ARUP

Ecostructure Output Guide

A guide for practitioners on how to use the tools and resources from the Ecostructure project to facilitate eco-engineering and biosecurity of coastal and marine developments

https://ecostructureproject.aber.ac.uk

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Executive Summary

The Ecostructure project brought together five universities in Wales and Ireland to explore how eco-engineering could be used to increase the biodiversity of artificial marine structures, how it could bring other benefits to society and the environment and explored the potential impacts of invasive non-native species.

Between 2014 and 2022 several research streams resulted in outputs such as applications (‘apps’), tools and papers. This Guide compiles and describes the outputs to raise awareness and facilitate eco-engineering and biosecurity interventions in the coastal and marine environment.

Use the following diagram to navigate the various outputs included in the Guide.

Ecostructure Output	**Output summary and objective**	**Who is it for?**				**Stage of project**			
		Regulators	**Designers**	**Planners**	**Asset Managers**	**Planning**	**Design**	**Construction**	**Monitoring**
1. Mapping repository of the Irish and Welsh shores	Mapping data set for existing artificial structures along the Irish Sea coastline	✓	✓	✓	✓	✓			✓
2. BioPredict Tool	Online tool to map data collected in the Irish Sea and model relationships between physical and environmental parameters and a range of biodiversity metrics to predict biodiversity in different structures	✓	✓	✓	✓	✓	✓		
3. Ecosystem Functions and Prediction Tool	Downloadable tool for predicting ecosystem functions, rates and processes for coastal intertidal communities around the UK and Ireland		✓	✓	✓	✓	✓		
4. Conservation Evidence Synopsys - Biodiversity of Marine Artificial Structures	Synopsys covering published evidence of conservation interventions to support decision making for enhancing biodiversity of marine structures	✓	✓	✓		✓			✓
5. New approaches to eco-engineering: photogrammetry and 3D printing	Papers "Artificial shorelines lack natural structuralcomplexity across scales" and “Replicating natural topography on marine artificial structures – A novel approach to eco-engineering” which demonstrate the use of photogrammetry and 3D printing to investigate surface complexity at different scales as well as replicating natural surfaces		✓				✓	✓	
6. Guidance for integration of stakeholder interests into eco-engineering project	Guidance document including steps for successful stakeholder engagement, methods and procedures commonly used such as workshops, site visits, community engagement and media & press.		✓			✓	✓		
7. Report on impacts of eco-engineering upon cultural and amenity value of artificial structures	Paper "Species diversity enhances perceptions of urban coastlines at multiple scales" to explore the cultural and amenity perception of artificial structures in the intertidal environment.		✓	✓	✓	✓	✓		
8. Designs for artificial habitat units for european lobster	Research focused on laboratory and in-situ trials of different habitat types for European lobster to support the design of habitat enhancement, both for conservation and commercial activities		✓		✓		✓		✓
9. Policy briefs on coastal eco-engineering, based on a review of relevant policies, legal requirements and management practices	Policy Briefs to help users navigate the planning and licencing process and a Report which details the legal systems in Ireland and Wales, describing national and local authority policies and legal requirements	✓		✓		✓			
10. Larval Dispersal Tool	Online tool to analyse and visualise larval dispersal within the Irish Sea based on user selection of release location, season of release, length of larval lifetime and larval behaviour		✓	✓	✓	✓			✓
11. Models of the effects of existing and proposed offshore renewable energy structures on dispersal of non-native species	Research focused on impacts to connectivity of marine species and populations from present and future offshore renewable energy structures and climate change in the Irish Sea	✓		✓		✓			✓
12. Stakeholder engagement to improve biosecurity in ports and marinas	Paper "Determining the most effective educational interventions to encourage biosecurity and pro-environmental behaviour amongst recreational boaters"; Interactive training tool for recreational boating and paddling organisations and marina operators.	✓			✓	✓			
13. Methodologies for the early detection of non-native species from environmental DNA in water samples	Paper "The use of environmental DNA metabarcoding and quantitative PCR for molecular detection of marine invasive non-native species associated with artificial structures" which demonstrates the use of two techniques for species detection and in particular INNS	✓			✓	✓			✓

The Ecostructure project

The coastlines and inshore waters of Britain, Europe and the rest of the World are under increasing pressure from urbanisation, construction of maritime infrastructure such as ports and marinas, renewable energy infrastructure such as offshore wind turbines and others. The need to protect homes and infrastructure from erosion and storms has led to further coastal modification, through the construction of sea walls, breakwaters, groynes and other forms of coastal defence and increased sea levels due to global climate change are likely to increase the demand for coastal modification even further in the future.

Ecostructure brought together five universities in Wales and Ireland - Aberystwyth University, Bangor University, Swansea University, University College Cork and University College Dublin and was part-funded by the European Regional Development Fund (ERDF) though the Ireland-Wales Cooperation programme 2014-2020.

The focus of the Ecostructure project was to:

- Explore how eco-engineering could be used to increase the biodiversity and ecosystem functions of artificial coastal and marine structures.
- Explore the potential impacts of artificial coastal and marine structures on the spread of marine invasive non-native species.
- Promote the incorporation of secondary ecological and societal benefits into coastal defence and renewable energy structures, with benefits to the environment, to coastal communities, and to the blue and green sectors of the Irish and Welsh economies.

To accompany the research and experimental designs, Ecostructure produced practitioner facing tools and resources designed to raise awareness and facilitate uptake of opportunities to employ coastal eco-engineering solutions to climate change adaptation and support evidence-based planning and decision-making for marine artificial structures. This Guide produced by Arup for Ecostructure compiles and describes the main Ecostructure project outputs to allow practitioners to understand the research objectives of each one, main findings and how they can be used in practice to support decision making.

CONTACT DETAILS AND RESOURCES

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Ecostructure website

1. Mapping repository of the Irish and Welsh shores

INTRODUCTION AND DRIVERS

Ecostructure researchers have provided a repository of all the artificial structures within the Irish Sea coastline for all users interested in the relationship between artificial structures and the quality of the marine environment. This repository contains maps and data that characterise the key features of artificial structures in the Irish Sea and the environmental contexts in which they are placed. The purpose of this resource is to enable the identification of features that are associated with minimal impacts on natural ecosystems that may also give rise to conservation and societal benefits.

Both the east coast of Ireland and the entire coastline of Wales are dotted with numerous artificial structures including sea walls, groynes, jetties, platforms, access ramps, etc. There is currently little other freely available information on the physical properties or ecological importance of these structures. The Ecostructure repository provides a GIS based map of all artificial structures on the east coast of Ireland (from Louth to Kerry) and the entire coast of Wales, providing detail on: structure type, location, material the structure is made from, exposure and salinity level, aspect of the structure, slope, tidal height respective of the structure and the distance to the nearest natural shoreline.

The data for all sites in the repository were digitally determined with several locations throughout Ireland and Wales physically sampled to verify the data.

This resource is aimed at a variety of users including planners, consultants and researchers who may need to understand the nature of the built environment along the coastline to support decision making.

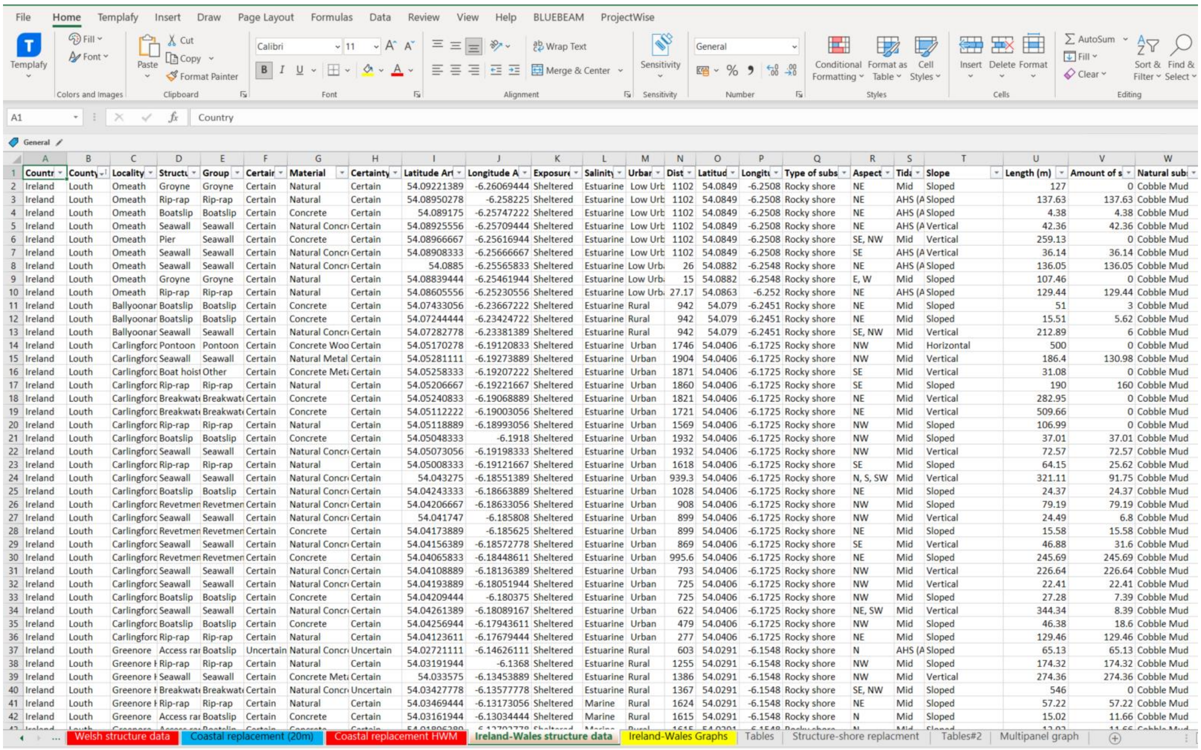
HOW TO USE THE TOOL

This tool provides details of artificial structures on the Irish Sea Coastline in Ireland and Wales and the data repository can be accessed at the link provided at the bottom of this Section.

The tool allows for the visualisation of each mapped artificial structure within the Irish Sea and identification of locations for potential future projects. Within the repository there is a suite of statistical analyses of the mapped features found on the tab ‘Ireland-Wales Graphs’. The statistical analyses relate to factors such as: structure type, location, aspect, tidal height, slope, structures per habitat, salinity, exposure and degree of urbanisation.

A user will require access to a GIS enabled platform to visualise the data.

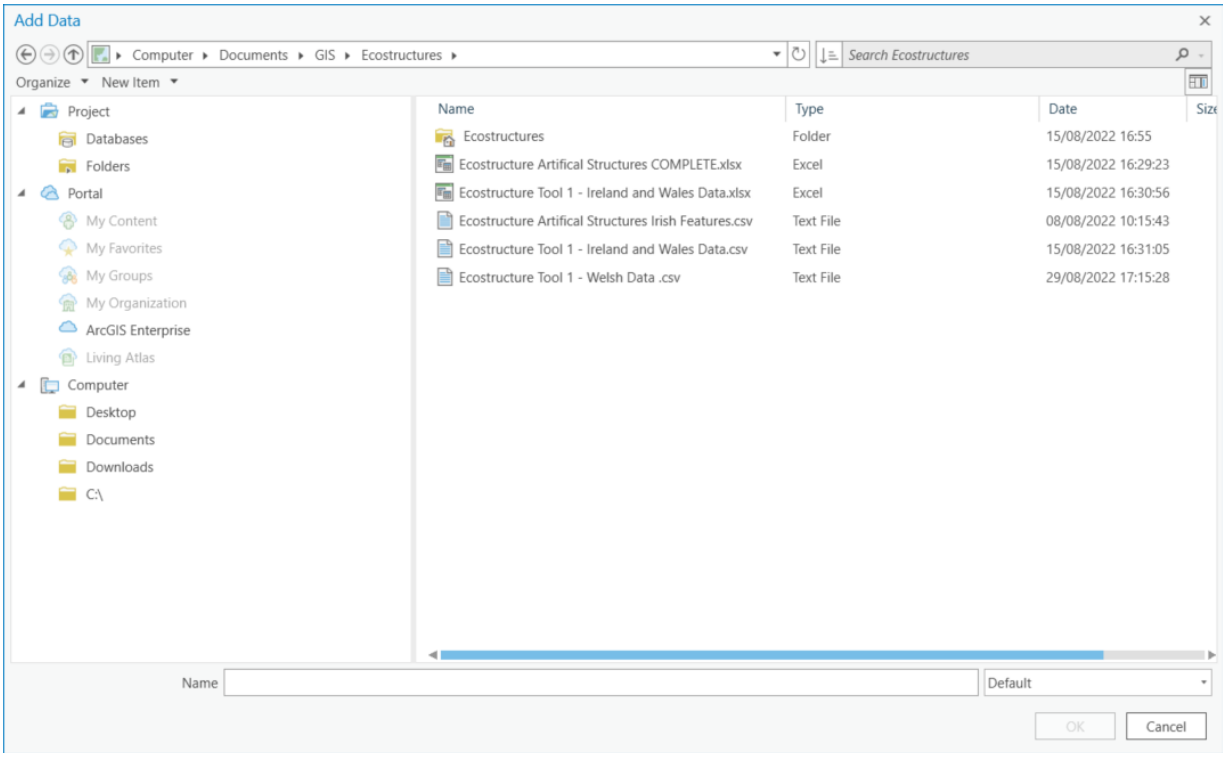
The repository is provided in Excel format:



