

**Modelling the state of soft-sediment benthic
communities in Welsh coastal waters**

J.G. Hiddink

CCW Contract Science Report No 733

“This is a report of research commissioned by the Countryside Council for Wales. The Council has a programme of research in scientific and other areas, which supports the development of policies and practical work and helps point the way to new countryside legislation. **However, the views and recommendations presented in this report are not necessarily those of the Council and should, therefore, not be attributed to the Countryside Council for Wales.** No part of this report may be reproduced, stored in a retrieval system, or transmitted, in any form or by any means, electronic, mechanical, photocopying, recording, or otherwise, without the prior permission of the Countryside Council for Wales.”



Llywodraeth Cynulliad Cymru
Welsh Assembly Government

CORFF NODDEDIG | SPONSORED BODY



Cyngor Cefn Gwlad Cymru
Countryside Council for Wales

Report Number: 733
Publication Date: March 2006
Contract Number: FC 73-02-240
Nominated Officers: Kirsten Ramsay
Title: Modelling the state of soft-sediment benthic communities in Welsh coastal waters
Authors: J.G. Hiddink
Restrictions: None

Distribution List:

Core:

CCW HQ Library
CCW North East Area Library
CCW North West Library
CCW South Area Library
CCW West Area Library
National Library of Wales
National Assembly of Wales Library
British Library
English Nature Library
SNH Library
JNCC

Others

Clare Eno, CCW
Rowland Sharp, CCW

Modelling the state of soft-sediment benthic communities in Welsh coastal waters

J.G. Hiddink

School of Ocean Sciences, University of Wales, Bangor, Menai Bridge, Anglesey,
LL59 5AB, United Kingdom, +44 (0)1248 388124, email: J.Hiddink@bangor.ac.uk

Acknowledgements

Alan Elliot and Simon Neill are thanked for supplying bed stress data. Francis Gohin (IFREMER) supplied chlorophyll a measurements. Fisheries overflight observations were supplied by the Marine Fisheries Agency. The digital BGS sediment maps were used under license 2003/133.

Summary

To facilitate an evaluation of the economic impacts of different types of fisheries management, soft-sediment benthic invertebrate communities in the coastal zone of Wales were modelled using a size-based model. Biomass, production and species richness were modelled as a function of local environmental conditions and bottom trawling disturbance. Modelled biomass, production and species richness were highest in the coastal areas, in particular in Carmarthen Bay, Cardigan Bay and Liverpool Bay. Bottom trawling strongly reduced biomass and species richness and to a lesser extent production of benthic communities.

Crynodeb

Er mwyn ei gwneud yn haws gwerthuso effeithiau economaidd gwahanol ddulliau o reoli pysgodfeydd, modelwyd cymunedau di-asgwrn cefn benthig gwaddod meddal ym mharth arfordirol Cymru gan ddefnyddio model ar sail maint. Modelwyd biomas, cynhyrchiant a chyfoeth rhywogaethau fel ffwythiant amodau amgylcheddol lleol a tharfiant oherwydd treillio ar waelod y môr. Roedd biomas, cynhyrchiant a chyfoeth rhywogaethau a fodelwyd ar eu huchaf yn yr ardaloedd arfordirol, yn enwedig ym Mae Caerfyrddin, Bae Ceredigion, a Bae Lerpwl. Roedd treillio ar waelod y môr yn lleihau biomas a chyfoeth rhywogaethau'n ddirfawr ac i raddau llai gynhyrchiant cymunedau benthig.

Contents

Acknowledgements	iii
Summary	iii
Contents	iv
List of figures	v
1. INTRODUCTION	1
2. METHODS	1
2.1 Model of trawling impacts on size-structure	1
2.2 Carrying capacity	2
2.3 Tidal bed shear stress	2
2.4 Sediment erosion	2
2.5 Sediment type	3
2.6 Fishing effort of bottom trawlers	3
2.7 Model runs	3
3. RESULTS	4
4. DISCUSSION	4
5. REFERENCES	6

List of figures

Figure 1. Modelled biomass of benthic invertebrate communities in the Irish Sea at current levels of bottom trawling.	page 7
Figure 2. Modelled production of benthic invertebrate communities in the Irish Sea at current levels of bottom trawling.	8
Figure 3. Modelled species richness of benthic invertebrate communities in the Irish Sea at current levels of bottom trawling.	9
Figure 4. Modelled biomass of benthic invertebrate communities in the Irish Sea without bottom trawling.	10
Figure 5. Modelled production of benthic invertebrate communities in the Irish Sea without bottom trawling.	11
Figure 6. Modelled species richness of benthic invertebrate communities in the Irish Sea without bottom trawling.	12
Figure 7. Seabed areas with very coarse sediments or rock seabed (black), where the model prediction may not be accurate.	13

