



## Original Article

# Combined application of biophysical habitat mapping and systematic conservation planning to assess efficiency and representativeness of the existing High Seas MPA network in the Northeast Atlantic

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The High Seas are increasingly the subject of exploitation. Although Marine Protected Areas (MPAs) are seen as a useful tool in the sustainable management of the oceans, progress in the implementation of MPA networks in areas beyond national jurisdiction has been limited. Specifically, the criteria of “representativeness” has received little consideration. This study uses the systematic conservation planning software Marxan coupled with a biologically meaningful biophysical habitat map to investigate representative MPA network scenarios and to assess the efficiency and representativeness of the existing High Seas MPA network in the Northeast Atlantic. Habitat maps were created based on the layers of water mass structure and seabed topography resulting in 30 different habitats, in six distinct regions. Conservation targets were set at 10 and 30% representation of each habitat within the final network. Two portfolios were created. The first portfolio (P1) ignored the presence of the existing MPA network within the study area allowing a non-biased selection of planning units (PUs) or sites to be chosen. The second (P2) enforced the selection of areas within the existing MPA network. Efficiency was measured as the difference in the percentage area contained within the “best scenario” MPAs from the un-biased run (P1) compared with (P2). Representativity of the existing network was assessed through the investigation of the properties of PUs included within MPAs in the “best scenario” Marxan output of P2. The results suggest that the current MPA network is neither efficient nor representative. There were clear differences in the spatial distribution of PUs selected in P1 compared with P2. The area required to be protected to achieve that the representation of 10 and 30% of each habitat was 8–10 and 1–4% higher, respectively, in P2 compared with P1. Abyssal areas in all regions are underrepresented within the current MPA network.

**Keywords:** biophysical, deep-sea, habitat classification, Marine Protected Areas, Marxan.

## Introduction Background

The deep-sea is vast, and although it represents ~63% of the Earth's surface (Smith *et al.*, 2008) a mere 0.0001% of it has been the focus of biological, scientific investigation (Benn *et al.*, 2010). In the past, the remoteness and inaccessibility of the deep seabed has protected it from exploitation but has also severely limited research (Benn *et al.*, 2010). However, there is increasing evidence that human activities are causing serious damage in the High Seas [or areas

beyond national jurisdiction (ABNJ); McClain and Hardy, 2010; Ramirez-Llodra *et al.*, 2011; Pham *et al.*, 2014]. ABNJ include all areas outside of the 200 nautical mile economically exclusive zones (EEZs), set in place in 1994 by the 1982 United Nations Convention on the Law of the Sea (UNCLOS) which is the main comprehensive, legal framework relating to the High Seas (O'Leary *et al.*, 2012).

As technology improves, previously inaccessible areas containing economically viable resources are being exploited (McClain

and Hardy, 2010; Ramirez-Llodra *et al.*, 2011). Knowledge of slow growth rates and extreme longevity of many deep-sea species and awareness of the damage fishing and mining practices can inflict (Laffoley, 2005) suggests that any marine habitats at risk from anthropogenic activities require protection.

## Conservation tools

### Marine Protected Areas

The main response to anthropogenic threats to the marine environment in recent years has been the development of Marine Protected Areas (MPAs). MPAs are experiencing growing political support (O'Leary *et al.*, 2012) and are increasingly seen as an important tool for conserving marine biodiversity (Lubchenco *et al.*, 2003; Wood *et al.*, 2008; Metcalfe *et al.*, 2012). MPAs have become a powerful management tools to prevent the overexploitation of marine resources (Agardy *et al.*, 2011; Hansen *et al.*, 2011) and to ameliorate the impact of human-use disturbances (Levy and Ban, 2013). Currently, it is estimated that MPAs cover 1.17% of the world's oceans (Fox *et al.*, 2012) and only 0.08% are completely protected as no-take zones (Wood *et al.*, 2008). The distribution of current MPAs is sporadic, tending to be small, individual opportunistic reserves within territorial waters, often community driven (Ban *et al.*, 2009). It has been debated how well these MPAs protect and represent the local ecosystem (Smith *et al.*, 2009). New research has made it apparent that MPAs need to be representative, and furthermore need to have a level of connectivity to neighbouring MPAs to effectively preserve biodiversity (Pressey *et al.*, 2007; O'Leary *et al.*, 2012). Small, individual MPAs, while often having a positive effect, rarely fulfil such criteria. Systematic, science-based approaches for MPA selection are now encouraged, adopting varying degrees of implementation, in an effort to achieve conservation objectives at a low cost (Ban *et al.*, 2009b; O'Leary *et al.*, 2012). However, the lack of existing scientific data and the evident absence of MPAs in ABNJ suggest that the justification and application of deep-sea MPAs are difficult (Ardrón *et al.*, 2008).