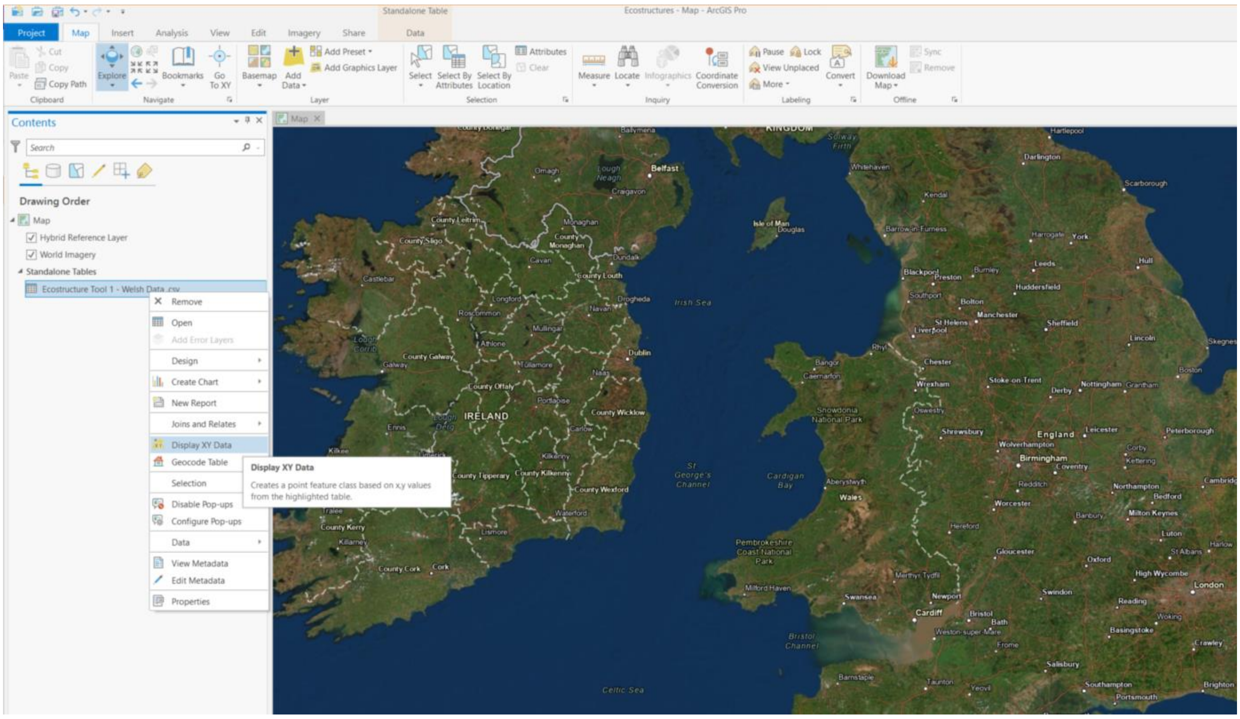
To display the data in GIS format, the following steps are applicable to ESRI ArcPro.

1. In Excel, **view** either the Irish Structure Data tab or the Ecostructure Tool 1 - Welsh Data tab.
2. Save as > .csv to a known destination within the internal hard drive of the computer:

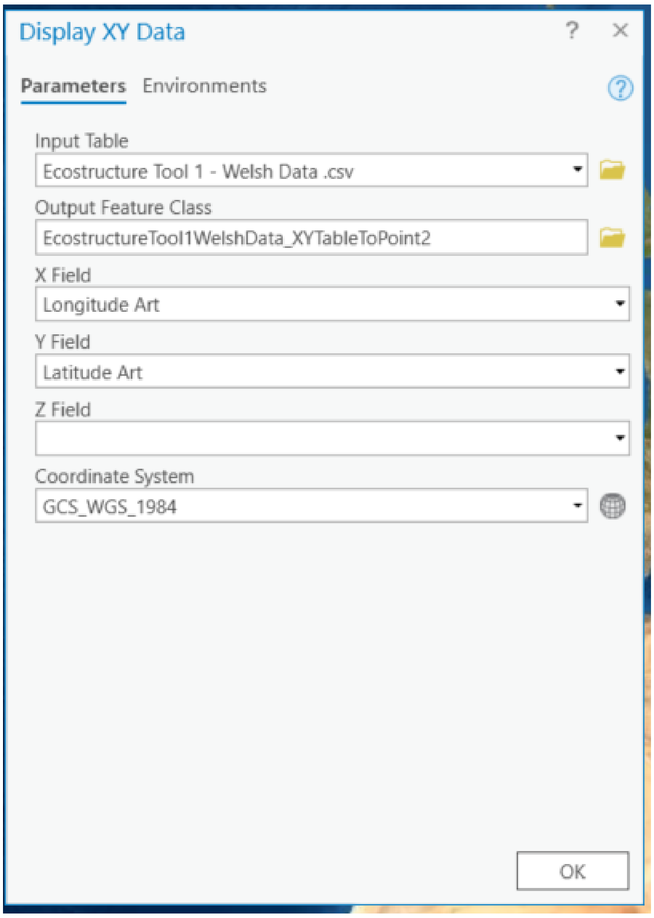
3. Open ArcPro > New Project > Add Map
4. Set co-ordinate system to WGS 1984.
5. Add data > navigate to the saved .csv file> Ok



6. Within the Drawing Order, navigate to the ‘Standalone Tables’ and right-click the table imported in > Display XY Data:



7. In the ‘Display XY Data’ pop-up, input longitude and latitudes into the X and Y fields > Ok:



8. The points will be displayed on the map chosen (Welsh example below):

OPPORTUNITIES AND LIMITATIONS

Opportunities:

- Allows a practitioner to evaluate locations where a new structure may be built based on factors such as coastal erosion, climate change and expanding human populations.
- Future opportunities lie in producing a similar output for the west coast of Ireland, the Scottish and English coastlines.
- A paper on this project is due to be published in the future.

Limitations:

- The dataset that informs this repository was generated in 2018 and therefore, the data may not be up-to-date at all locations.
- The data is subjective to each practitioner, and it is advised that this data be used as baseline data prior to specific ground-truthing carried out per future project.

CONTACT DETAILS AND RESOURCES

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- Mapping Repository
- Ecostructure Conference presentation Ecostructure 'GIS Maps and Database of Artificial Structures'
- Ecostructure Conference presentation 'From surveys to practical tools: the Ecostructure Mapping Database and BioPredict Tool'

2. BioPredict Tool

INTRODUCTION AND DRIVERS

Artificial structures are built along coastlines to protect property and to provide access for sea-based activities. There is growing interest predicting the most likely biological communities that will colonise new structures. This interest stems from the potential of these new surfaces to provide stepping-stones for problem species and/or to provide surrogate habitats for coastal biodiversity, both topics of interest in regard to climate change, biodiversity and biosecurity.

BioPredict is a tool that comprises new and existing data describing the physical features (e.g. material, structure type); environmental context (e.g. wave exposure, salinity) and biological communities of 69 intertidal artificial structures around the Irish Sea coasts of Wales and Ireland. It can be used to model the relationships between the physical and environmental parameters ('predictor variables') and a range of biodiversity metrics calculated for each structure.

This tool is very flexible and users with different backgrounds and objectives can explore the baseline data in multiple ways from awareness raising to gathering evidence and justifying decision making and recommendations.

HOW TO USE THE TOOL

The tool provides four different ways of exploring the data and the models. Each can be accessed via tabs on the BioPredict Tool webpage:

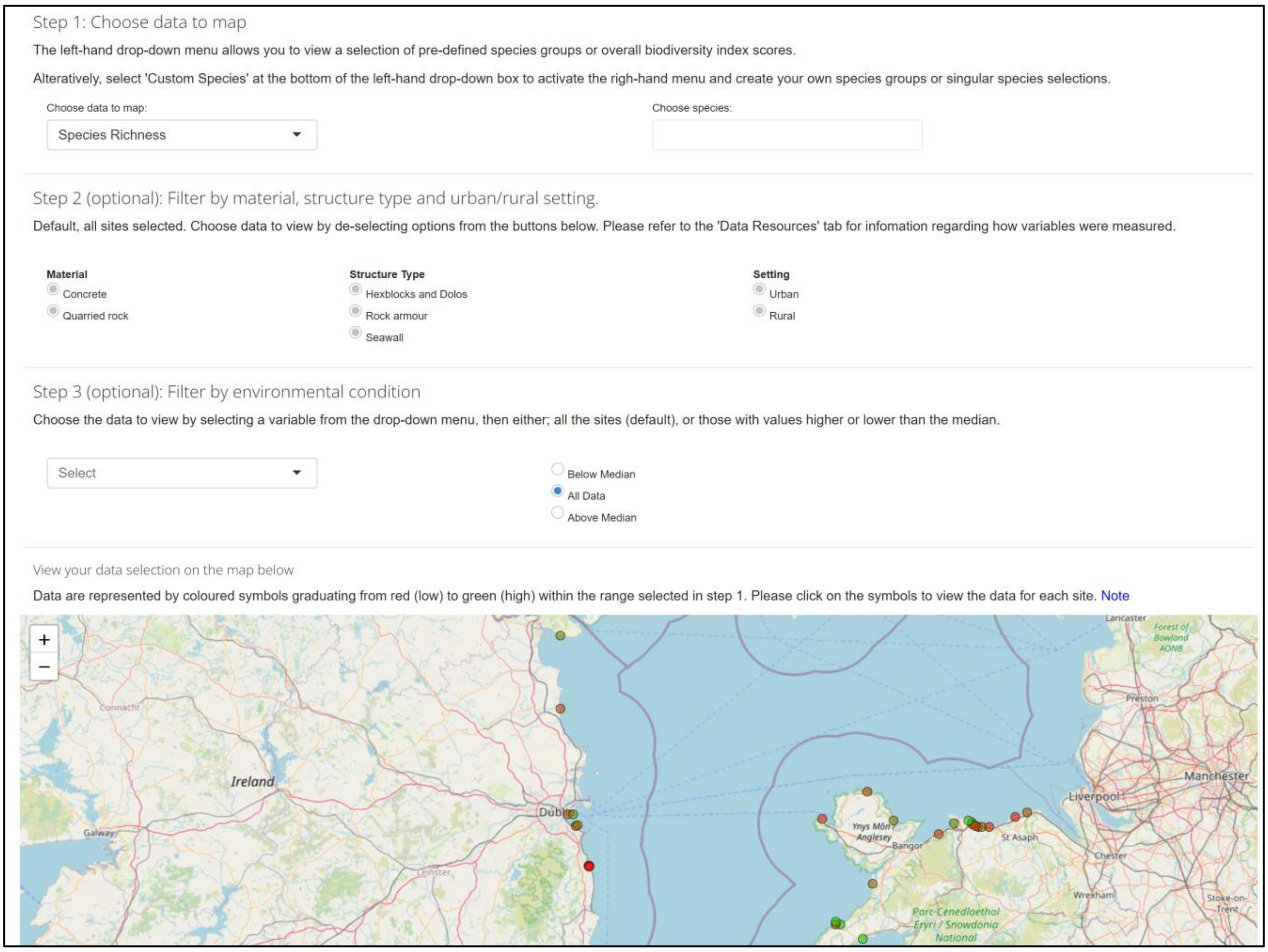
1. *Map the data*

This page allows you to map the data used to build this Ecostructure tool in many ways. You can view the survey sites (69 artificial coastal structures) around the Irish Sea and see what biodiversity (numerous indices) was recorded on them. The number or value shown on the points in the map is based on the SACFOR scale or presence/absence. The baseline information is provided in the Data Resources page, the number presented is typically an indicative total organism density per m2 (though not always the case and therefore familiarity with Data Resources is advised).

Step 1: Choose species, group, or index.

Step 2 (optional): Filter sites by material, structure type or setting.

Step 3 (optional): See the sites above and below the median for a selected environmental condition.



2. *Pre-defined Models*

This page contains pre-defined models (by the Ecostructure team) that have been run for selected species, groups or indices. The outputs provide plots revealing the most influential predictor variables but also the current potential and uncertainty of the collected data.

Step 1: Choose species, group, or index to model.

Step 2: Explore model outputs including the decision tree, model accuracy (confusion matrix), the number and the variables that best predict the chosen index. Further information about the outputs is included in the Tool webpage.

3. Custom Models

In the custom models tab you can select any species, group of species or index and run models in real time to characterise their occurrence given a suite of variables of interest to you.