1. INTRODUCTION

CCW has been contributing to a PhD at the School of Ocean Sciences being undertaken by Liz Richardson entitled *The socio-economic and ecological implications of inshore fisheries management* (project FC 73-02-740). The final part of this PhD includes an evaluation of the economic impacts of different types of fisheries management, including no take zones and areas where no fishing with towed gears is permitted. In order to base this economic analysis on realistic scenarios, data is needed concerning the locations which would most benefit from the protection described. The objective of the current project was to model the biomass, production and species richness of benthic invertebrate communities for the coastal zone of Wales (Irish Sea). This was done using a size-based model that was originally developed and validated for the North Sea (Hiddink et al. In press). This model predicts the biomass, production and species richness of soft sediment benthic invertebrate communities as a function of local environmental conditions and bottom trawling disturbance. These results will be used by Liz Richardson to identify areas that could be protected.

2. METHODS

2.1 Model of trawling impacts on size-structure

We used a size-based model of the response of soft-sediment benthic communities to trawling disturbance to predict the recovery time of these communities after trawling. Details of the development and use of the model are given in Duplisea et al. (2002) and Hiddink et al. (In press). In summary, the model contained 32 state variables, in two faunal groups (soft and hard bodied macrofauna). Growth of the population biomass in each body mass – organism type compartment was modelled by modifying Lotka–Volterra competition equations to give the population biomass flux for a compartment. The interaction between habitat type and trawling effects was modelled by including relationships between growth and mortality and the environment in the model. We included the effect of sediment type on trawling mortality, the effect of bed shear stress on population growth rate, the effects of chlorophyll a content of the sediment on carrying capacity and the effects of sediment erosion on mortality.

Recovery in the model can only take place through growth of the local populations, as the model assumes that there is no migration between adjacent areas.

The model needs the following input layers: tidal bottom shear stress, sediment erosion due to wave and tidal bed stress, carrying capacity, sediment type and fishing effort by bottom trawlers. This data was collated in Arcview 3 for 3x3 km cells in a UTM zone 30-projection. When necessary, data was interpolated using the Inverse Distance Weighing procedure.

2.2 Carrying capacity

The North Sea model used chlorophyll a content of the sediment as a measure of carrying capacity, but this data is not available for the Irish Sea. Instead, we used remote sensed chlorophyll content of the surface waters (Gohin 2005). The annual average chlorophyll a content from 1998 to 2004 was used as a measure of carrying capacity:

$$\text{Carrying capacity} = M * \text{surface chlorophyll a content (mg m}^{-3}\text{)}$$

M is a constant which was set at $M = 800$ to scale carrying capacity to similar levels as the North Sea model (a benthic biomass of approximately 10-60 g WW m⁻²).

Species numbers are modelled by examining if the biomass per log₃-size class is below 5% of a pristine reference level. Because this reference level depends on the carrying capacity, it was recalculated as the average biomass per log₃-size class for the examined area of the Irish Sea under a scenario without the presence of bottom-trawling disturbance.

2.3 Tidal bed shear stress

Peak tidal bed shear stress at the time of mean tides (N m⁻²) was modelled using standard oceanographic equations (Neill 2005).

2.4 Sediment erosion

Bed shear stress due to waves and tides was modelled for the Irish Sea (Neill 2005). Wave-induced bed stress was modelled for a storm event in January 2005. This is based on a non-stationary SWAN wave model run, which has been nested inside a larger shelf model. We used a statistical relationship between bed stress and sea bed

erosion from the southern North Sea to calculate sea bed erosion from these stress data:

$$\text{Erosion} = 0.0549 * (\text{Tide Stress} + \text{Wave Stress}) + 0.0308 \quad (R^2 = 0.8336)$$

2.5 Sediment type

Sediment data were obtained from digital British Geological Survey (BGS) sediment maps. When reporting the value of the indicators for different sediment types we classified sediments with a gravel content of more than 5% as gravel. For sediments with less than 5% gravel, sediments with a sand:mud ratio of more than 9:1 were classified as sand. Sediments with a sand:mud ratio between 1:1 and 9:1 were classified as muddy sand, and sediments with a sand:mud ratio smaller than 1:1 were classified as mud.

