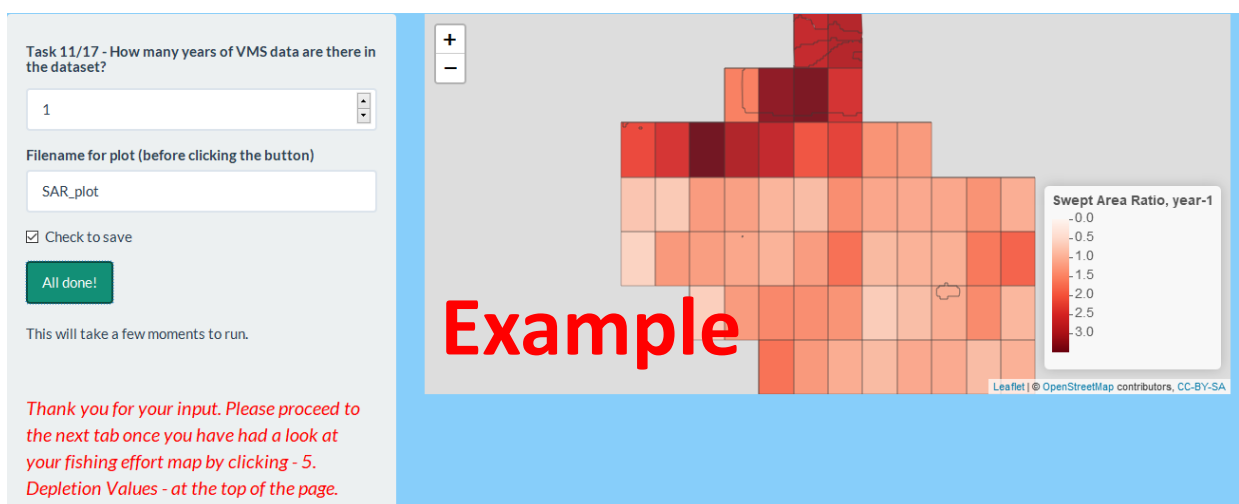
(again this is interactive, so have a look around)

9.6 Tab 4 – SAR continued

… and a histogram of SAR counts.

Below, a histogram will appear which will highlight the frequency distribution of the Swept Area Ratio within your assessment area.

Navigate to next tab…

9.7 Tab 5 – Depletion Values

The fourth tab of the tool associates depletion values to the data already uploaded. The depletion defines the fraction of organisms killed by a trawl pass and is dependent on gear and sediment type (see the assessment framework for further details, section 2).

Firstly, we need to select the gear type under assessment. This is a critical task, as it will influence the rest of the calculations within this tool.

The gear type of assessed fishery needs to be chosen here by modifying the dropdown box, the corresponding penetration depth her sediment type will then be highlighted for your interest.

The gear type has already been chosen in the previous tab… so no need to interact. If you would like to see the values for other gear types, click on the drop down to choose. However, make sure that your chosen gear type is the selected gear type for processing in the Tool.

Now we need to associate the habitat to a sediment type (if available / known).

Task 13/17 - If sediment type is known, choose either mud, sand or gravel from the dropdown box next to the associated habitat type. If sediment is unknown, table modification is not required.

	Habitat.Type	Sediments
1	A4.27	No sediment type chosen
2	A5.14	No sediment type chosen
3	A5.15	No sediment type chosen
4	A5.25 or A5.26	No sediment type chosen
5	A5.27	No sediment type chosen
6	A5.45	No sediment type chosen

Choose sediment type here from dropdown box (if known)

Example

	Habitat.Type	Sediments
1	A4.27	mud
2	A5.14	sand
3	A5.15	mud
4	A5.25 or A5.26	gravel
5	A5.27	gravel
6	A5.45	sand

Example

Task 14a/17 - Choose between standard gear types or modified gear types

◉ standard
◯ modified

Task 14 allows the user to choose between standard gear types (data already within tool) or modified gear types (data to be supplied by user). If choosing a modified gear type, please proceed to 14 b and 14c.