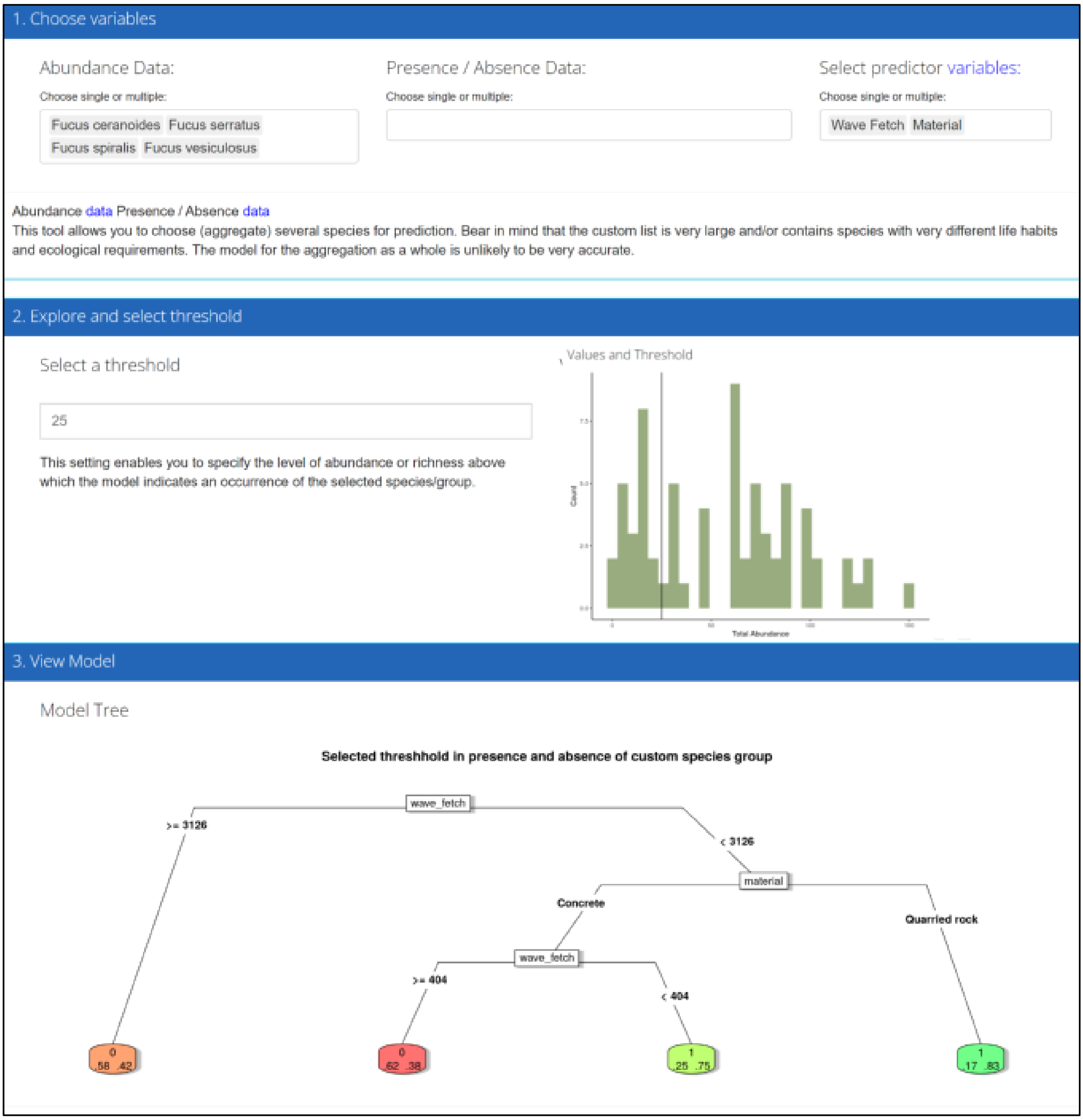
Step 1: Choose your variables.

A: Select from “Abundance” or “Presence / Absence” data.

B: Select from on-site and/or remote sensed data to predict your biotic variable.

Step 2: Select a threshold. (Below which would indicate a “Fail” or undesirable result).

Step 3: Explore model outputs, in particular the decision tree.



4. Data Resources

This page allows you to access and download the raw and meta-data used to build this tool.

Resource 1: Raw Ecostructure survey data.

Resource 2: Meta-data (Environmental variables).

Resource 3: Meta-data (Biotic data collection).

OPPORTUNITIES AND LIMITATIONS

Opportunities

- The tool is intended for sites within the Irish sea, as this is where the 69 data points are. However, it could be used for other areas if these are considered ecologically similar as indicative guide or comparison.
- Additional data can be added (in the right format) to the existing dataset which is freely available in the Data Resources, thus improving the tool. The 'Custom Models' will run on the expanded dataset, however, the 'Pre-defined Models' will not be updated and would still be based on the data from the original 69 locations.
- The code for the tool itself is stored online. The tool could be optimised and edited for any scale.

Limitations

- The outputs generally require a level of user interpretation and understanding of statistics.
- The tool has been created from data collected at 69 locations and although they cover a wide range of locations and conditions, it is localised data at a specific point in time.

CONTACT DETAILS AND RESOURCES

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BioPredict Tool

3. Ecosystem Functions and Prediction Tool

INTRODUCTION AND DRIVERS

The ecosystem functions and prediction tool, known as EFPREDICT tool was developed by researchers at Swansea University using R statistical programming software to predict ecosystem functional rates and service indicators. For the long term benefits to biodiversity, it is vital that ecosystem functions and services are integrated into environmental management frameworks. However, it is recognised that there is a lack of information regarding how species and whole communities can contribute to multiple functions and services, especially in the marine environment. The EFPREDICT tool aims to use species trait models to predict how modification of environmental conditions or community composition can change the variety and rates of ecosystem functions performed. The tool was informed by case study scenarios for intertidal coastlines, based on real surveyed locations to demonstrate how promoting existing marine coastal communities through naturalistic shoreline design can contribute to a healthy and resilient ecosystem across the seasons.

The primary driver of this tool was to give an indication of the ecological condition of a site and bridge the gap between ecological information and the ecosystem functions and benefits it provides. Knowledge of these ecosystem services is becoming critical for policy making and has been designed for policy makers, planners, ecologists and developers as well as researchers. Feedback from those that have used the tool have commented that it is user-friendly.

The tool calculates a range of ecosystem processes and functions for intertidal animal and algal communities. 230 species are represented within this database. This package is suitable to apply to artificial coastal structures and natural intertidal habitats, such as rocky reefs. It allows the predictions for oxygen fluxes (respiration, primary productivity), nutrient fluxes (uptake/excretion of ammonium and nitrate), filtration efficiency (clearance rate), carbon flux, biomass and the cultural ecosystem service indicator of aesthetic appeal.

HOW TO USE THE TOOL

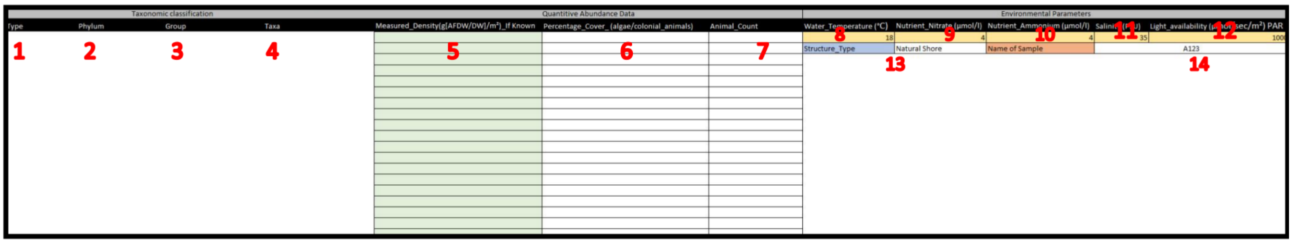
A full breakdown of the methodology is summarised within the EFPREDICT guide which is linked at the bottom of this section. This tool utilises excel templates to populate the required data fields from a variety of different survey formats. Additionally, the package uses R or R-Studio statistical analysis. It is advised to install the following packages from *cran* before installing the EFPREDICT package: *<vegan><readxl><openxlsx>*

Before Starting:

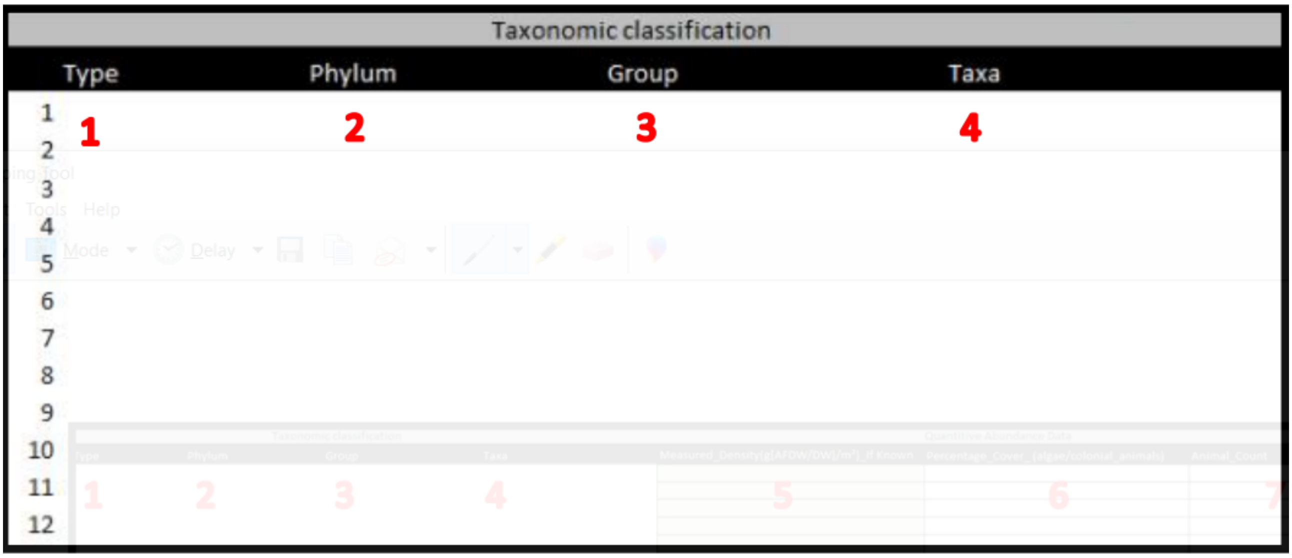
1. Download the "Input.xlxs" datasheet from this link.
2. Save a version of the excel sheet under a new name to your working directory.
3. A copy of the "Outputs.xlsx" file should also be added to your working directory, but this should not be modified.

Using the Tool

4. Open the newly named version of the "Input.xlxs" file.
5. The excel spreadsheet should look like this:



6. **Taxonomic data**: Regarding fields 1-4, these are the taxonomic classification fields that are used to input the community data into the model. Data fields provide drop down menus for selecting responses, and cell choices cascade from 1-4, and have to be completed in sequence.



7. **Abundance data**: Fields 5-7 (as shown below) represent the abundance data and requires input. There is some flexibility with the input data as the tool can take either measured biomass data (field 5), percentage cover data (field 6) and the animal count data (per m^2) (field 7).

8. **Environmental data:** Guidance on these parameters is available in the guidance tab on the input sheet. Fields include water temperature (field 8), nutrient nitrate level (field 9), nutrient ammonium level (field 10), salinity (field 11), light availability (field 12), structure type (field 13 and name of sample (field 14).

The environmental data can be inputted for a variety of scenarios, changing either one factor or multiple dependent on the scenario that is applicable to a project.

Environmental Parameters				
Water_Temperature (°C)	Nutrient_Nitrate (µmol/l)	Nutrient_Ammonium (µmol/l)	Salinity (PSU)	Light_availability (µmol/sec/m^2) PAR
8 18	9 4	10 4	11 35	12 1000
Structure_Type	Natural Shore	Name of Sample		A123
	13			14

9. Once the input fields have been populated, in the output sheet, each major ecosystem function, process or service indicator predicted by the model is represented accompanied by a modelled estimate for each function and upper (95% Cl) and lower (5% Cl) bounds for the estimate. (An example of an output is shown below)

Ecosystem Function Run Output Sheet

Ecosystem Processes	Estimate	Lower (5% CI) Estimate	Upper (95% CI) Estimate
Community Oxygen Flux (mg O_2/m²/hr^{-1})	0	0	0
Community Respiration Rate (mg O_2/m²/hr^{-1})	0	0	0
Community Primary Productivity Rate (mg O_2/m²/hr^{-1})	0	0	0
Community Ammonium Flux (µmol NH_4/m²/hr^{-1})	0	0	0
Community Ammonium Excretion Rate (µmol NH_4/m²/hr^{-1}	0	0	0
Community Ammonium Uptake Rate (µmol NH_4/m²/hr^{-1})	0	0	0
Community Nitrate Uptake Rate (µmol NO_3/m^2/hr^{-1})	0	0	0
Metabolic Carbon Flux (mg C/m²/hr^{-1}	0	0	0
Community Clearance Rate (Litres cleared/hr^{-1})	0	0	0
Community Algal Biomass (g DW/m²)	0		
Community Animal Biomass (g AFDW/m²)	0		
Aesthetic Services	**Estimate**	**Lower (5% CI) Estimate**	**Upper (95% CI) Estimate**
Community aesthetic Preference Score (ELO)	0	0	0
Community Diversity Metrics	**Estimate**		
Species Richness	0		
Species Evenness	0.00		
Species Diversity (Shannon)	0.00		

10. The summary output provides the magnitude and direction of the process including easy to understand traffic-light style high-medium-low indicators), a measure of confidence in the model predictions (based on individual species performance and coverage of equivalent taxa in the training dataset), as well as a broad interpretation of the results:

Magnitude	Confidence	Significance
No Detectable Oxygen flux (1)	Not Applicable	The community on the structure is providing no net oxygenation or oxygen uptake effects
No Detectable Respiration (1)	Not Applicable	No measurable oxygen production is occuring
No Detectable Productivity (1)	Not Applicable	No measurable oxygen production is occuring
No Detectable Ammomium Flux (1)	Not Applicable	The community on the structure is providing no net ammonium excretion or uptake
No detectable Ammonium Excretion (1)	Not Applicable	The community on the structure is providing no ammonium excretion
No detectable Ammonium Uptake (1)	Not Applicable	The community on the structure is providing no net ammonium excretion or uptake
No Detectable Nitrate Uptake (1)	Not Applicable	The community on the structure is providing no net nitrate excretion or uptake
No Detectable Oxygen flux (1)	Not Applicable	The community on the structure is providing no net carbon uptake or output effects
No detectable Clearance (1)	Not Applicable	The community on the structure is providing no particulate removal clearance function
No Algal Biomass (1)		The community on the structure is providing no algal biomass
No Animal Biomass (1)		The community on the structure is providing no animal biomass
Value	**Confidence**	**Significance**
Could Not Be Calculated, Insufficient Inform	Not Applicable	Insufficient information has been supplied to calculate aesthetics. Please check the input file

OPPORTUNITIES AND LIMITATIONS

Opportunities

- Allows a user to assess how modifying a structure and/or an environment can enhance the functionality of a structure.
- Data from other projects can also be used to feed into the tool, subject to availability and quality.