### Mapping biodiversity using surrogates

To design a representative system of MPAs that will facilitate conservation of deep-sea biodiversity, a number of issues need to be resolved. Gaining support for MPAs in data poor areas, such as ABNJ, is necessary. The paucity of data in the deep-sea will not be solved soon and will always lag behind exploration (O'Leary *et al.*, 2012). This is fuelling a growing body of research that uses various surrogates to represent biological diversity, and more recently the use of predictive modelling to map the distributions of habitats (Howell *et al.*, 2011; Ross and Howell, 2012). The use of biophysical surrogates as indicators of benthic habitats has become an established method of habitat mapping (Roff and Taylor, 2000; Harris and Whiteway, 2009; Howell, 2010). These surrogates are often organized into a hierarchical classification system, the examples of which include the European Nature Information System (EUNIS; Davies *et al.*, 2004) and the Global Open Oceans and Deep-sea Seabed (GOODS UNESCO, 2009); for a detailed review, see Howell (2010).

These habitat classification systems can then be used to assist the creation of habitat maps to convey spatial information that is relevant to the distribution of biodiversity (Metcalfe *et al.*, 2012). A study by Roff *et al.* (2003) was one of the first to establish that by using simple mapping and Geographical Information System (GIS) techniques, a map of representative habitats can be created that follows a classification system. A GIS overlay approach, based

on Boolean logic (Harris *et al.*, 2008), using a geophysical (i.e. physiographic and oceanographic) framework identified different broad scale, natural regions termed "seascapes" for the entire Canadian coastline and Scotian Shelf.

Following this initial example, a number of studies have emulated Roff *et al.* (2003), using a variety of spatially different surrogates to systematically map different regions around the world; the Australian continental shelf (Harris *et al.*, 2008), Scottish continental shelf (Howell, 2010), and the global seabed (Greene *et al.*, 1999; Agnostini *et al.*, 2008; Harris and Whiteway, 2009).

To be relevant and of use understanding the distribution of biodiversity and hence the design of MPAs, any surrogates must exert control on (i.e. be a surrogate for) the occurrence of species (Roff *et al.*, 2003; Harris *et al.*, 2008; Harris and Whiteway, 2009; Howell, 2010). A representative MPA system will contain a full range of seabed features and ecosystems that can be identified and mapped using surrogates.

### Systematic conservation planning

Systematic conservation planning (SCP) is a recent, widely used approach in the development of MPA networks that meet scientific criteria. This approach aims to identify priority areas which can be compiled into a representative and viable network of MPAs; that also minimize size and subsequent costs (Ball *et al.*, 2009; Smith *et al.*, 2009).

An initial step in SCP is to produce a list of important species or habitats (conservation features) using mapping techniques, conservation targets can then be set that protect a minimum amount of each feature. Several conservation planning software packages are available (C-Plan, Marxan) to help achieve these targets and provide multiple and detailed outputs (Metcalfe *et al.*, 2012). Being able to set a quantitative target such as those specified by the Convention on Biological Diversity (CBD) of 10% of coastal and marine areas to be protected by 2020 (CBD, 2011) provides a key foundation for conservation decisions. Being able to design MPA networks with an exact area or target is beneficial as it reduces the impact on various stakeholders and increases the likelihood of implementation (Knight *et al.*, 2006; Smith *et al.*, 2009).

Biophysical surrogates for diversity can be used effectively alongside systematic conservation software to provide pragmatic reserve systems that can be of great use to decision-makers.