2.6 Fishing effort of bottom trawlers

Trawling intensity was expressed as the average area covered by trawling in a year (y^{-1}) for each cell, e.g. a trawling intensity of 2 y^{-1} means that an area was trawled twice a year. The trawling disturbance at each site was determined from records of vessel sightings by fishery protection aircraft as described by Jennings *et al.* (2002). These aircraft patrol the fishing grounds around the United Kingdom and record a description and location of all vessels that they observe fishing. Trawling disturbance can therefore be estimated as the number of beam trawler sightings per aircraft visit (sightings per unit effort, SPUE). For each cell, we calculated trawler SPUE from 2000 to 2003. The SPUE data were converted to a mean frequency of trawling at each site. For the calculation of trawling intensity (y^{-1}), it was assumed that trawlers cover an area of 0.22 km^2 per hour (i.e., 2 beam trawls of 12 m wide at 5 knots or one 48 m otter trawl at a speed of 2.5 knots, Davidse and De Wilde 2001). A trawler thus fishes 2336 km^2 per year and therefore, an SPUE of 1 (a trawler is always sighted in a 9 km^2 cell) should equate to the entire area of the site being trawled, on average, 260 times yr^{-1} .

2.7 Model runs

The model run using observed trawling effort predicts the current state of the benthic community in the Irish Sea. We also carried out a model run with trawling set to zero, to examine the potential distribution of biomass, production and species richness of

the benthic community if areas were closed to bottom trawling and allowed to recover in the absence of trawling.

3. RESULTS

Biomass, production and species richness should all be interpreted as relative values. Modelled biomass, production and species richness were highest in the coastal zones of Wales, in particular in Carmarthen Bay, Cardigan Bay and Liverpool Bay (Figure 1-3). Because of the formulation of the model, areas with high biomass, production and species richness coincide. Fishing strongly reduced biomass and species richness and to a lesser extent production of benthic communities in the areas that are affected by bottom trawling (Figure 3-6).

4. DISCUSSION

The benthic model predicted that the coastal areas of Wales are important for soft-sediment benthic invertebrate communities. The model was validated for the North Sea, but some modifications had to be made to the parameterisation of the model to allow running of the model for the Irish Sea using the available datasets. As no suitable datasets existed for validation of these model predictions in the Irish Sea, model predictions have to be used with care. Nevertheless, the distribution patterns that are predicted by the model, with the coastal zones being most important in terms of biomass and species richness, coincides with patterns that are observed in other shelf seas (Holtmann et al. 1996).

We classified all sediments with a grain size $>2\text{mm}$ as gravel, which covers anything up to boulders and bedrock. In the Irish Sea there are areas where the sea bed consists of a high proportion of cobbles and boulders. The model formulation assumed no direct effect of sediment on benthic growth or mortality rates (Snelgrove and Butman 1994). Instead we assumed that any correlations between sediment type and benthic community biomass can be explained through the correlation of sediment type with shear stress, chlorophyll a content and erosion rates. However, sediment composition does affect the direct mortality that was caused by bottom trawling and the parameter values we used may not be realistic for areas with a high proportion of cobbles, boulders or bedrock. However, a comparison of the spatial distribution of trawling effort and sediment types showed that virtually no trawling is carried out in areas with

these kind of seabeds, and that therefore the accuracy of model predictions was not affected in these areas. However, we modelled the benthic invertebrate community in sedimentary environments, ranging from mud to gravel. Hard surface communities are likely to interact differently with the environment than soft sediment communities and therefore our model cannot be assumed to be representative for these communities. Therefore, model predictions in the inner Bristol Channel and off the north-west coast of Anglesey (where BGS sediments maps coarse sediment or bedrock) are unlikely to be accurate (Figure 7).

The means by which erosion was estimated from tidal and wave bed stress is unlikely to be precise and the modelled state of the benthic community may have been affected by this in an unknown direction. Because we used a linear relationship between carrying capacity and surface chlorophyll a content, benthic biomass in areas with very high chlorophyll a contents may have been overestimated relative to other areas. Judging from the observed patterns, this only seems to be important for very few coastal cells. Because of these limitations of the model predictions, the model results are best used as a proof of concept, rather than for actually planning the location of marine reserves.

The model predicted a strong impact of current bottom trawling levels on benthic communities in offshore areas. Recovery of benthic communities is likely to take a long time (5-15 years) in most areas (Hiddink et al. In revision). When selecting areas to protect, the timescale over which the area will be protected is therefore important in determining which areas to protect. If an area will be closed to fishing on a seasonal basis or for a few years, the benthic community is unlikely to recover to pristine levels (Hiddink et al. Submitted) and it is best to use model predictions that include trawling impacts. When permanent (>20 year) area closures are considered, the modelled 'pristine' benthic community, in the absence of trawling, may be used for selecting the protected areas.