Limitations

- There is no data for sandy shore environments or the sub-tidal environment.
- The by-species models assume additive species - ecosystem function relationships, and may not accurately capture complex across- and within-species interactions which can modify whole-community functionality.
- Not all environmental parameters, which can vary across sites and may affect functionality, are captured within this model (e.g. water flow velocity, emersion time or water other chemistry parameters).

CONTACT DETAILS AND RESOURCES

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EF Predict Tool

EF Predict Tool User Guide

4. Conservation Evidence Synopsis - Biodiversity of Marine Artificial Structures

INTRODUCTION AND DRIVERS

Conservation Evidence Project

Much of what we understand about the benefits of ecological engineering is driven by academic research. This can cause barriers in communication and accessibility of this information. Conservation Evidence summarises this information into a free, authoritative resource designed to support decisions about how to maintain and restore global biodiversity.

Conservation Evidence provides easy access to the latest and most relevant knowledge to support conservation policy or management decisions. The various synopses provide a comprehensive review of the effectiveness of all actions that could be implemented to conserve a given species group or habitat or to tackle a particular conservation issue. Expert panels are then asked to assess the effectiveness (or not) of actions, based on the summarised evidence.

Synopsis - Enhancing the Biodiversity of Marine Artificial Structures

The synopsis *Enhancing the Biodiversity of Marine Artificial Structures* was published in 2021, designed so that it can be updated as new scientific evidence emerges. It covers published evidence of conservation interventions aimed at enhancing the biodiversity of marine artificial structures that are engineered to fulfil a primary function other than providing artificial habitats. It includes both intertidal and subtidal structures built or placed along coastlines (including in estuaries) and offshore, on the seabed and in the water column.

43 conservation actions (22 intertidal and 21 subtidal) were identified for Enhancing the Biodiversity of Marine Artificial Structures and 176 studies (118 intertidal and 58 subtidal) reporting their effects. However, it is important to be aware that the studies for each category are generally still small in number with only 1-5 studies linked to most of the actions. This compares with several dozen for some land-based enhancements. Further deployment and reporting of monitoring results is key to continue building on the evidence base and improve decision making in the future.

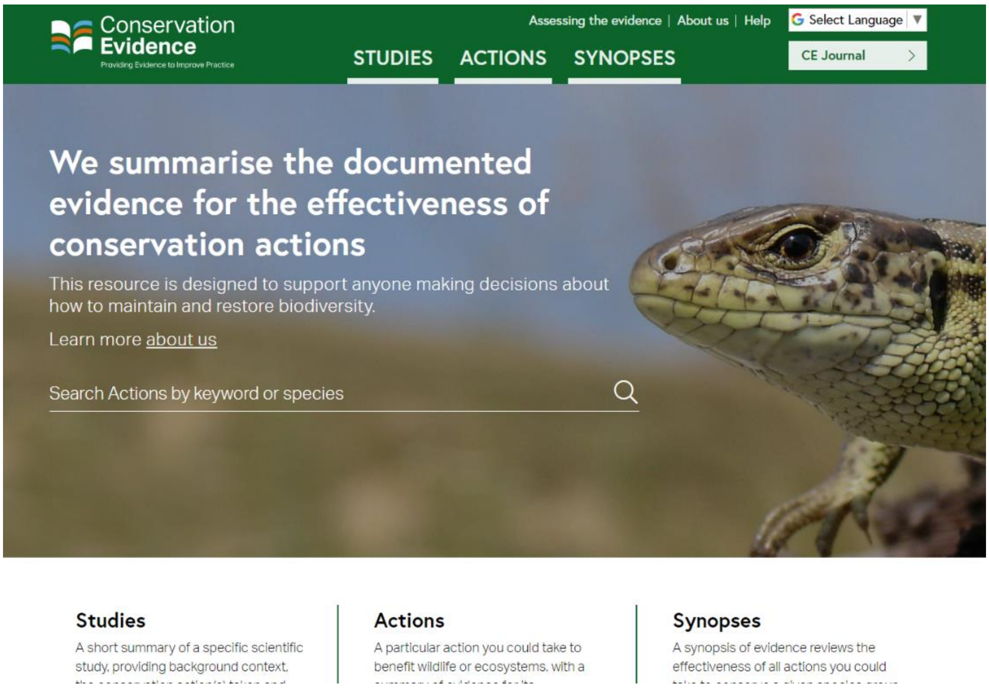
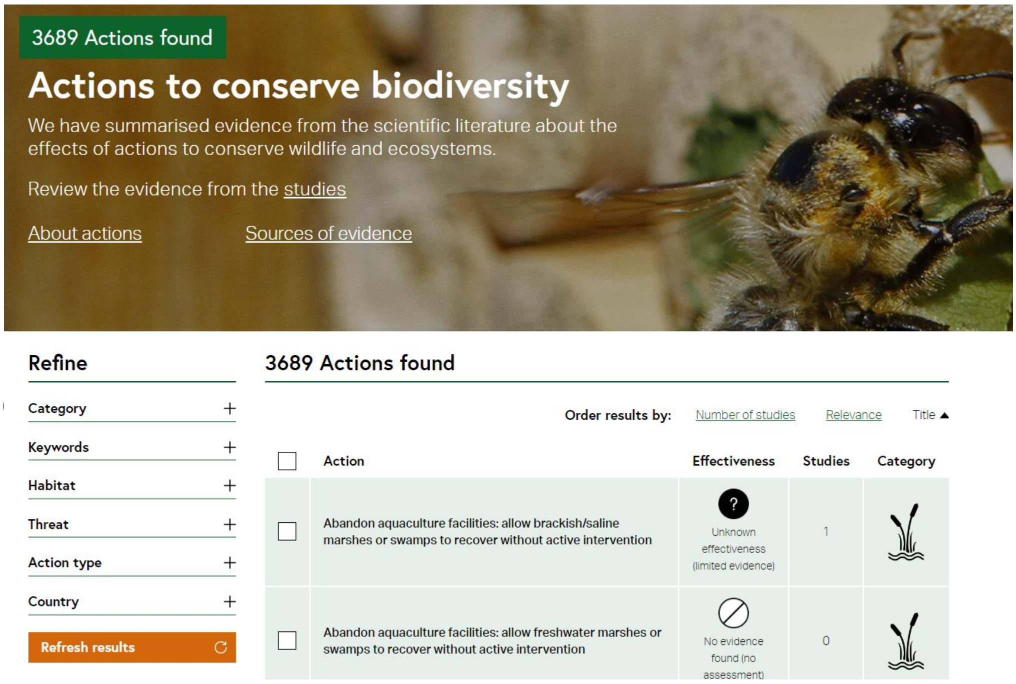
HOW TO USE THE TOOL

The synopsis can be downloaded to read as an offline PDF; however, the below steps outline how to use the webpage.

First, navigate to the "Actions" page of the website. You will be presented with a list of possible actions you could take to conserve biodiversity, along with a plain English summary of the available evidence for whether each one is effective (or not). It will also provide expert assessment of the effectiveness, based on the summarized evidence.

On the "Actions" tab of the Conservation Evidence website, click the "Category" drop down. Select "Biodiversity of Marine Artificial Structures."

Choose actions of interest and download results. This will download a summary of the evidence available for the chosen actions.

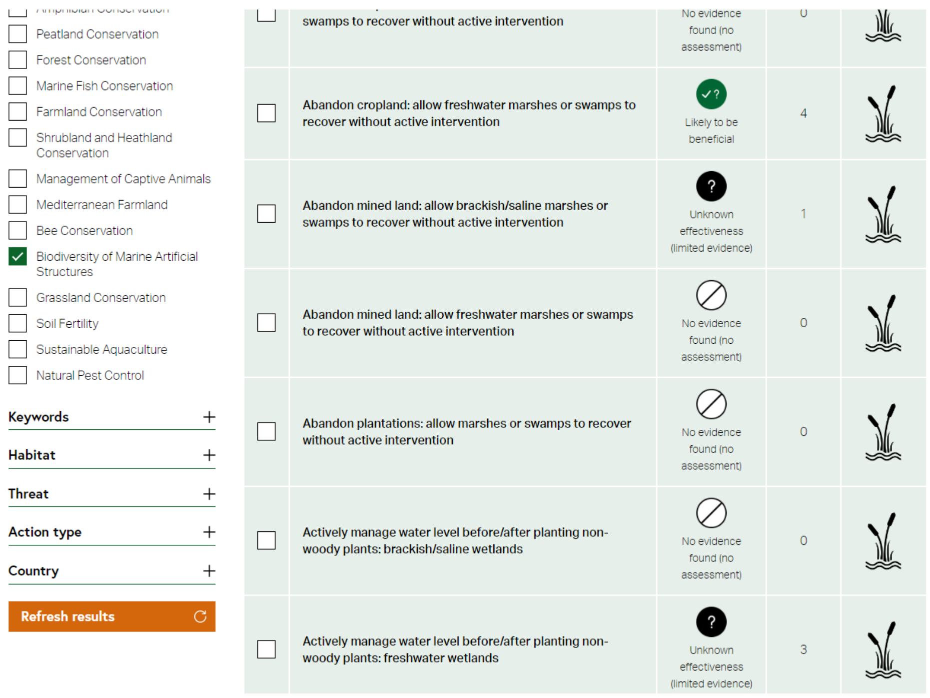
Step 1: Navigate to the "Actions" page.	
Step 2: On the "Actions" tab of the Conservation Evidence website, click the "Category" drop down.	

Step 3:

Refine by Category.

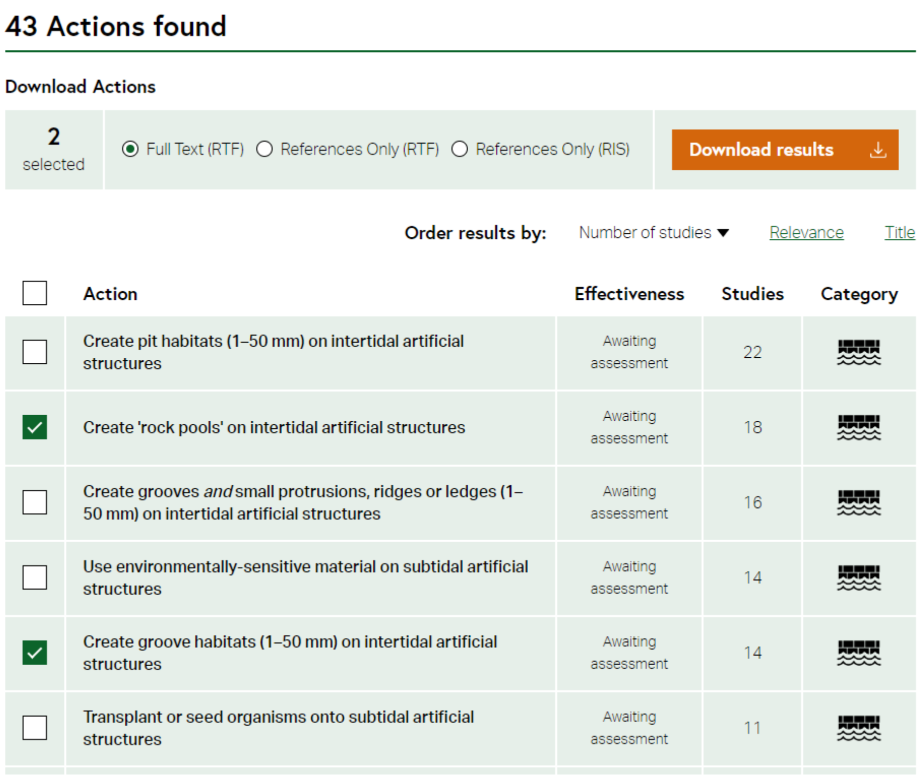
In this case "Biodiversity of Marine Artificial Structures."

Click "refresh results."



Step 4:

Choose actions of interest and download results.



OPPORTUNITIES AND LIMITATIONS

Opportunities

- The Conservation Evidence Synopsis provides a comprehensive summary of evidence of the suitability of ecological interventions on marine and coastal artificial structures. This can be utilised by engineers, consultancies, local authorities, and environmental regulators as an aid to decision making when considering ecological interventions and biodiversity enhancements.
- Evidence from the scientific literature about the effects of actions to conserve wildlife and ecosystems is summarised and housed on a website that is freely available and can be continually updated.

Limitations

- The evidence base is best utilised if the user first considers what they wish to achieve with their ecological intervention. Factors worth considering are the type of coastline, geography, type of structure and biodiversity outcome (e.g., increase species richness, increase the abundance of target species).
- The Conservation Evidence synopsis does not make recommendations. This is because it is difficult to give evidence-based conservation advice that is appropriate for every context. The tool provides evidence and an assessment of that evidence, which should be interpreted by users who understand their own site and national or regional situation.
- It is worth considering that ecological engineering interventions may not be suitable to all projects, and expert advice should be sought.

CONTACT DETAILS AND RESOURCES

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Conservation Evidence Synopsis – Biodiversity of Marine Artificial Structures (PDF)

Conservation Evidence Website

How to use the Conservation Evidence Website

5. New approaches to eco-engineering: photogrammetry and 3D printing

INTRODUCTION AND DRIVERS

Habitat structural complexity plays a direct role in the provision of physical living space, with increased complexity supporting higher biodiversity and ecosystem functioning. Coastal development and construction of artificial shorelines are altering natural landscapes and reducing habitat complexity. Artificial structures in the marine environment often support less diverse communities than natural rocky shore habitats due to low topographical complexity. Approaches to combat this include building in habitat designs to mimic features of natural reef topography that are important for biodiversity. Most designs mimic discrete microhabitat features like crevices or holes and are geometrically simplified.