## The present study

The Northeast Atlantic is one of the most heavily utilized areas of the world's oceans; however, there are international conventions and management bodies for this region that have taken some significant steps into managing the ABNJ sustainably. Two key management bodies are, the Convention for the Protection of the Marine Environment of the Northeast Atlantic (OSPAR) and the North East Atlantic Fisheries Commission (NEAFC), dealing with environmental protection and fisheries management, respectively (Kvalvik, 2012). In 2003, the OSPAR commission signed a joint-ministerial statement (JMM, 2003) agreeing to establish "an ecologically coherent, representative network of well-managed MPAs by 2010" (Ardrón, 2008; OSPAR, 2010). An ecologically coherent, representative network should interact with and support the wider environment and maintain the processes, functions, and structures of the intended protected features across their natural range (Laffoley, 2005). OSPAR's main assessment criteria are adequacy/viability, representativity, replication, and connectivity. As of 31 December 2010, the OSPAR Network of MPAs comprises a

total of 181 sites, of which only 6 are located in ABNJ. Collectively, the sites in ABNJ cover 439 679 km<sup>2</sup> or 3.15% of the OSPAR maritime area (O'Leary *et al.*, 2012). Site selection to date has been based on identifying areas of perceived ecological significance with little focus on the assessment of the network as a whole.

This study aims to assess the efficiency and representativity of the existing MPA network in the ABNJ in the Northeast Atlantic using the systematic conservation planning software Marxan parameterized using a biophysical habitat map. Our objectives were to: (1) create a biologically relevant biophysical habitat map for an area of the Northeast Atlantic and (2) use Marxan to design a representative MPA network for the study area under two scenarios, where (i) is an unbiased network aimed at achieving representation of all habitats in the most space efficient manner and (ii) includes the current OSPAR MPA network and NEAFC closure zones (Figure 1).

## Material and methods

### Study area

The area selected for the study represents a significant part of the OSPAR area V (Figure 1) and extends between 63.5 and 36°N and from 8 to 31.2°W, excluding any EEZs. We chose to restrict our analysis to part of OSPAR area V east of the Mid Atlantic Ridge (MAR) as the MAR may also represent a biogeographic boundary (Vinogradova, 1997; Zezina, 1997). The study area occupies an

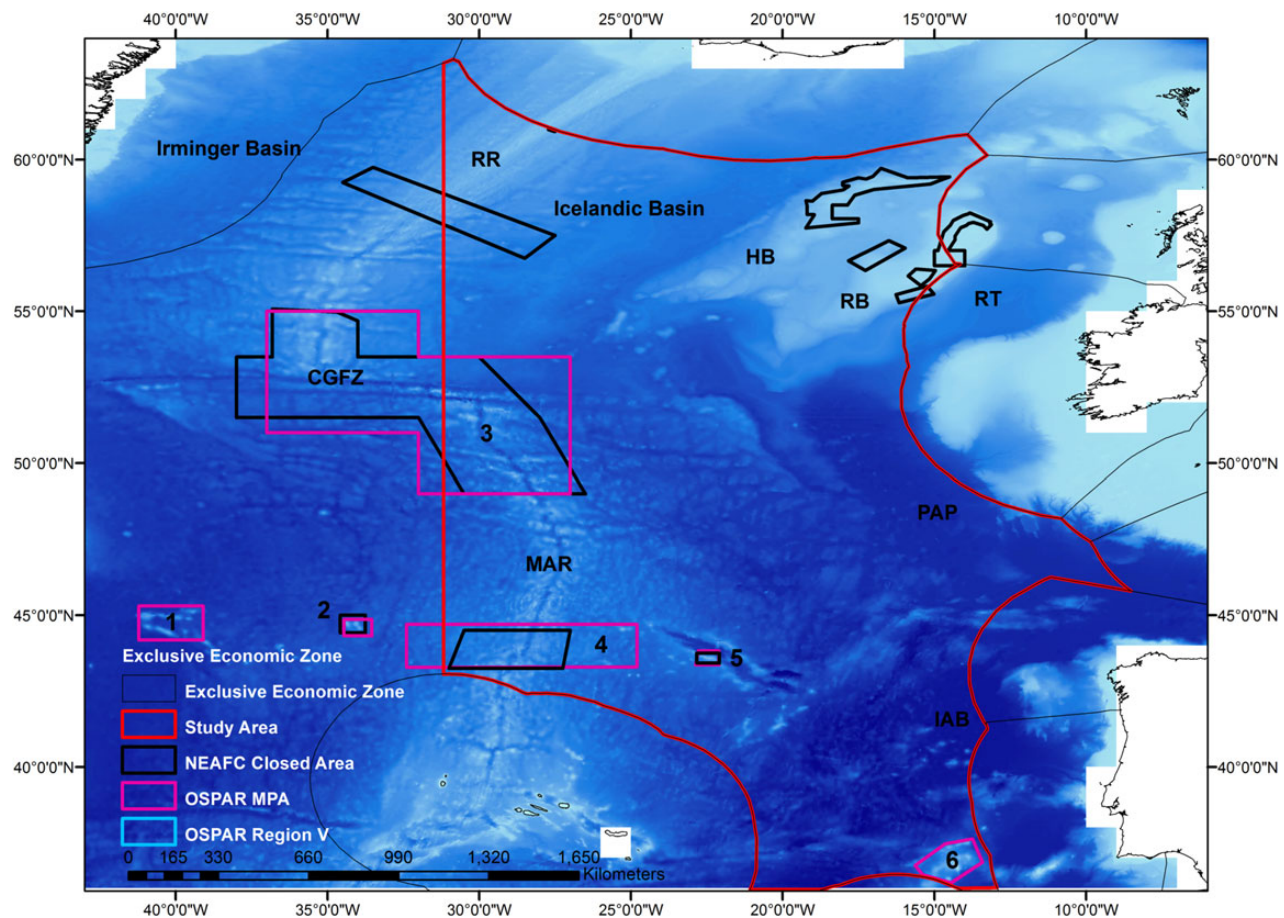
area of 2 930 313 km<sup>2</sup>, compared with 6 366 023 km<sup>2</sup> for the whole of region V (including EEZs). Within this area, the depth varies from 200 to 5800 m and has a number of known key deep-sea environments, e.g. seamounts, hydrothermal vents, abyssal plains, fracture zones, and ridges (OSPAR, 2000). The study area also contains or partially contains four MPAs from OSPAR's network of MPAs in ABNJ (Supplementary Table A.2) and ten NEAFC closure zones (Figure 1).