Task 14b/17 - Do you have a gear modification or novel gear type? If so, choose CSV File of data for gear, sediment and penetration depth (click the button once only)

| Browse... | No file selected |

Task 14b and 14c are both options for the user, if penetration depths per sediment types are available, upload data for 14b (for help with data formatting click here). If depletion data per modified gear type are available, upload data for 14c (for help with data formatting click here).

Task 14c/17 - Do you have a gear modification or novel gear type? If so, choose CSV File of data for gear and average depletion (click the button once only)

| Browse... | No file selected |

Click to generate depletion values

When ready to move on, click on the 'Click to generate...' button:

9.8 Tab 5 – Depletion Values continued

Depletion values for the fishery will be generated in a table, alongside the gear type, habitat names(s) and sediment type:

Example

Gear Type	Habitat Name(s)	Sediment Type	Depletion (fraction)
TBB	A4.27	mud	0.18
TBB	A5.14	sand	0.13
TBB	A5.15	mud	0.18
TBB	A5.25 or A5.26	gravel	0.18
TBB	A5.27	gravel	0.18
TBB	A5.45	sand	0.13

Depletion values registered. Please proceed to the next tab by clicking - 6. Recovery Rates - at the top of the page.

Navigate to next tab…

9.9 Tab 6 – Recovery Rates

The sixth tab of the tool calculates recovery rates, based on the longevity of species within the unit of assessment. This tab gives the user three options:

Option 1: Input longevity distribution parameters.

TASK 15/17 - How will you determine the recovery rates to use?

○ Input longevity distribution parameters
○ Input species data
◉ Use a default setting

This option requires prior knowledge of the longevity distribution, and the plotting of the logistic model outside of the tool. A table is available to input the m slope and b coefficient values per habitat type. For interest, two plots with sliders are also available which can be modified. However, only the values entered into the table will be registered by the Tool.

|	habitat	m_slope	b
1	A4.27	Add value	Add value
2	A5.14	Add value	Add value
3	A5.15	Add value	Add value
4	A5.25 or A5.26	Add value	Add value
5	A5.27	Add value	Add value
6	A5.45	Add value	Add value