This research, as published in the two papers "*Artificial shorelines lack natural structural complexity across scales*" and "*Replicating natural topography on marine artificial structures – A novel approach to eco-engineering*" (links below), which utilises photogrammetry and 3D printing to investigate surface complexity and variation at a range of scales.

MAIN FINDINGS

Artificial shorelines lack natural structural complexity across scales (Lawrence et al., 2021)

Structural complexity of natural rocky shorelines offers increased habitat complexity, directly correlating to greater species diversity and abundance. This study evaluated how much structural complexity is missing on artificial coastal structures compared to natural rocky shorelines. Three remote sensing approaches were used to capture the three-dimensional structural complexity of the artificial and natural habitats at a range of spatial scales relevant to intertidal rocky shore organisms: fine scale (1–10mm), medium scale (10–50cm) and large scale (1–10m).

Findings:

Natural shorelines were typically more structurally complex than artificial ones and offered greater variation between locations; providing a complex of fine, medium, and large-scale structural complexity that directly correlates with increased species diversity indices.

Results varied depending on the type of artificial structure (e.g., rock armour versus concrete seawall) and the scale at which complexity was measured:

- At fine scales, the structural complexity of rock armour and seawalls was significantly lower than natural shores, typically 17 to 29% less complexity.
- At medium scales seawalls were up to 41% less structurally complex than natural shores, however rock armour was found to be more similar to natural shores (only significantly different at the 50cm scale).
- At large scales there was higher variability in complexity between shore types but fewer significant differences between artificial and natural shores but. Seawalls were 3 to 43% less complex than natural shores at 5 and 10m scales and rock armour was almost 50% less complex at the 10m scale.

- Overall, seawalls were deficient in complexity at all scales (approx. 20–40% less complex than natural shores), whereas rock armour was deficient at the smallest and largest scales (approx. 20–50%).

Rock armour provides one consistent spatial scale and fundamentally lacks structural diversity and therefore can limit biodiversity. However, the widespread use of rock armour for coastline protection can represent a large opportunity for introduction of enhancements

Replicating natural topography on marine artificial structures – A novel approach to eco-engineering (Evans et al., 2021)

This work proposes a novel technique to allow replication of the full fingerprint of natural reef topography in habitat designs to satisfy specific eco-engineering objectives. A five-step process was developed for designing natural topography-based eco-engineering interventions for marine artificial structures:

Step 1 - A baseline survey to sample the biology and topography of local reef habitats that support target species / communities to varying degrees.

Step 2 - A biological selection step to identify subsets of the 'best' and 'worst' samples from the baseline survey for target species / communities.

Step 3 - Topographic selection step to identify topographic features characteristic of the 'best' but not the 'worst' samples, then to shortlist the 'best candidates' based on these.

Step 4 - an engineering selection step to identify potential practical issues for manufacturing eco-engineering habitat units based on the 'best candidates.'

Step 5 - To manufacture habitat units replicating the ultimately selected 'best' samples of reef substrate.

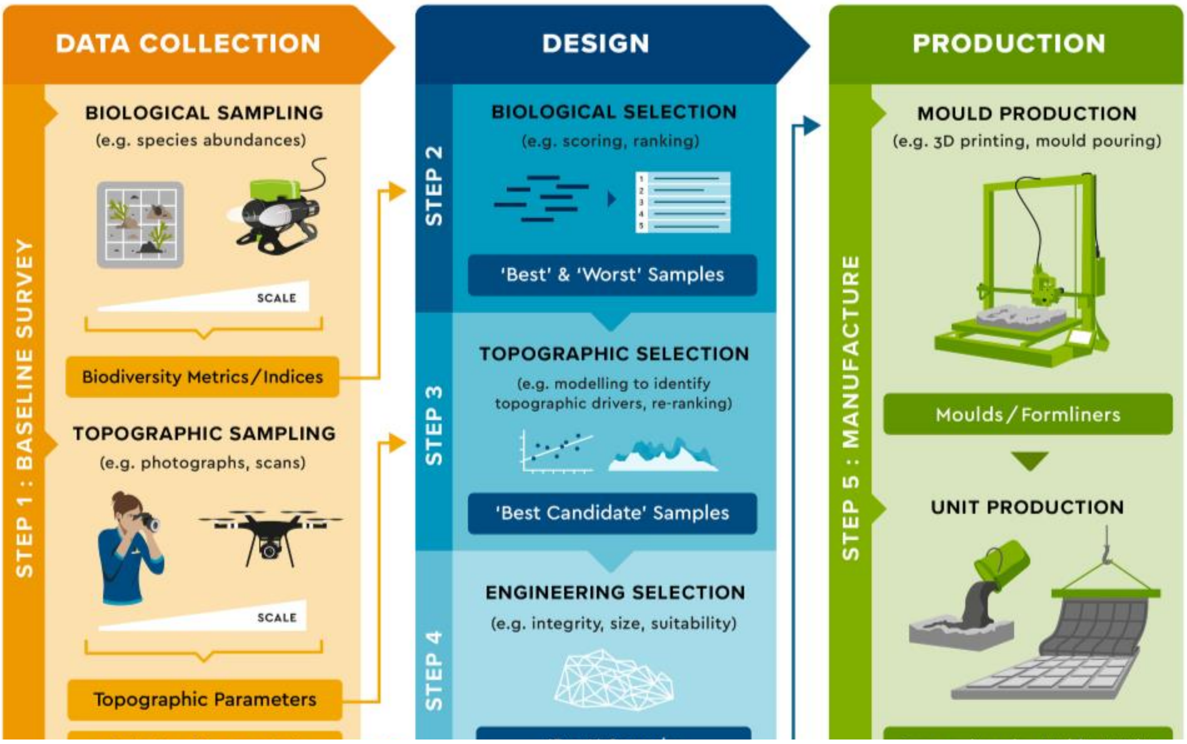

Figure 1 - Five-step process for designing natural topography-based eco-engineering interventions for marine artificial structures. Source: Evans et al. (2021)

Using the five-step process:

Researchers applied this process to design experimental-scale (25×25cm) habitat units for mid-shore seaward-facing surfaces on intertidal structures. They applied the approach with three eco-engineering objectives in mind: (A) to maximise the richness of colonising communities; (B) to promote local rocky reef species that are normally deficient on artificial structures but found on natural reefs; and (C) to promote rocky reef species that are rare in our region on both natural reefs and artificial structures. The habitat units replicated the topography from within three of the 'best' natural rocky reef quadrat samples from the baseline survey.

The Digital Elevation Models (DEMs) of the five 'best candidate' quadrats selected for each biodiversity index were inspected for their suitability for moulding and casting into eco-engineering habitat units. The stereolithography (STL) files of the three selected 'best' natural topography samples were 3D printed. Mould-making silicone rubber was poured in layers over the printed samples and a rigid support shell was built around each mould. Concrete was poured into the moulds to cast habitat units replicating the original topography samples – see Figure 2.

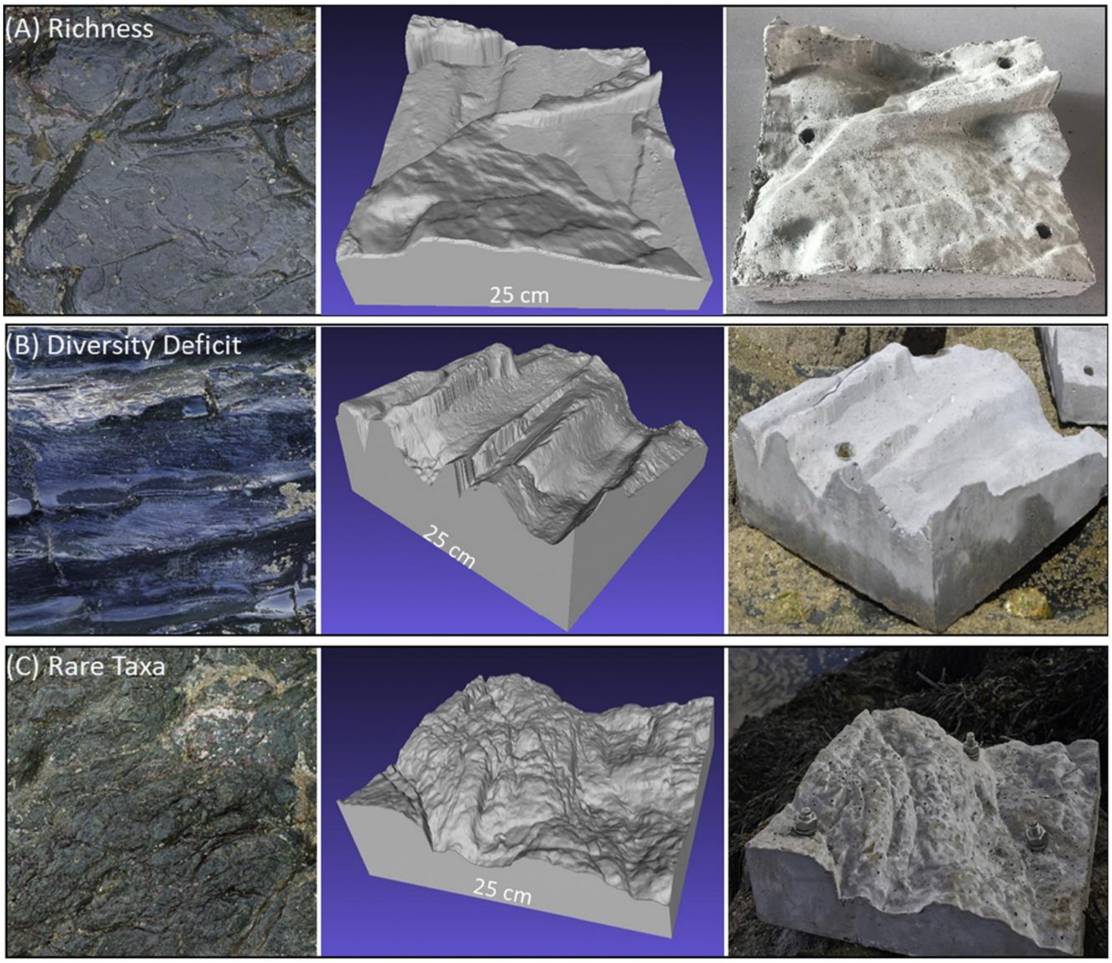

Figure 2 - Left-to-right: in situ photographs, STLs and concrete habitat units of the 'best' selected topography samples for three biodiversity indices (A–C). Source: Evans et al. (2021)

Regarding the concrete mixed used, a separate study by Natanzi et al. (2020) explored the impact of concrete binder composition, aggregate type and plasticizer on surface chemistry and early biofilm formation which influence subsequent colonisation. The findings suggest that concrete composition can alter the surface chemistry of structures and thereby can improve their ecological value while meeting the requirements from Eurocode 2 (in term of resistance, serviceability, durability) with respect to the selected exposure class.

The habitat units were deployed experimentally on artificial structures around Irish Sea coasts during 2019. Ongoing monitoring has shown promising signs that the tiles support higher levels of diversity, with several species colonising, including pioneer algae and adult and juvenile limpets, however the data has not been fully analysed.

OPPORTUNITIES AND LIMITATIONS

Opportunities

- New approaches such as photogrammetry and 3D printing demonstrate that there is scope for incorporating multi-scale natural surface complexity into the construction of artificial structures.
- Digital habitat modelling and 3D printing technologies have become increasingly affordable and accessible in recent years.
- Decision-makers should weigh-up the options available to them according to their biodiversity objectives, engineering limitations and budget, consulting the evidence base for what they can expect the value of using these techniques to be.

Limitations

- Biodiversity metrics and topographic parameters used to identify optimal areas of topography to be replicated need to be relevant to the target deployment area, therefore expertise from marine ecologists, engineers and surveyors is recommended to support decision making.
- Costs per panel/tile can be very high and economies of scale are visible only if producing dozens of panels.

CONTACT DETAILS AND RESOURCES

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Lawrence, P. et al. (2021). ‘Artificial shorelines lack natural structural complexity across scales’. Proc. R. Soc. B288: 20210329

Evans, A. et al. (2021). ‘Replicating natural topography on marine artificial structures – a novel approach to eco-engineering’. Ecological Engineering 160

Natanzi, A., Thompson, B., Brooks, P., Crowe, T., McNally, C. (2021). ‘Influence of concrete properties on the initial biological colonisation of marine artificial structures’. Ecological Engineering 159

6. Guidance for integration of stakeholder interests into eco-engineering projects

INTRODUCTION AND DRIVERS

For eco-engineering projects there is a wide range of stakeholders. The scale and nature of infrastructure projects and their location determines the stakeholder community.

The guidance document includes general steps of successful stakeholder engagement which were adapted for eco-engineering projects from the H2020 GRRIP project document 'Stakeholder Engagement Guidelines'.

The guidance answers the question 'How to engage with stakeholders?' through methods and procedures commonly used namely workshops of diverse nature, one-to-one engagement, site visits, community engagement and media & press.

The Guidance document will be published in due course in the Blue Cube website.

CONTACT DETAILS

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7. Report on impacts of eco-engineering upon cultural and amenity value of artificial structures

INTRODUCTION AND DRIVERS

Little is known of the public perception of eco-engineering on marine artificial structures, particularly as it is an understudied area of environmental psychology, which in itself, is a relatively new field of study. Whilst there is data on the environmental, biodiversity and economic impacts of artificial structures in the intertidal environment, little is known of the social impact. The main driver of this research was to understand the public's perception on a cultural and amenity level.