## Biophysical habitat map development

### Variable selection

Choosing physical variables to use as surrogates for variation in deep-sea benthic biodiversity is a difficult task; the absence of scientific data limits choice and it must be considered whether a chosen surrogate is available globally. Howell (2010) undertook an extensive review of existing deep-sea classification systems and found those physical environmental variables used as surrogates for biodiversity that were common to most to include biogeographical province, depth, geomorphology, and substrate type.

As this study is limited to the Northeast Atlantic, the study area does not include the Arctic biogeographical province; although a small area west of the MAR is included, for the purposes of this investigation, we have assumed the study area to be within one



**Figure 1.** Map of the Northeast Atlantic including outline of OSPAR region V, study area, and current protected areas: numbers refer to OSPAR MPAs (Supplementary Table A.2). MAR, Mid-Atlantic Ridge; CGFZ, Charlie–Gibbs Fracture Zone; PAP, Porcupine Abyssal Plain; IAB, Iberian Abyssal Plain; RR, Reykjanes Ridge; HB, Hatton Bank; RB, Rockall Bank; RT, Rockall Trough.



biogeographical province and thus have not included biogeography as a variable in surrogate map development.

Depth is an easily measured, globally available dataset. In studies of deep-sea benthic assemblages, depth is the single most important variable driving deep-sea community structure. However, depth is an indirect surrogate that is related to changes in temperature, pressure, oxygen, sediment type, water mass structure, and food supply. Howell (2010) identified a number of depth-related faunal boundaries that occur in deep sea communities and suggested potential depth classes that could be used to represent the variation in benthic community structure for the Northeast Atlantic. Recent research has re-emphasized the importance of water mass structure in deep-sea benthic community ecology, particularly in regard to population connectivity (Miller *et al.*, 2011). In this study, we have elected to use water mass structure as opposed to depth to represent the change in faunal composition with depth.

The limitations of using geomorphology as a surrogate for biology have been discussed by Howell (2010) and will not be repeated here. Although we have not used geomorphology as a variable in map development, we have used topographic variables as described below. The substrate is an important surrogate for predicting changes in benthic habitats and communities. The use of a substrate in habitat classification systems is universal and its strength as a fine scale surrogate for deep-sea biodiversity variation is well established (Howell, 2010).