Click to input values

**Navigate to next tab if this option is chosen...**

9.10   Tab 6 – Recovery Rates continued

Option 2: Input species data

This option allows the user to input further species longevity data for the habitats under assessment (if available). See Data formatting section for further information on data type.
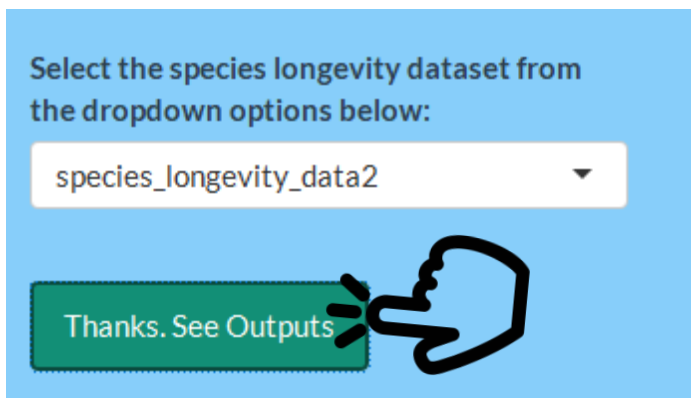
Then click on the 'Click to load…' button to load the new dataset into the tool. A plot and table of the data will be displayed. See example below.
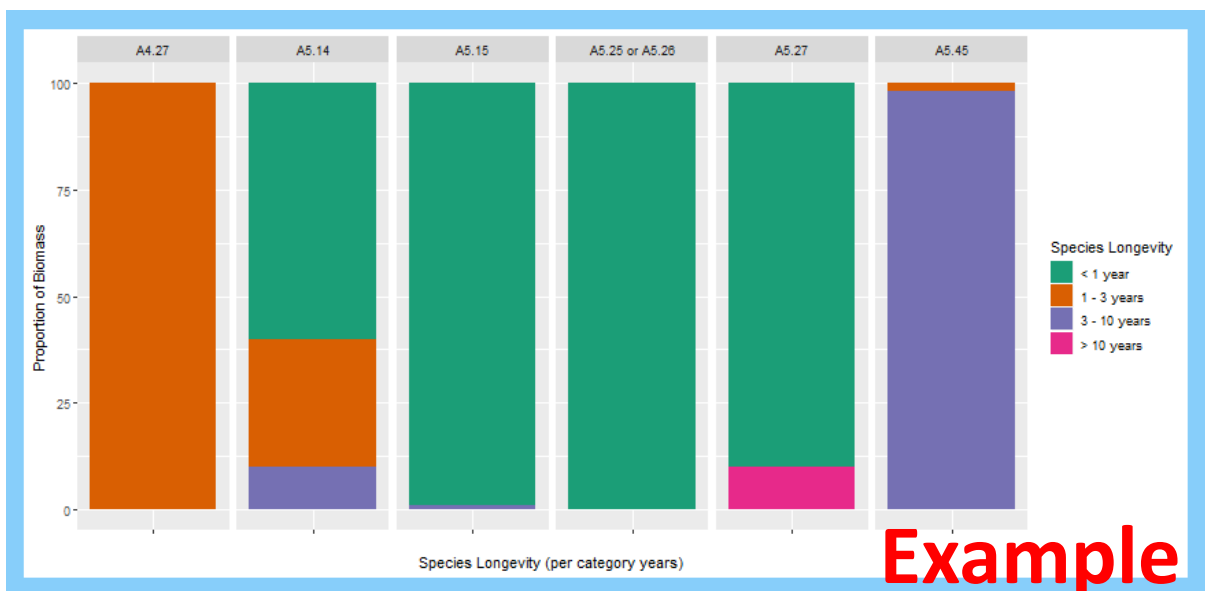
Habitat	Recovery Rate (overall)	Recovery Rate (CI60)	Recovery Rate (CI70)	Recovery Rate (CI80)
A4.27	0.22	0.20	0.18	0.16
A5.14	1.16	1.04	0.94	0.83
A5.15	0.86	0.7	0.70	0.62
A5.25 or A5.26	0.00	0.2	0.65	0.57
A5.27	0.58	0.52	0.47	0.41
A5.45	0.25	0.23	0.21	0.18

Thank you for your recovery rates. Please proceed to the next tab by clicking - 7. Benthic Status - at the top of the page.

Navigate to next tab if this option is chosen...

9.11 Tab 6 – Recovery Rates continued

Option 3: Use a default setting

This default setting is the value 0.42. This was chosen as the lower confidence interval estimate of r based on work by Hiddink *et al.,* (2017). For further information, see The Science section or consult the published peer-reviewed journal paper.
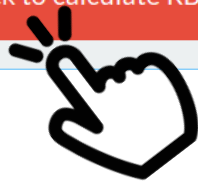
9.12   Tab 7 – Benthic Status

The Relative Benthic Status (RBS) will be calculated on this seventh tab. The RBS combines the data and information provided on previous tabs and considers the ratio between depletion and recovery. Click on the 'Calculate…' button.


The RBS map will automatically be saved to your working directory as "RBS_map1.png". Please navigate to this folder and rename the file, as previously explained.

The histogram is an optional plot to download here. Add a filename and check the box to save the histogram to the working directory (i.e. your data folder).