This study incorporated research into the types of artificial structures that exist on the Irish Sea coastline and included a questionnaire that was received by 973 participants. 783 of those participants completed sections relating to demographics and voluntary questions. The questionnaire ranked the indication of preference for each participant.

Computer-generated images were provided within the questionnaire to the participants, which varied from a completely uninhabited artificial structure to one that was completely covered in marine organisms. All images had the same background as this could have an impact on public perceptions, with the images made to look as realistic as possible – see Figure 3. Multiple question types were included to disentangle the role of different dimensions of biodiversity on aesthetic appraisals. Participants were invited to rank images by aesthetic appeal, using paired image comparison questions, and to rate how they perceived each image for: a) aesthetic appeal, b) interest, and c) providing a sense of calm. The study also included free text questions to understand individuals' drivers of appeal.

The result of this research provides an evidence base of the benefits of well-being from the marine environment through eco-engineering of artificial structures.

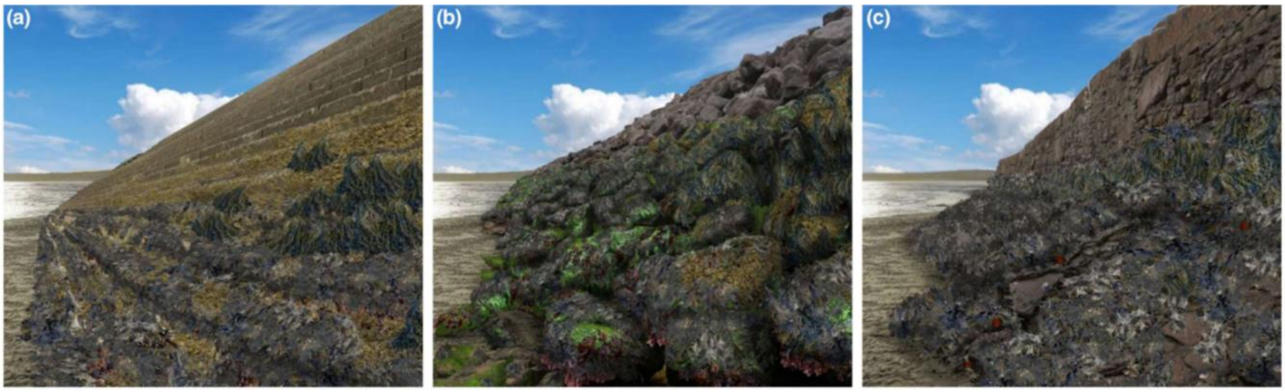

Figure 3 - Examples of images of structures (a-c) used in the survey. Variation in the underlying structures, from stepped walls (a) to rip-rap walls (b) and heritage stone walls (c). Source: Fairchild et al. (2022)

MAIN FINDINGS

The study investigated the social benefits of enhancing coastal infrastructure with the findings that both the biodiversity of communities colonising coastal structures and structure type influenced public perception. Participants strongly preferred structures that had more diverse animal and seaweed communities, with species richness particularly influencing how aesthetically appealing, interesting, and calming structures were to look at. This was found in participants ranking and rating images of diverse coastal structures more highly than those with less species. It was also highlighted as an important driver of appeal through free text questions in which participants reported that both the perceived naturalness of structures, and the diversity of the ecological communities, were important factors in determining their perceptions.

As well as the importance of biodiversity in determining perceptions and aesthetic appeal, the underlying structure can also be important. Infrastructure that has become ‘aged’, or has ‘old’ and less uniform features such as stone walls are seen more favourably by the public as it more closely reflects the natural environment compared with other artificial structures such as rock revetments, concrete seawalls and stepped revetments, etc. Furthermore, existing evidence suggests that these more variable, naturalistic structures also often can enhance biodiversity by creating more varied habitats, providing the benefits of both increased perceived naturalness of the structure, while often improving species diversity - which is overall likely to improve attitudes and perceptions towards infrastructure.

Therefore, promoting more natural and less obviously structured coastal infrastructure through the inclusion of ecologically sensitive design is expected to provide cultural, wellbeing, and aesthetic benefits to people.

OPPORTUNITIES AND LIMITATIONS

Opportunities

- The study was subject to a robust scientific process representative of a large dataset with participants from a variety of backgrounds. Researchers were careful to ensure that they avoided an imbalance of responses from specialists.
- The main findings of positive biodiversity effects on peoples’ perceptions and attitudes towards coastal infrastructure support calls for integration of ecologically sensitive design into existing and new structures. This builds on evidence that enhancement of structures can provide both ecological benefits (existing knowledge base) but may also provide human benefits simultaneously (this study). These findings should be used to inform future coastal resilience planning, while also demonstrating the value of stakeholder engagement in design
- Further research regarding public perceptions could include all five senses and approach this study in a holistic manner.

Limitations

- This study assessed public perception on one sense only: visual.
- The study found that their participants were heavily represented by women with males under-represented which slightly skewed the data.

CONTACT DETAILS AND RESOURCES

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Fairchild, T., Weedon, J. & Griffin, J. (2022). ‘Species diversity enhances perceptions of urban coastlines at multiple scales’. People and Nature, 4, 931– 948

8. Designs for artificial habitat units for European lobster

INTRODUCTION AND DRIVERS

Urbanisation of the marine environment through construction of artificial structures, such as offshore wind farms, provides the potential to create habitat for key marine species. Although a common side effect of offshore development is the reduction in habitat for commercial species sought after by the fishing sector, there exists the potential for eco-engineering of artificial structures and marine renewable infrastructure to incorporate habitat spaces into their design.

Species, such as brown crab (*Cancer pagurus*) and European lobster (*Homarus gammarus*), have a high commercial value and could potentially be enhanced through habitat creation in new offshore structures. For the purposes of this study, European lobster was chosen as the study species with the driver to understand how they utilise different hole sizes and shapes as habitat, and whether habitat preferences could be used to enhance the designs of subtidal infrastructure.

Researchers from the University of Aberystwyth and University of Swansea conducted laboratory and in-situ trials of different habitat types for European lobster. This study caters for a spectrum of professionals, including developers, environmental managers, researchers and fishermen.

MAIN FINDINGS

Experiments were carried out in a laboratory environment followed by on-site trials off the coast of Wales. In the lab, researchers conducted 144 individual trials comparing different habitat designs and the corresponding behaviour of European lobsters of different sizes. The laboratory experiments suggested that lobsters are selective with regard to the size and shape of cavities used as refuges, with a preference towards tightly fitting holes with a wider front aperture that allows them to spread their claws – see Figure 4.

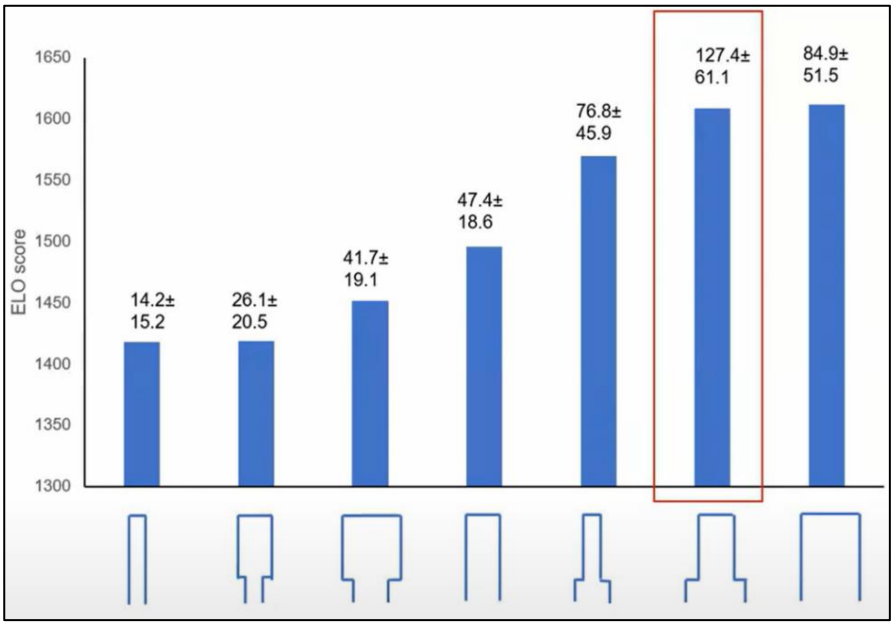

Figure 4 - Geometry of refuges tested in the lab and ELO score of lobster preference. Source: Ecostructure Conference presentation 'A home for lobsters – integrating lobster habitats into coastal infrastructure'

In-situ trials were informed by the lab results, with concrete units of four different habitat types deployed at two locations off the Welsh coast. Two sets of in-situ trials took place with the first hampered by nearby dredging activities, smothering the units in sediment. The second trial took place mid-summer 2022 with units deployed close to existing subtidal infrastructure. Unfortunately, the relocated habitat units became damaged by yachts and recreational boats using the buoys for mooring, therefore not enough data was gathered to draw robust conclusions.

Nevertheless, results from the lab study can support the design of habitat enhancement, both for conservation and commercial fishery operations. As European lobsters have a large dispersion range (2-4km) it is hypothesised that species may be found in any locality where there is suitable habitat.

OPPORTUNITIES AND LIMITATIONS

Opportunities

- Potential for increase in European lobster population and distribution due to the provision of additional and tailored habitat.
- Provides additional areas for commercial fishing, to supplement additional techniques such as potting in wind farm zones (subject to permission).
- Potential for new habitat deployments to act as a source population to bolster numbers, increase range and support habitats for all ages of lobsters.

Limitations

- Whilst the lab trials were robust, there exists more variability in the marine environment than could be replicated in the lab. There are limitations to the in-situ tests with on-site monitoring (diving teams and ROV deployment) as it is limited to a snapshot of activity.
- Research did not investigate the cannibalistic nature of lobsters i.e. that in natural habitats larger lobsters will predate smaller individuals in areas over-populated by hatched and reared lobsters

CONTACT DETAILS AND RESOURCES

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Ecostructure Conference presentation ‘A home for lobsters – integrating lobster habitats into coastal infrastructure’

9. Policy briefs on coastal eco-engineering, based on a review of relevant policies, legal requirements and management practices

INTRODUCTION AND DRIVERS

The purpose of this review was to investigate governance within Wales and the Republic of Ireland regarding policies, legal requirements and management practices relating to potential coastal and marine eco-engineering solutions. Wales and the Rep of Ireland have different legal systems and therefore there are differences regarding activities that require licences and permits within the marine and coastal environments. This project was driven by the requirement to understand how both licensing systems work and to provide an information source that outlines to policy makers, planners, developers and interested parties the legal steps that are involved in acquiring a licence / permit for a coastal eco-engineering project.

The project provides two outputs:

i) the Policy Briefs, which are short and succinct fact sheets aiming to provide users with a starting point to navigate the planning and licencing process and;

ii) the Report, which details the legal systems in Ireland and Wales, describing national and local authority policies and legal requirements.

It must be noted that the Republic of Ireland is currently updating its marine licensing system with the passing of the Maritime Area Planning Bill 2021[3] in December 2021 and the formation of the National Marine Planning Framework. As a result, there will be changes to the licensing and planning process by the Department of Housing, Local Government and Heritage[4] as it transitions from one system to another.

The Policy Briefs and Report are still in progress and they will be published in the Marine Renewable Energy Ireland (MaREI) website.

MAIN FINDINGS

The legal requirements and policies for coastal eco-engineering applications within Wales and Ireland.

Early in the Ecostructure project, amidst the specialisms of biology, ecology and engineering, researchers identified a gap in the application of coastal eco-engineering projects: the governance and legal application. Researchers investigated the national and local authority planning and licensing process for such projects across Wales and the Republic of Ireland. During this research, it was noted that the legal system in the Republic of Ireland differs significantly from that of Wales.

Within the Republic of Ireland, planning and licensing process differs between local authorities, with planning policies found both in county development plans and within inshore management plans. It is important to highlight to all users, that should planning permission and / or licensing be

[3] Maritime Area Planning Bill 2021 passes through all stages of the Oireachtas. Accessed at https://www.gov.ie/en/press-release/d13b0-maritime-area-planning-bill-2021-passes-through-all-stages-of-the-oireachtas/ on 26/09/2022

[4] Department of Housing, Local Government and Heritage. National Marine Planning Framework. Accessed at https://www.gov.ie/en/collection/fcf62-national-marine-planning-framework/ on 26/09/2022

required for the application of a relevant project within the Republic of Ireland, these Policy Briefs provide guidance to the complexity of the process with more detailed information detailed in the Report. In contrast, the Welsh planning and marine licensing system is a more streamlined process with applications made directly to Natural Resources Wales from the webpage.

The Policy Briefs provide all users with a starting point on how to navigate respective planning and licensing processes. These Policy Briefs are written and designed to provide basic information to anyone interested in the legislative and legal process, while the Report provides detailed information on the local authorities and the differences between national and local policies. Additionally, there will be case studies and worked examples provided within the outputs.

OPPORTUNITIES AND LIMITATIONS

Opportunities:

- An easy method for users to start the legal process of applying an eco-engineering method within the coastal environment.
- Further study into the complexity of governance in the application of eco-engineering projects (subject to funding).

Limitations:

- The Policy Briefs do not contain all the fine detail that the Report does and therefore there is a risk to users that they will miss this without reading the Report.
- The complexities of legal systems in the Rep of Ireland and Wales and the differences in how their planning and licensing process operate may provide a challenge for users to understand.
- Northern Ireland, Scotland and England's marine planning and licensing processes are not included within the scope of this study.