#### Bottom water mass layer

The distributions of water masses and currents below 800 m have not been comprehensively mapped (Roff and Zacharias, 2011) and knowledge regarding them is exiguous. An in-depth study of existing literature relating to deep-sea ocean currents suggests that there are six distinctly different water masses within the study area (Table 1). These water masses can be distinguished using factors including but not limited to; oxygen levels, nutrient levels, salinity,

and temperature (Haine *et al.*, 2006; McGrath *et al.*, 2012). Using the General Bathymetric Chart of the Ocean (GEBCO, 2003) data to delineate boundaries between water masses as described in the literature, polygons were drawn where a water mass had been measured *in situ* by relevant studies, using ESRI ArcGIS 10 (ESRI, CA, USA). Where gaps were present within the newly drawn polygon layer, expert judgement was used to interpret likely water mass class by considering topography, depth, and known direction of current flow as determined from the literature review and their similarity to neighbouring areas (this occurred for ~20% of the study area). The water mass layer was derived from the GEBCO depth layer which is at 30 arc seconds resolution. In all, 17 polygons depict six water masses that overlay the deep seabed to produce the bottom water mass (BWM) layer (Figure 2a).

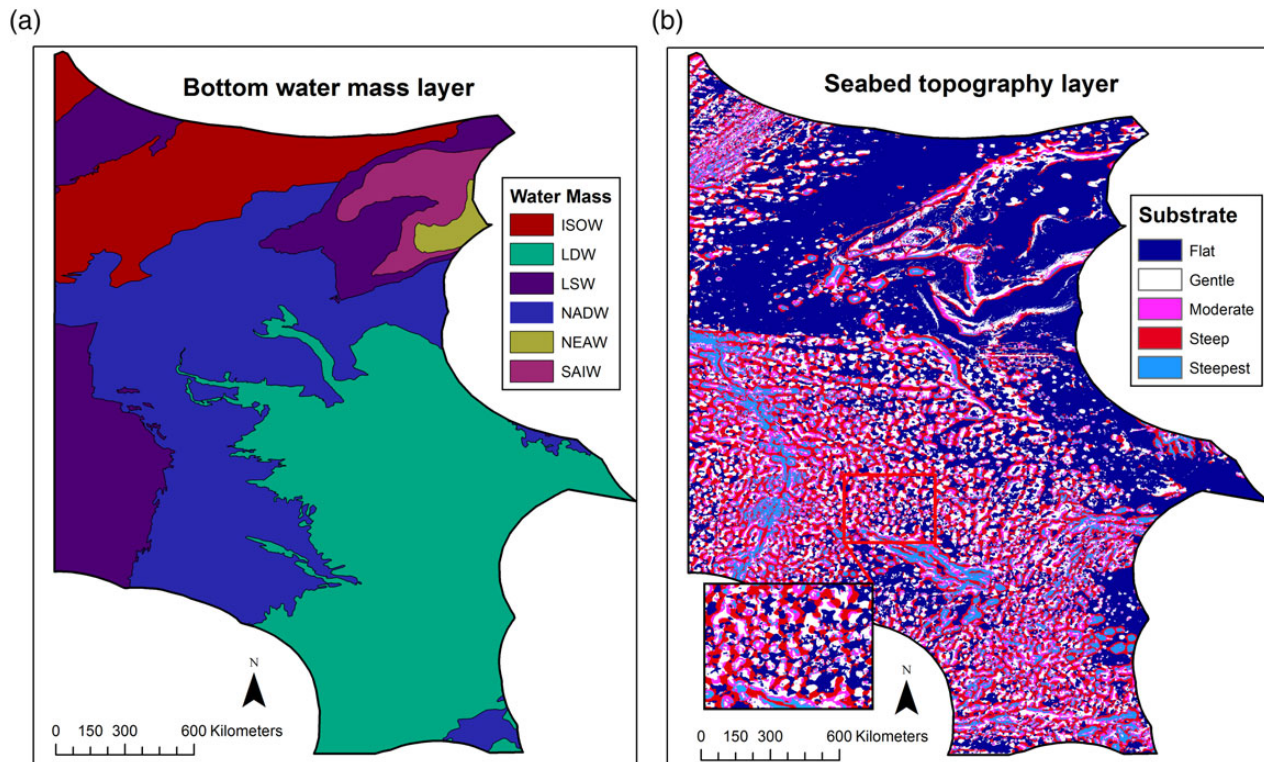
#### Substrate (seabed topography) layer