This will output an interactive map, a table and histograms per habitat type.
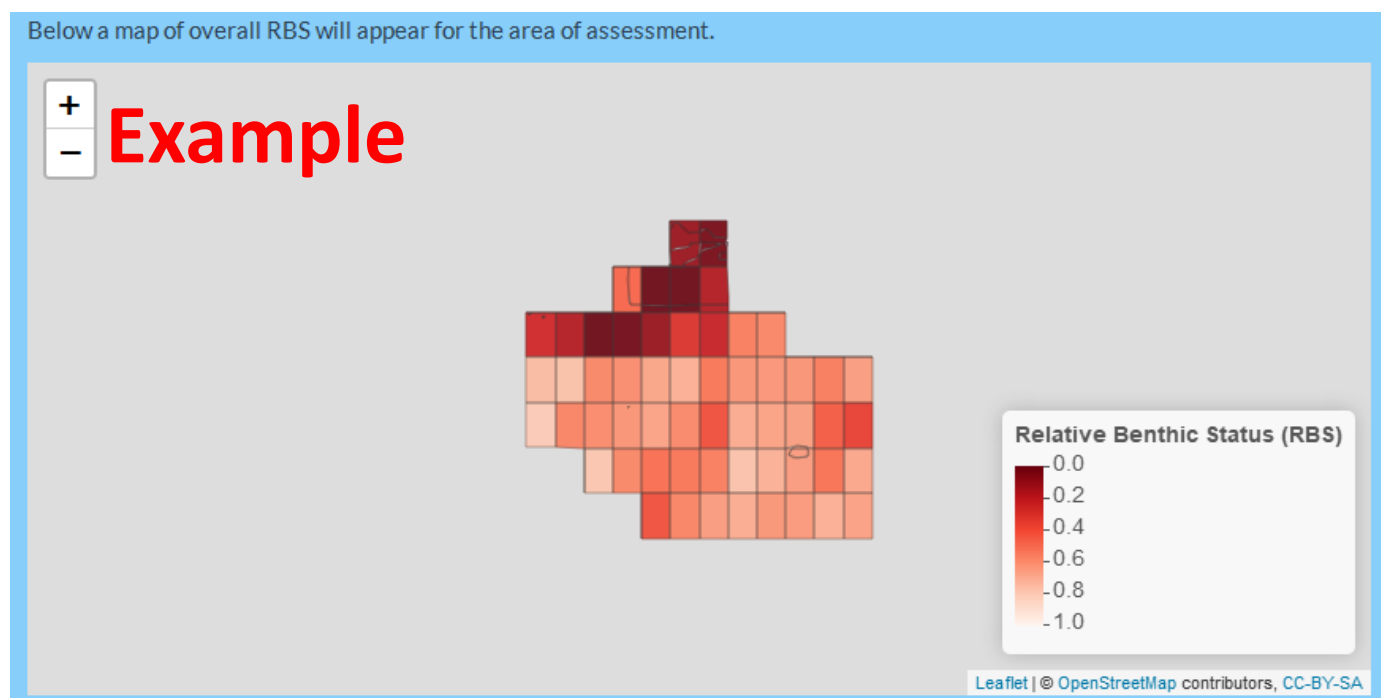
Weighted overall RBS scores per habitat type:

Example

Example

Habitat Type	Overall RBS Score	Total Area of Habitat Type (Km^2)
A4.27	0.60	0.14
A5.14	0.57	20.33
A5.15	0.77	1032.01
A5.25 or A5.26	0.92	0.80
A5.27	0.64	66.75
A5.45	0.98	2.85

The plot below illustrates the distribution of RBS scores when using the entire longevity distribution per habitat.
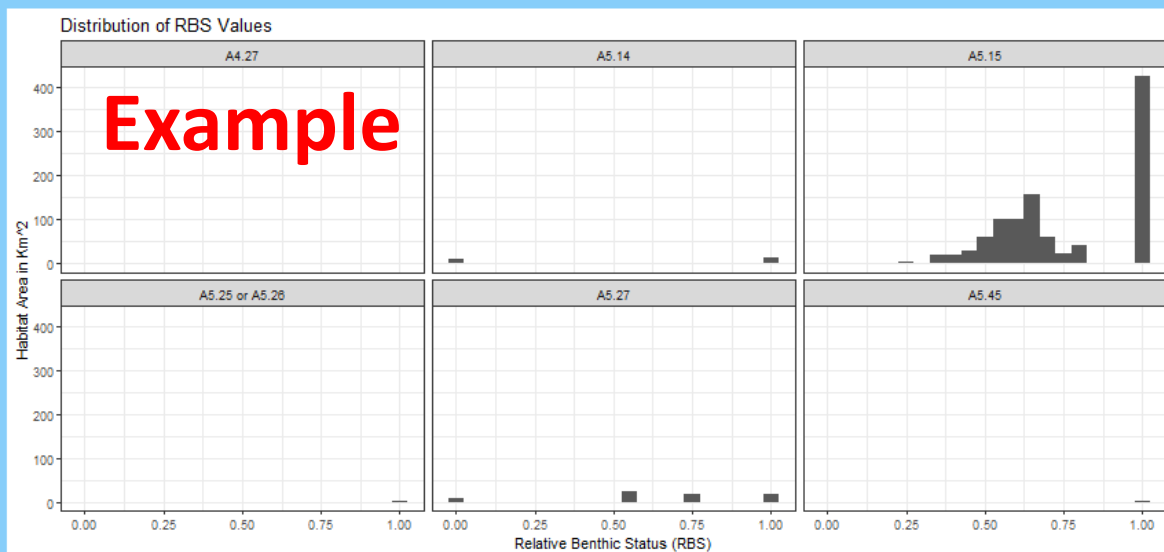
Distribution of RBS Values