5. REFERENCES

- Davidse, W. P., and J. W. De Wilde. 2001. The impact of technological progress on fishing effort. Case study report. The Dutch beam trawl fishery for flatfish. LEI, Den Haag.
- Duplisea, D. E., S. Jennings, K. J. Warr, and T. A. Dinmore. 2002. A size-based model of the impacts of bottom trawling on benthic community structure. *Canadian Journal of Fisheries and Aquatic Sciences* 59:1785-1795.
- Gohin, F. 2005. ROSES Remote sensing browser for the English Channel and the Southern North-Sea. <http://www.ifremer.fr/cersat/facilities/browse/del/roses/browse.htm>. *in*. IFREMER.
- Hiddink, J. G., T. Hutton, S. Jennings, and M. J. Kaiser. Submitted. Predicting the effects of area closures and fishing effort restrictions on the production, biomass and species richness of North Sea benthic invertebrate communities. *ICES Journal of Marine Science*.
- Hiddink, J. G., S. Jennings, and M. J. Kaiser. In revision. Recovery status as an indicator of the large scale ecological impact of bottom trawling. *Ecosystems*.
- Hiddink, J. G., S. Jennings, M. J. Kaiser, A. M. Queirós, D. E. Duplisea, and G. J. Piet. In press. Cumulative impacts of seabed trawl disturbance on benthic biomass, production and species richness in different habitats. *Canadian Journal of Fisheries and Aquatic Sciences* 63.
- Holtmann, S. E., A. Groenewold, K. H. M. Schrader, J. Asjes, J. A. Craeymeersch, G. C. A. Duineveld, A. J. Van Bostelen, and J. Van der Meer. 1996. Atlas of the zoobenthos of the Dutch continental shelf. Ministry of Transport, Public Works and Water Management, North Sea Directorate, Rijswijk.
- Jennings, S., M. D. Nicholson, T. A. Dinmore, and J. Lancaster. 2002. The effect of chronic trawling disturbance on the production of infaunal communities. *Marine Ecology Progress Series* 243:251-260.
- Neill, S. P. 2005. A morphological model of the Irish Sea. Centre for Applied Marine Sciences, University of Wales (Bangor), Menai Bridge.
- Snelgrove, P. V. R., and C. A. Butman. 1994. Animal Sediment Relationships Revisited - Cause Versus Effect. Pages 111-177 *in* *Oceanography and Marine Biology*, Vol 32.

FIGURES

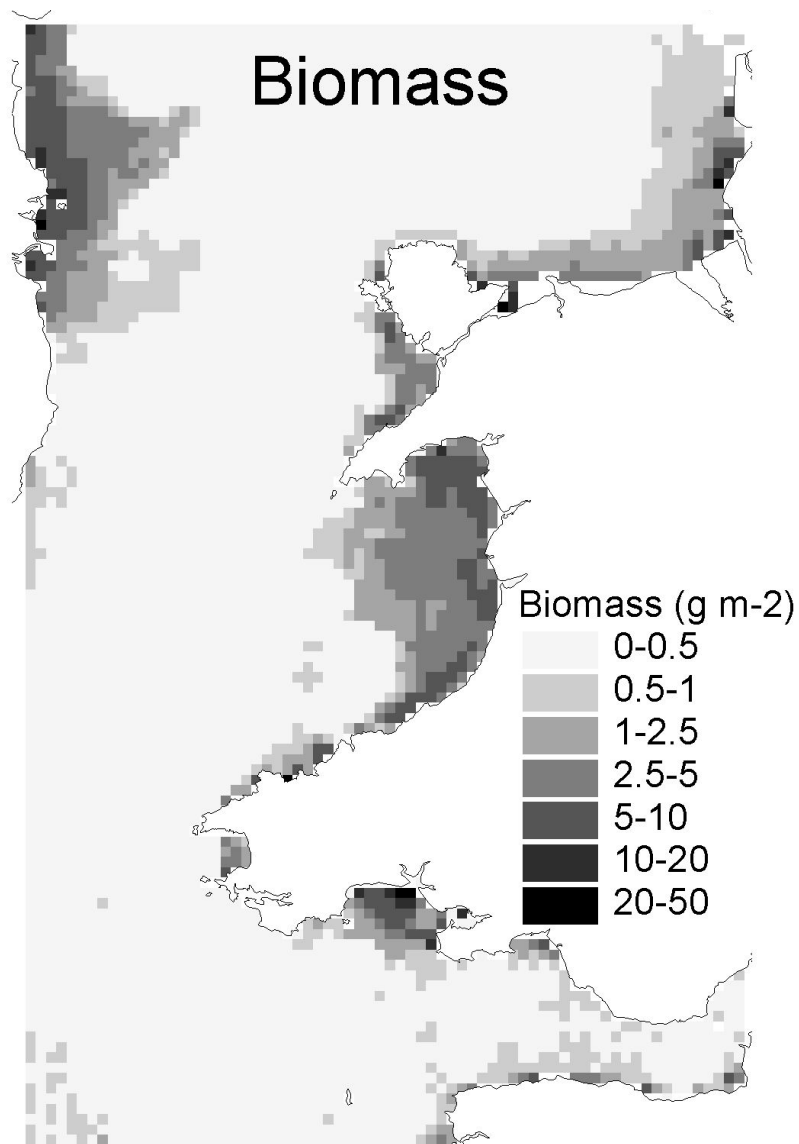


Figure 1. Modelled biomass of benthic invertebrate communities in the Irish Sea at current levels of bottom trawling.