CONTACT DETAILS

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10. Larval Dispersal Tool

INTRODUCTION AND DRIVERS

Artificial coastal structures are frequently colonised by non-native species due to their association with boat traffic (e.g. in ports and marinas) and their lack of native organisms at the time that they are deployed. After arriving through human transport and establishing at coastal sites, non-native species will potentially spread through natural means, such as larval dispersal. Our understanding of the mechanisms of dispersal of marine invertebrates through their larval stages and our ability to predict dispersal through understanding of shelf sea and coastal hydrodynamics has made important advances over the last 20 years.

However, such predictive capacity is rarely available to coastal stakeholders in an accessible and timely manner. Ecostructure researchers at the School of Ocean Sciences, Bangor University, have produced a freely-available online tool for coastal managers to predict the dispersal of marine invertebrate larvae from over 100 coastal locations around the Irish Sea with a primary focus on management of marine invasive non-native species.

HOW TO USE THE TOOL

The tool allows selection of release location (coastal sites throughout the Irish Sea), season of release, length of larval lifetime and larval behaviour - all factors which are known to have significant impact on dispersal patterns.

The tool allows visualisation of the spread of cohorts of marine invertebrates through larval dispersal from locations around the Irish Sea, allowing for variability due to tidal state at the time of release. It is intended to assist in the management of marine invasive non-native species which, after arriving through human transport and establishing at coastal sites will potentially spread through natural means. This tool can help in the early warning and rapid response by providing an understanding of potential natural spread.

The tool simulates the potential spread of larvae from coastal natural habitats and man-made structures. The larvae simulated within this app are transported from coastal 'spawning' locations within the Irish Sea by simulated (modelled) ocean currents. These simulations are based on a sophisticated hydrodynamic model which predicts flows in three-dimensions, driven by the tide, wind and temperature inputs. The model has a 500m horizontal resolution and uses data from 2014 and encompasses the larval spawning season from April to October. The hydrodynamic model was well validated against temperature records, tide gauges and ADCP (Acoustic Doppler current profiler) velocity deployments.

The simulated ocean currents are coupled with a Particle Tracking Model which simulates virtual particle (representing larvae) trajectories based on the simulated 3D velocity field. These particles are dispersed through the Irish Sea waters for their pelagic larval duration. A range of release (spawning) periods can be chosen to incorporate changes in seasonal heat-driven flows.

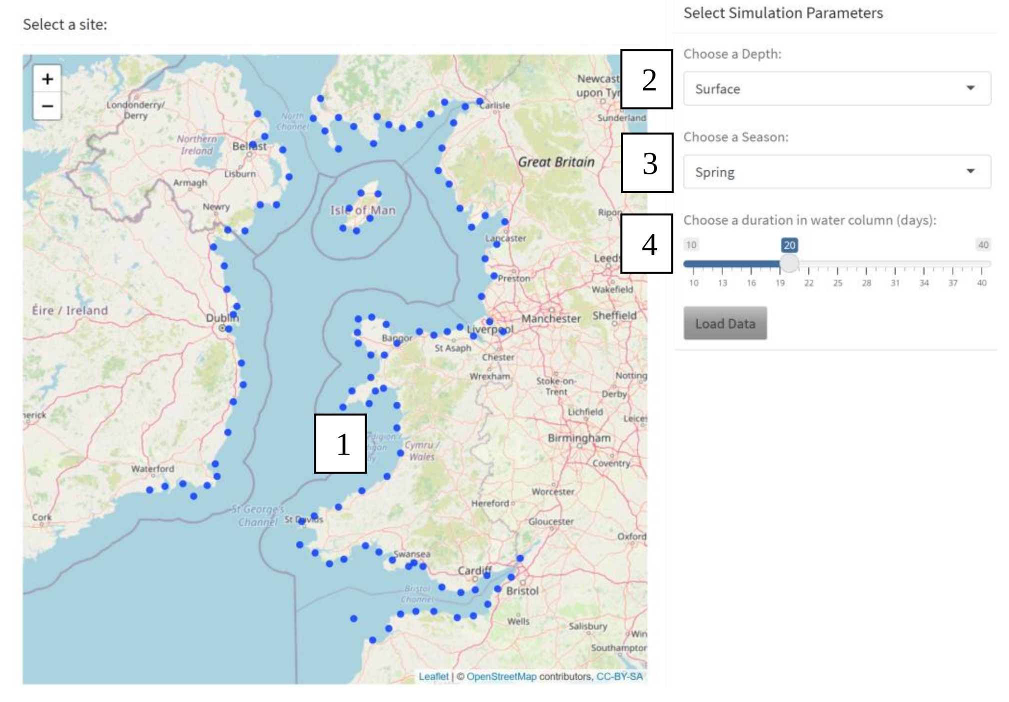
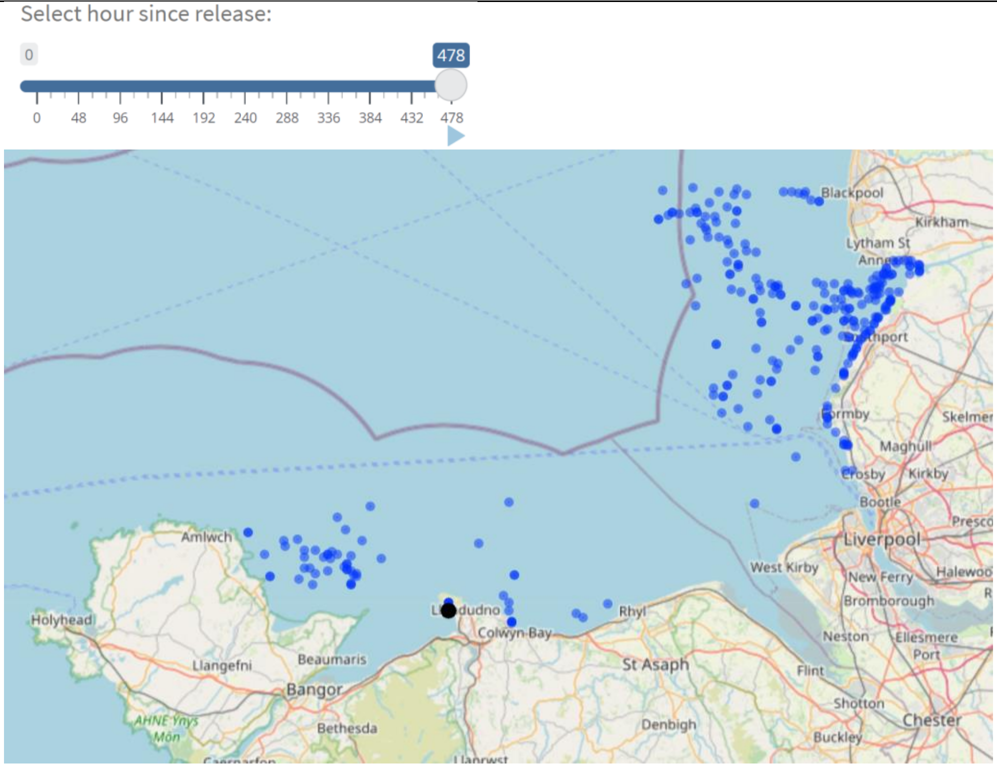
In addition, larvae particles can be simulated in two scenarios:

i) positioned in surface waters, and

ii) positioned in mid-water.

This represents two plausible larval behavioural patterns, with surface-only larvae submitted to tidal-, heat- and wind-driven currents, whereas larvae in mid-waters are submitted to tidal- and heat-driven currents.

Users should carry out several simulations to understand the natural variability and uncertainty associated with the results.

Step 1: Select a location from the selection map **Step 2:** Select a depth for particle release **Step 3:** Select what time of year particles are released **Step 4:** Select how long particles stay in the water column. This is subject to user input based on knowledge of larval maturation	
Step 5: Once selections are complete, move to the simulation and density map tabs to view outputs	

OPPORTUNITIES AND LIMITATIONS

Opportunities:

- The work has been developed with a primary focus on management of invasive non-native species, however, the online tool can be used for mapping colonisation by preferred species, for those interested in dispersion of contaminants such as plastics and oil and for education purposes.
- The tool allows the user to select either surface or mid-water depth for particle release. Dispersal close to the seabed is considered to occur only for last stages of larvae development, before they attach, therefore it is not included in the tool.
- The tool can be used to link with known invasive non-native species locations to provide an understanding of risk of spread for management purposes.

Limitations:

- The model resolution is 500m, therefore nearshore coastal processes may not be well resolved. Future work will assess what is the adequate resolution required to capture nearshore coastal processes.
- The number of release locations along the coastline was reduced when publishing the online tool due to computational efficiency. For further detail and further locations please get in touch through the contact details provided.
- Larvae can attach to materials such as plastics or debris which can influence the dispersal patterns which are not covered by the model.
- The hydrodynamic model corresponds to the year 2014 which is assumed to be a representative year for hydrodynamic conditions.

CONTACT DETAILS AND RESOURCES

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Larval Dispersal Tool

Ecostructure Conference presentation ‘How to Use Ecostructure's Larval Dispersal Prediction Tool’

11. Models of the effects of existing and proposed offshore renewable energy structures on dispersal of Invasive Non-Native Species

INTRODUCTION AND DRIVERS

Implications of offshore renewable energy structures for marine connectivity

The most prominent offshore structures in the Irish Sea are offshore wind farms and associated scour protection (rock armour). By providing islands of hard substrate analogous to natural rocky shores, these structures have the potential to facilitate dispersal of Invasive Non-Native Species (INNS) from their points of introduction by acting as "stepping stones" across areas of unsuitable habitat. This project modelled connectivity (the potential for spread of INNS) between coastal locations around the Irish Sea with no offshore structures - see Figure 5 (left). Subsequently it investigated how connectivity may change in the presence of existing and planned offshore renewable energy structures. This information is intended to assist developers by providing insights into whether existing and planned wind farms have the potential to act as marine "stepping stones" for INNS.

Climate change and marine connectivity

As climate change causes changes in ocean circulation and sea water temperatures, the background hydrodynamics (ocean currents) of the Irish Sea will likely be altered. This in turn will have wide ranging implications on the dispersal of species within the Irish Sea; e.g. through changes in background circulation, warming waters affecting how long larvae stay in the water column and through changes in seasonal stratification (both strength and duration). For example, as larvae disperse, they are entrained in the water column. As waters warm and conditions change, spawning periods will extend and pelagic larval duration (how long larvae stay in the water column) will change, likely altering connectivity. For example, a larvae may spend two weeks in the water column under present-day water temperatures, but this duration could be reduced with warmer sea waters, thus changing the dispersal pattern and population connectivity – see Figure 5 (right).

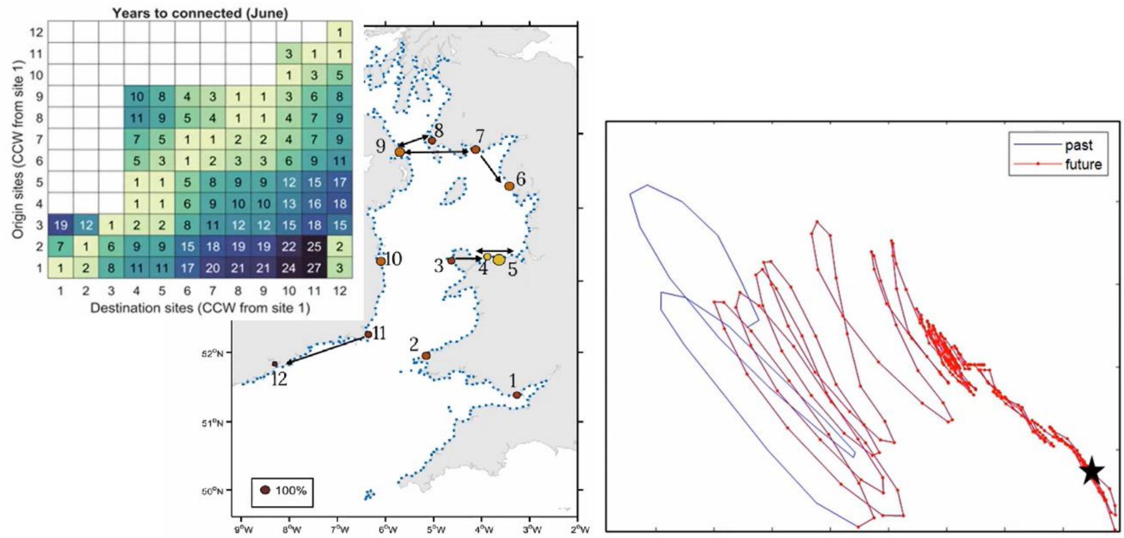

Figure 5 - Connectivity in the Irish Sea, example matrix of June (left). Larval dispersal impact from reduced duration in the water column (right). Source: Ecostructure Conference presentation 'Modelling larval dispersal and gene flow: towards practical tools for management'

This project has modelled larval dispersal under future climate change scenarios provided by the MetOffice to understand how these changes may alter connectivity, and therefore the spread of INNS. Seasonal, geographical and year-on-year variation have been factored into the models.

OUTPUTS

This work is still in progress at time of writing of this Guide; however, it is anticipated that a paper will be published in due course.

The working title of paper is "*How offshore renewable energy installations and climate change may alter marine population connectivity in the Irish Sea*".

This paper will be published in an open access journal and will be written in an accessible format, with a range of audiences in mind. The methods section will be comprehensive; however, the introduction and results will be accessible and understandable to users without technical background knowledge.

OPPORTUNITIES AND LIMITATIONS

Opportunities:

- The model can highlight areas of the Irish Sea sensitive to Invasive Non-Native Species dispersal and colonisation.
- Outputs from the model can raise awareness and inform developers, practitioners, regulators and licensing authorities when assessing future structures in the Irish Sea regarding the potential impact of the spread of Invasive Non-Native Species.