Example

9.13   Tab 8 – Recovery Time

The eighth and final tab calculates a projected recovery time per habitat type. These outputs will be used alongside other data by assessment teams to support their consideration adaptive marine protected area management. Again, we consider all the data uploaded and values calculated from previous tabs to calculate an estimated recovery time trajectory for each habitat type within the community.

To commence this calculation, click on the 'Calculate recovery time' button.

Filename for plot

recovery_plot

☑ Check to save

TASK 17/17 - Click to calculate recovery time

The histogram is an optional plot to download here. Add a filename and check the box to save the histogram to the working directory (i.e. your data folder).

The first plot generated will highlight the recovery trajectory when considering the entire longevity distribution of species in the community.

Each plot represents one habitat type, the grey lines illustrate the recovery trajectory for an individual grid cell, and the black lines indicate the total recovery trajectory across all species. The dashed line indicates an RBS of 0.8 (this is 80% habitat carrying capacity).

Predicted Recovery Trajectories per Habitat Type
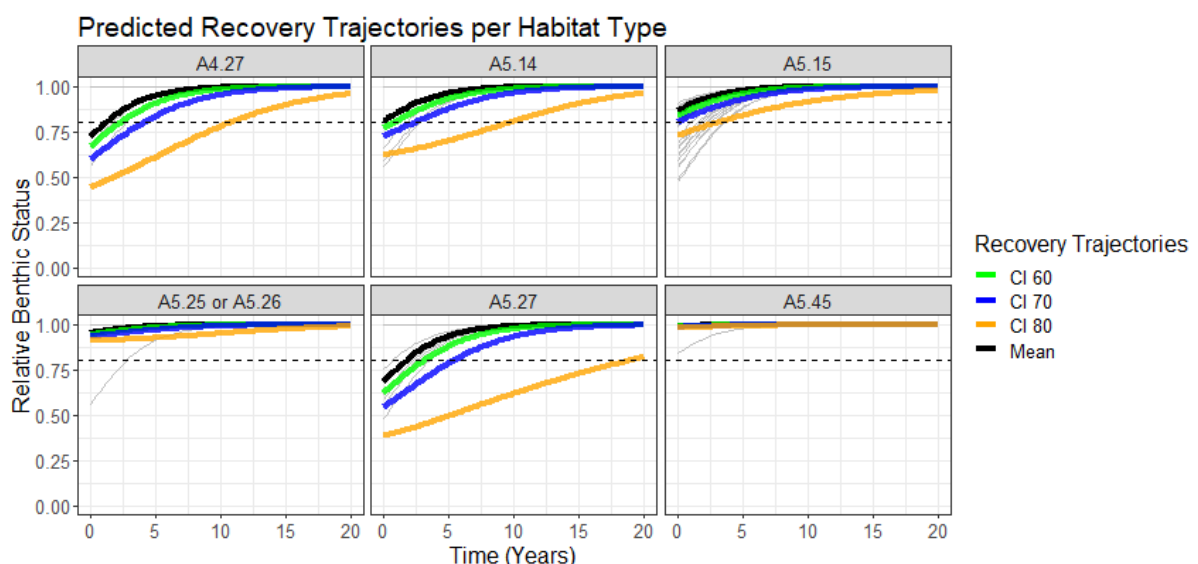
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Hiddink, J.G., Jennings, S., Sciberras, M., Szostek, C.L., Hughes, K.M., Ellis, N., Rijnsdorp, A.D., McConnaughey, R.A., Mazor, T., Hilborn, R., Collie, J.S., Pitcher, R., Amoroso, R.O., Parma, A.M., Suuronen, P. & Kaiser, M.J. (2017) Global analysis of depletion and recovery of seabed biota following bottom trawling disturbance. *Proceedings of the National Academy of Sciences*, **114**, 8301–8306.