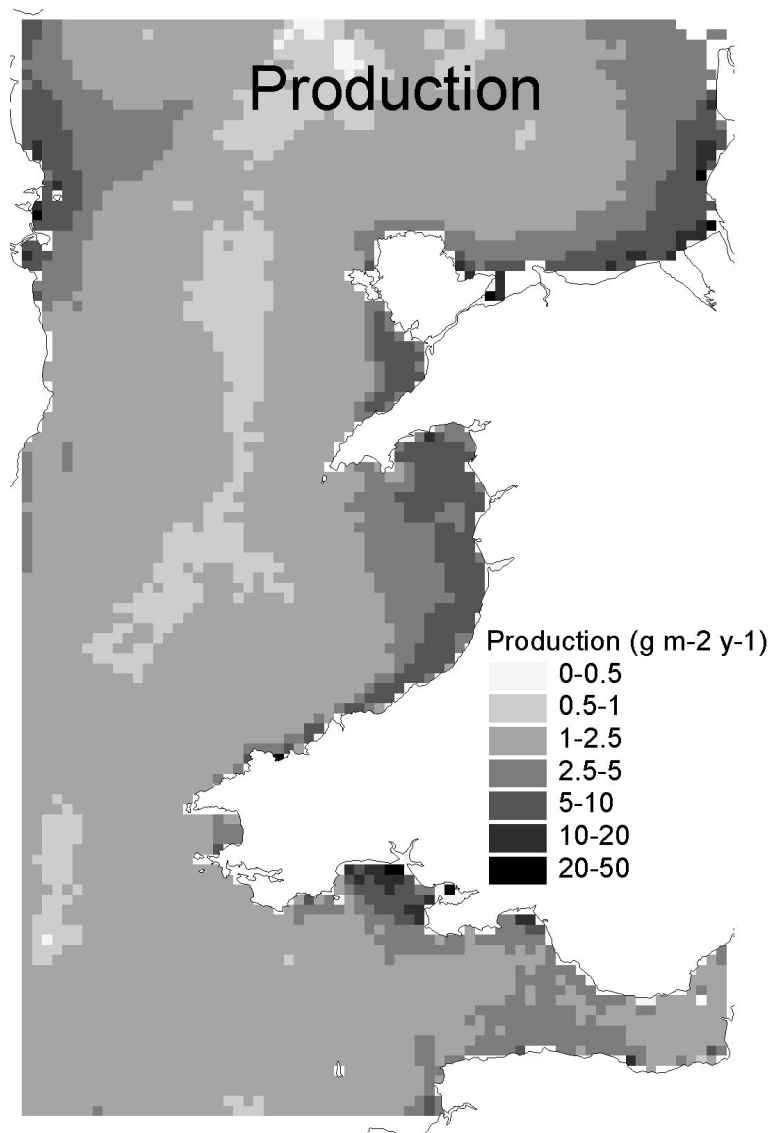


Figure 2. Modelled production of benthic invertebrate communities in the Irish Sea at current levels of bottom trawling.