Limitations:

- This work is based on hypothetical scenarios, there is still significant uncertainty regarding how climate change will affect the background hydrodynamics in the Irish Sea and what offshore structures are going to be installed in the future.
- The research has not considered cabling associated with offshore renewable structures, which is often protected by rock, rock bags, concrete mattresses and other solutions, which can represent linear pathways and increase connectivity.

CONTACT DETAILS AND RESOURCES

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Ecostructure Conference presentation 'Modelling larval dispersal and gene flow: towards practical tools for management'

12. Stakeholder engagement to improve biosecurity in ports and marinas: Free online training tool for boaters, paddlers, marinas and related organisations.

INTRODUCTION AND DRIVERS

Species that are moved beyond their natural range, by accident or design, are known as non-native species. Invasive Non-Native Species (INNS) have a detrimental impact on local species, human health and/or health of the local economy. As such, marine INNS, easily transferable through the water column, are a significant threat to global biodiversity and can have detrimental socio-economic impact on activities such as fishing, shipping and aquaculture. Recreational boats moving around and between water bodies (ie: across seas or moving boats from one launch spot to another) contribute to both initial introduction and secondary spread of aquatic INNS. As such, marinas and ports are subject to regular INNS introductions and are known to be INNS hotspots.

Biosecurity actions aim to prevent the introduction and spread of INNS. In many countries, there is little or no legal requirement for recreational boaters or marinas to implement biosecurity in day-to-day operations to reduce the risk of non-native species introduction. Instead, biosecurity amongst boaters and marinas is o voluntary, meaning uptake may be limited (Vye et al., 2020).

The work by Vye et al. (2020) aimed to better understand the range of perceptions of biosecurity implementation amongst marina operators. Workshops and focus groups were attended by operators from the Republic of Ireland, Northern Ireland and Wales to explore ‘hard’ engineering biosecurity measures for ports and marinas such as in-water quarantine berths, rotating pontoons and other solutions .

Uncertainty regarding the effectiveness of biosecurity education and interventions, negative public user perception associated with biosecurity in marinas, lack of industry guidance and legislation and lack of financial resources were considered to be barriers to biosecurity implementation in marinas. Drivers for marinas to implement biosecurity included the perceived benefits of a clean environment for business and presenting as having good environmental practice.

To provide evidence to marinas and ports owners / operators, research was then conducted by Liz Morris-Webb at Bangor University to determine which biosecurity education materials would be most effective at improving biosecurity intentions of marina and port users, namely recreational boaters.

The research was informed by consultation with the GB Non-Native Species Secretariat and Animal and Plant Health Agency, Official partners assisting in developing and advertising this research were: The Green Blue, Pen Llyn a’r Sarnau SAC, Natural Resources Wales, , RYA Cymru The effectiveness of passive education (posters, leaflets, videos) and active / interactive education (online interactive ‘gamified’ workshops and bespoke in-person workshops) was evaluated to see how effective they were in improving biosecurity intention amongst the boating and paddling participants.

Preliminary findings indicate that engaging with boaters with biosecurity is challenging. Paddlers / canoers (slipway users) had better prior knowledge of biosecurity than cruisers / yacht (marina users), but this didn’t affect their biosecurity intention. Interactive education (video education) was more effective at improving biosecurity intentions than printed materials.

Research indicates that to improve biosecurity amongst boaters, interactive training should be encouraged amongst marinas and boating / paddling organisations, but that these may need to be actively encourages as are not likely to be taken up voluntarily or passively.

A paper "*Determining the most effective educational interventions to encourage biosecurity and pro-environmental behaviour amongst recreational boaters*" is in preparation (target journal: Environment & Behavior) .

This research has also been embedded in NRW's forthcoming *"Recreational Boating Action Plan: Pen Llŷn a'r Sarnau SAC"*.

BIOSECURITY FOR BOATERS: FREE INTERACTIVE, 'GAMIFIED', ONLINE TRAINING TOOL FOR BOATING ORGANISATIONS AND MARINAS.

The aim of the 'virtual marina' tool is to provide an interactive training space, where boating organisations / marinas / boaters can invite and join the space to immerse themselves in education materials related to their hobby or organisation. Two virtual environments were created to support the learning about biosecurity and its importance, and they include:

1 – A Welcome arena, in which you can learn how to use the space and interact with others, and education materials

2 – Interaction tools: microphone, camera, sharing screen, etc.

3 – Underwater and immersive videos of the environment in the marina and in particular biofouling on a boat hull and pontoon.

4 – Information on key invasive species and where they are present.

5 - Check, clean and dry videos and key information.

6 – A recreational boating 'biosecurity decision tree' to help decide on your best biosecurity measures.

7 – Guidance on creating a biosecurity plan for your boating organisation or marina.

Note: Cleaning a heavily fouled hull in the marine environment can lead to spawning of larvae into the water column as a stress response from organisms, therefore potentially resulting in a more negative effect than no action, therefore regular cleaning before anything more than a film grows is recommended. Dry cleaning (away from water run off) is always preferred. However, this often results in additional costs from dry docking or and highlights the complexity of the implementation of biosecurity measures.

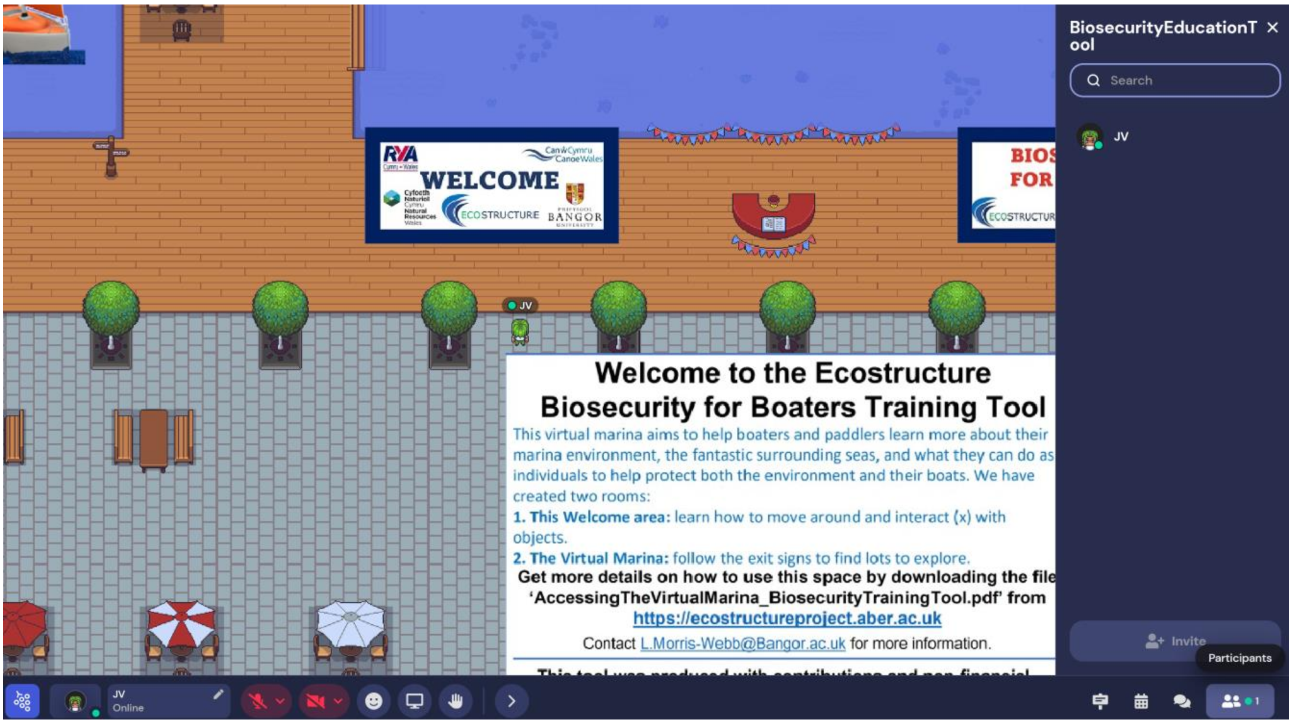

Figure 6 - Biosecurity Training Tool interactive environment (1/2)

Figure 7 – Biosecurity Training Tool interactive environment (2/2)

OPPORTUNITIES AND LIMITATIONS

Opportunities:

- The Biosecurity Training Tool can be used freely for groups less than 20 people as it is. In future, it could be updated or adapted for your marina or organisation, and content tailored to required uses.
- Using the tool and watching the videos could become mandatory induction when signing up to sailing / paddling / canoeing / water sports clubs or applying for marina berths
- Qualitative approach rather than quantitative can be more successful to generate a representative group / sample, since it is challenging to engage with recreational boaters.

Limitations:

- Boaters are already faced with lots of information regarding safety, navigation, etc., therefore additional information on biosecurity is generally perceived as less important.

CONTACT DETAILS AND RESOURCES

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Vye, S., Wynne-Jones, S., Masterson-Algar, P., Jenkins, S. (2020). ‘Exploring perceptions of marine biosecurity interventions: insights from the commercial marina sector’. Marine Policy 118

Ecostructure Conference presentation ‘Stakeholder engagement to improve biosecurity in ports and marinas’

Biosecurity Education Tool | Gather

Available PDF guidance for the Biodiversity Education Tool

13. Methodologies for the early detection of non-native species from environmental DNA in water samples

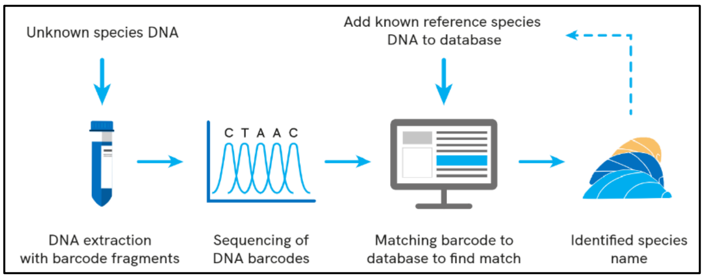
INTRODUCTION AND DRIVERS

Environmental DNA (eDNA) is DNA that is released from an organism into the environment. Sources of eDNA include skin cells, faeces, mucous, hair, eggs and sperm. eDNA samples can be collected from seawater, rivers, lakes, snow, soil and even air.

In the marine environment, collecting water samples is naturally much more cost effective than traditional methods which involve in-situ identification of species, often requiring diving or other labour intensive methods. However, when initially testing out eDNA methods, complementary ground truthing is generally required to validate results from eDNA.

There are two main approaches to analysing eDNA samples:

- Metabarcoding - provides DNA barcodes for everything that is in the sample. The process is carried out in two main stages: initial stage to filter and amplify the DNA and then sequencing of DNA.



- Quantitative (q)PCR - using a qPCR assay, with filtering followed by species (taxa) specific amplification and subsequent quantification of the amount of target DNA in a sample.

MAIN FINDINGS AND OUTPUTS

Gargan et al. (2022) researched the use of eDNA metabarcoding and qPCR for molecular detection of marine invasive non-native species associated with artificial structures.

A total of six sites were selected for this study and water samples were collected in triplicate from three locations within each site; close to the coastline or marina, mid-channel, and in the outer reaches of each site.

A qPCR assay was developed and was successful at detecting *Didemnum vexillum* (an invasive non-colonial tunicate) in seawater samples from all sampled sites where it is currently found in Ireland and Wales. Through metabarcoding of the same eDNA samples, the authors detected other Invasive Non-Native Species (INNS) at some sites but did not detect *D. vexillum*, even in locations where it is present. It was concluded that qPCR approach is more sensitive for targeted screening for specific INNS at coastal sites including those with artificial structures than metabarcoding. However, while metabarcoding is a less sensitive approach it is a valuable tool to detect a broad taxonomic range of native and non-native species with the potential of detecting non-targeted INNS.

Further work focusing on using metabarcoding at offshore sites is currently under way and the outputs will be published in due course.

OPPORTUNITIES AND LIMITATIONS

Opportunities:

- Rapid detections of species (qPCR and metabarcoding) but also general understanding of biodiversity of a site (metabarcoding). From collected samples, only part of the sample is used for analysis, the rest is stored and represents a timestamp of biodiversity.
- Early indicator which can inform further site / species-specific surveys. Detection of INNS at early stages is also useful, before they become well established and harder to eradicate.
- Cheaper and requires less human resources than traditional surveys.
- New portable technology such as MinION allows users to carry out DNA sequencing directly in the field in real time.
- Development in qPCR has the potential for close to real time detection and automation.

Limitations:

- Environmental conditions can result in the breakdown of DNA (e.g. high UV light) and DNA is diluted rapidly in the sea through currents that may lead to false negatives.
- Metabarcoding requires a reliable and comprehensive database of barcode sequences, which is not always available.
- Metabarcoding primers designed for marine invertebrates also detect some bacteria and bacterial DNA predominates in marine water samples which may lead to false positives
- Currents and predators can transport DNA for long distances, leading to false positives.
- Few facilities and companies carry out metabarcoding commercially. The qPCR and metabarcoding techniques are very sensitive and any contamination can lead to false positives, therefore often dedicated facilities are required.

CONTACT DETAILS AND RESOURCES

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Gargan, L., Brooks, P., Vye, S. et al. (2022). 'The use of environmental DNA metabarcoding and quantitative PCR for molecular detection of marine invasive non-native species associated with artificial structures'. Biological Invasions 24, 635–648

Ecostructure Conference presentation 'Early detection of non native species through use of environmental DNA'

Zafeiropoulos H, Gargan L, Hintikka S, Pavloudi C & Carlsson J. (2021). 'The Dark mAtteR iNvestigator (DARN) tool: getting to know the known unknowns in COI amplicon data'. Metabarcoding and Metagenomics 5: 163–174.