Hughes, K.M., Kaiser, M.J., Jennings, S., McConnaughey, R.A., Pitcher, R., Hilborn, R., Amoroso, R.O., Collie, J., Hiddink, J.G., Parma, A.M. & Rijnsdorp, A. (2014) Investigating the effects of mobile bottom fishing on benthic biota: a systematic review protocol. *Environmental Evidence*, **3**, 23

Pitcher, C.R., Ellis, N., Jennings, S., Hiddink, J.G., Mazor, T., Kaiser, M.J., Kangas, M.I., McConnaughey, R.A., Parma, A.M., Rijnsdorp, A.D., Suuronen, P., Collie, J.S., Amoroso, R., Hughes, K.M. & Hilborn, R. (2017) Estimating the sustainability of towed fishing-gear impacts on seabed habitats: a simple quantitative risk assessment method applicable to data-limited fisheries. *Methods in Ecology and Evolution*, **8**, 472-480.

Pitcher *et al* (In prep) Trawl impacts and seabed habitat status in 24 regions of the world.

Rijnsdorp, A.D., Bolam, S.G., Garcia, C., Hiddink, J.G., Hintzen, N., Kooten, T.v. & Denderen, P.D.v. (2018) Estimating the sensitivity seafloor habitats to disturbance by bottom trawling impacts based on the longevity of benthic fauna. *Ecological Applications*, **28**, 1302-1312.

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11. Acknowledgements

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See https://trawlingpractices.wordpress.com/ for further information.

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12. Glossary

- **Swept area ratio (SAR, year^{-1})** – The number of times an area is swept by fishing gear. If a grid cell has a yearly SAR of 1 this means on average the whole cell is swept once per year. A SAR of 0.5 means that on average half of the cell is swept once per year.

- **Relative Benthic Status (RBS)** – The RBS of a grid cell indicates what proportion of the benthos has been removed. An RBS of 1 means there has been no depletion, a value of 0 means a grid cell is totally depleted.

- **Vessel monitoring system (VMS)** – A satellite based monitoring system which provides data about the location, course and speed of vessels.

- **Vulnerable Marine Ecosystems (VMEs)** – Areas that may be vulnerable to impacts from fishing activities.

- **Automatic Identification System (AIS)** – An automatic tracking system that uses transponders on ships to record their location.

- **Depletion -** The depletion rate, d, relates to the fraction of organisms killed by a trawl pass (Hiddink *et al.,* 2017).

- **International Council for the Exploration of the Sea (ICES)** - An intergovernmental marine science organization, meeting societal needs for impartial evidence on the state and sustainable use of our seas and oceans.

- **Recovery Rates** – The recovery rate, r, relates to the ability of an organism to recover after disturbance.

- **Recovery Time** – The time taken for a habitat to recover to full (100%) or 80% (MSC standard) carrying capacity after the cessation of fishing (Hiddink *et al*., 2018).

- **Population Model** – A mathematical model which is applied to the study of population dynamics.

- **Marine Stewardship Council (MSC)** - An independent non-profit organisation which sets a standard for sustainable fishing. Read more at www.msc.org

- **Longevity** – the lifespan of a species in years

- **Shapefile** - a vector data storage format for storing the location, shape and attributes of geographic features. This includes a set of related files.

13. Helpdesk Information

For help regarding the tool, please contact:

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The Benthic Impacts Tool has been designed to be a web based application and may be made available as such in the future.

The Benthic Impacts Tool and User Manual were developed and compiled by Lowri E. Evans, Jennifer Shepperson and Jan G. Hiddink (Principal Investigator) at Bangor University.