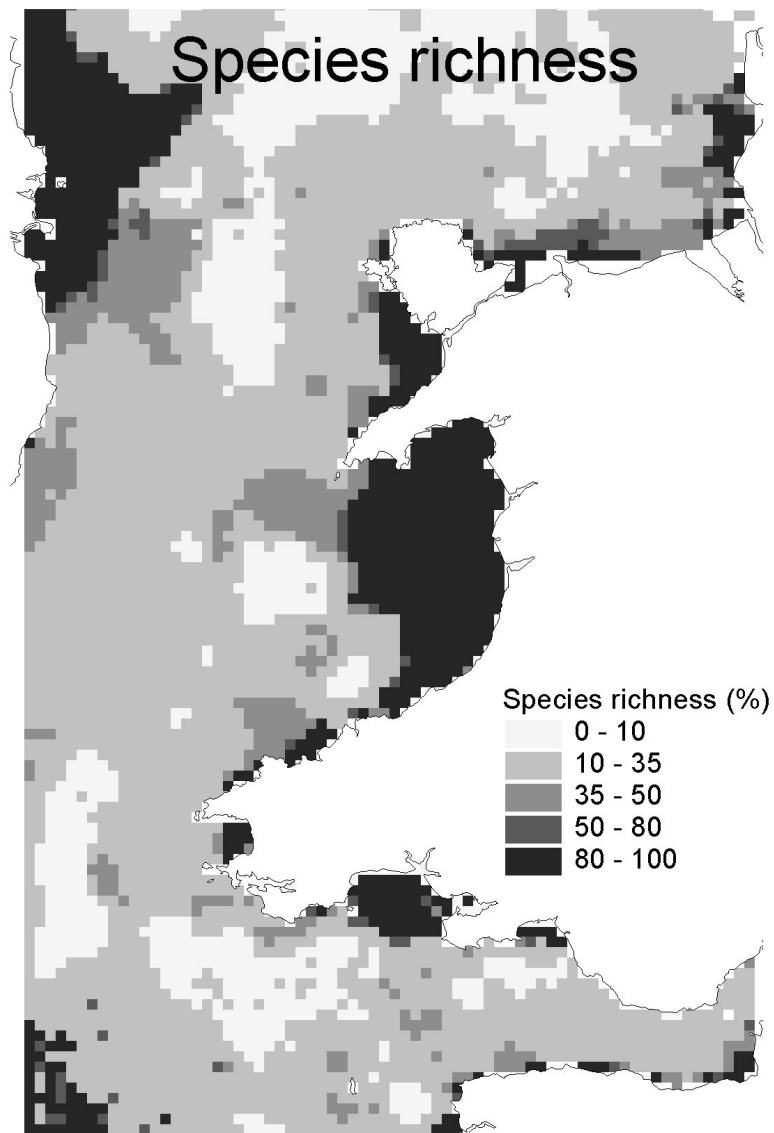


Figure 3. Modelled species richness of benthic invertebrate communities in the Irish Sea at current levels of bottom trawling.

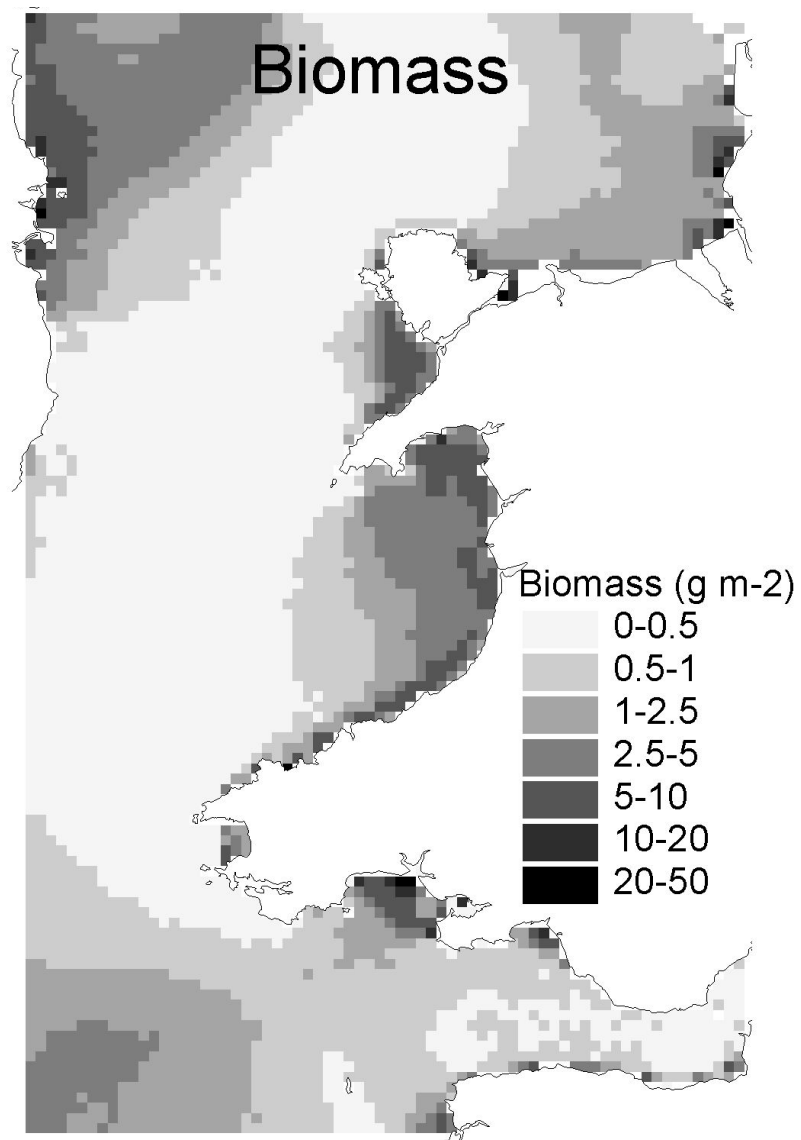


Figure 4. Modelled biomass of benthic invertebrate communities in the Irish Sea without bottom trawling.

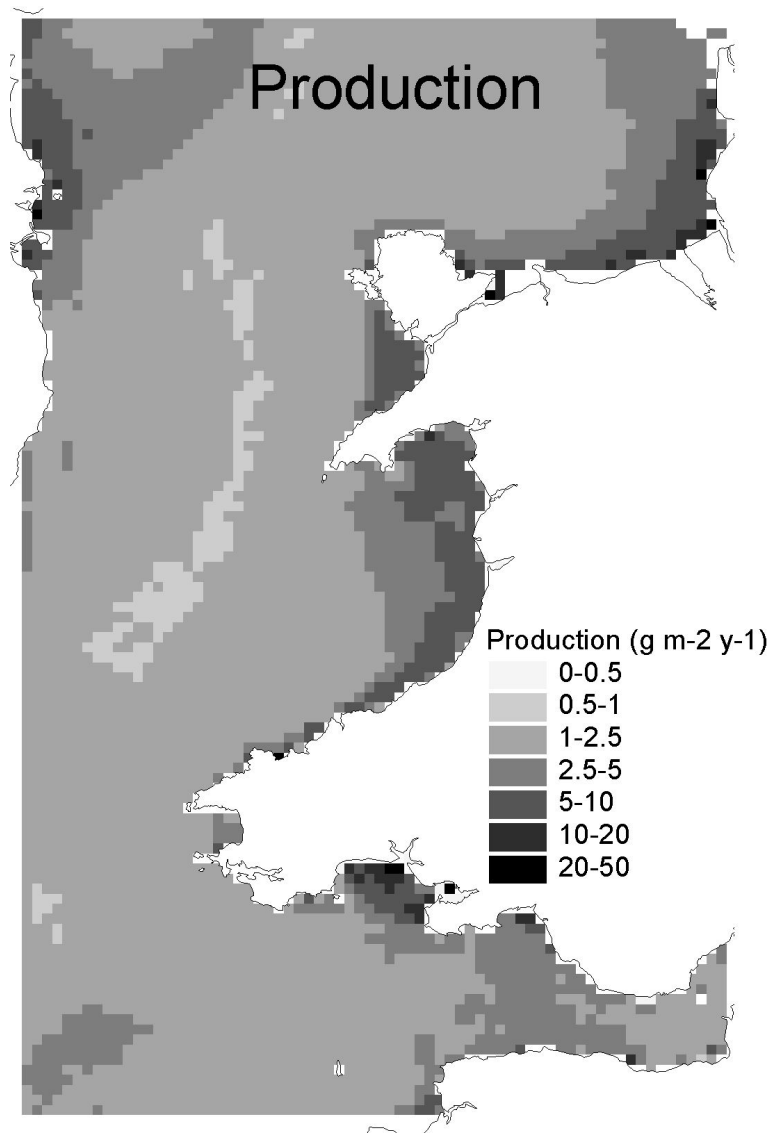


Figure 5. Modelled production of benthic invertebrate communities in the Irish Sea without bottom trawling.

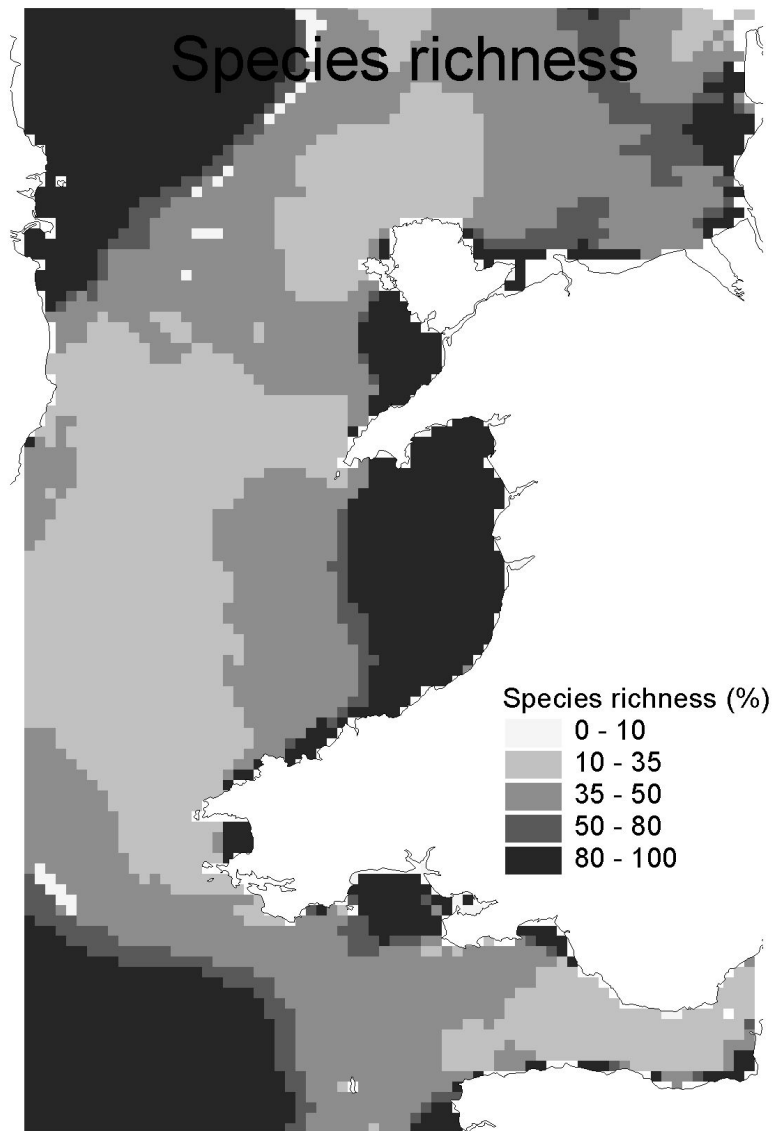


Figure 6. Modelled species richness of benthic invertebrate communities in the Irish Sea without bottom trawling.

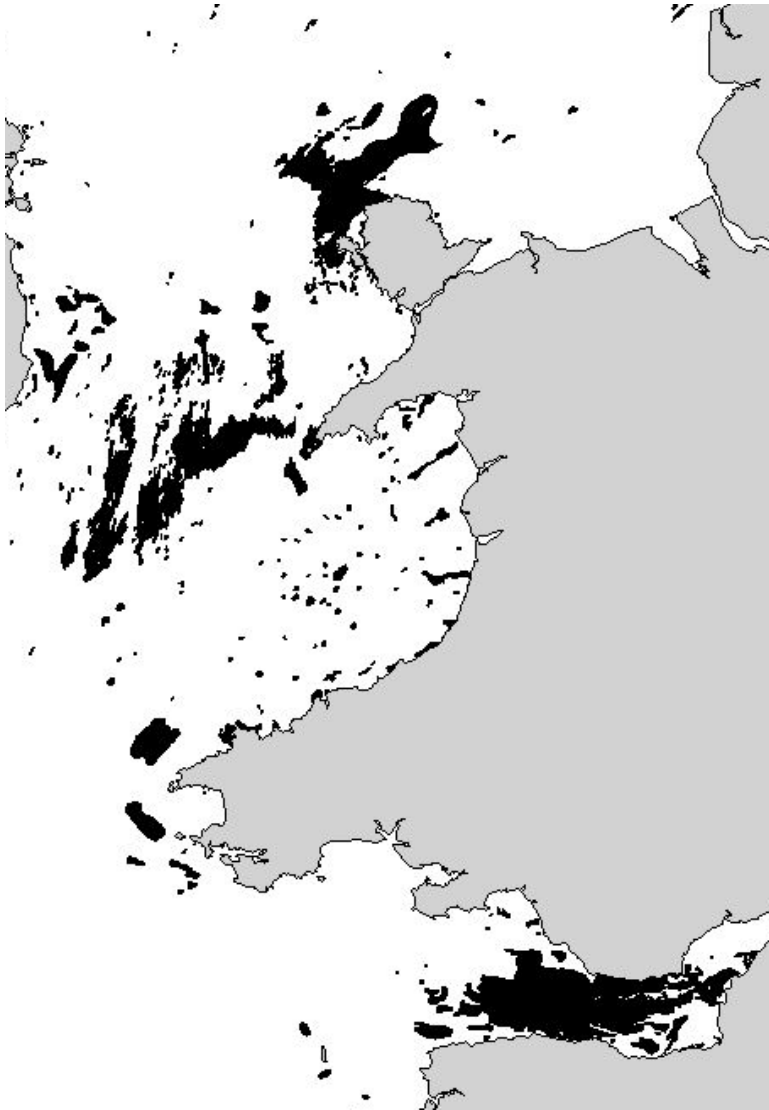


Figure 7. Seabed areas with very coarse sediments or rock seabed (black), where the model prediction may not be accurate.