There is no global map of a seabed substrate freely available for use in this project. However, topographic data and derived information can be used as a surrogate for a broad-scale substrate. Using the GEBCO digital bathymetry map, layers of the bathymetric position index, slope, and rugosity were derived and combined following a similar method to that of Harris and Whiteway (2009) to produce the classes of different seabed types:

- (i) each variable was re-classed so that its range was equal (0–255) to ensure equal weighting in the classification process;
- (ii) these three layers were combined and classified using the “Iso Class Unsupervised Classification” technique with ArcGIS 10, similar to the algorithm used by Harris *et al.* (2008) rather than the supervised method used by Roff *et al.* (2003);
- (iii) this tool allowed natural clusters of the data to define separate classes, creating five distinctly different substrate habitats given names that reflect the topography; i.e. flat for abyssal areas, steepest areas are ridges, seamounts, etc. (Figure 2b).

**Table 1.** Identification and properties of the six water masses identified for the BWM layer.

Water mass	Depth (m) (approximately)	T (°C)	Location/pathway	Reference
Icelandic- Scotland Overflow Water (ISOW) (Bottom Water)	2000–2600	1.8	Norwegian Sea south through Icelandic Basin > CGFZ > north through Irminger Basin	van Aken and de Boer (1995), van Aken (2000a, b), Read <i>et al.</i> (2010), Haine <i>et al.</i> (2006)
Northeast Atlantic Deep Water (NADW) (Bottom/intermediate water)	2500–4000	2.9–3.4	Combination of ISOW and LSW formed near the Mid-Atlantic Ridge (MAR) and travels Eastwards	McGrath <i>et al.</i> (2012), van Aken, (2000a, b), Haine <i>et al.</i> (2006)
Sub-Arctic Intermediate Water (SAIW) (Intermediate water)	600–1000	4–7	Travels Eastwards as far as Rockall Trough	McGrath <i>et al.</i> (2012), van Aken (2000b), Ullgren and White (2010)
Lower Deep Water (LDW) (Bottom water)	>4000	~2	Derivative of Antarctic Bottom Water travelling North from Equator, East side of MAR	Van Aken (2000a), Haine <i>et al.</i> (2006)
Labrador Sea Water (LSW) (Intermediate Water)	1300–2500	3–4	Labrador sea East > CGFZ > Spreads across NE Atlantic	Paillet <i>et al.</i> (1998), van Aken and de Boer (1995), McGrath <i>et al.</i> (2012), van Aken and de Boer (1995), Read <i>et al.</i> (2010), Kiekie <i>et al.</i> (2009), van Aken (2000b), Haine <i>et al.</i> (2006)
Northeast Atlantic Water (NEAW) (Surface water)	100–600	8–12	Surface layer > flowing North along West coast of Europe up as far as the Rockall Trough	McGrath <i>et al.</i> (2012), Ullgren and White (2010)



**Figure 2.** (a) BWM layer illustrating six distinctive water masses at the seabed of the Northeast Atlantic. (b) Seabed Topography layer compiled using the “Iso Cluster Unsupervised Classification” technique. Inset magnified square illustrating the complexity of the layer.

#### Combined final biophysical habitat layer

The BWM and seabed topography layers were overlaid within ArcGIS, using the “Combine” tool, to create a final layer of polygons that represent broad-scale physical habitat heterogeneity. It is assumed here that physical habitat heterogeneity may be used as a surrogate for variation in the biological communities of the deep-sea. The final habitat map for the study area contains 30 different habitats, in six distinct regions; depicting the location of various water masses (Figure 3a).

A focal variety analysis was performed on the biophysical habitat layer, to highlight physically diverse areas of the deep seabed. The variety focal analysis was performed in ArcGIS using the “Focal Statistic” tool (Harris *et al.*, 2008). A circular neighbourhood of 50 pixels, which equates to 0.25 of a decimal degree, was used to determine the diversity of each cell in respect to its surrounding cells followed by a low-pass ( $3 \times 3$ ) filter to smooth the edges.

#### Systematic MPA planning

The systematic conservation planning software Marxan (v2.43; Ball *et al.*, 2009) was used to create the portfolios of marine reserves.

#### Marxan software

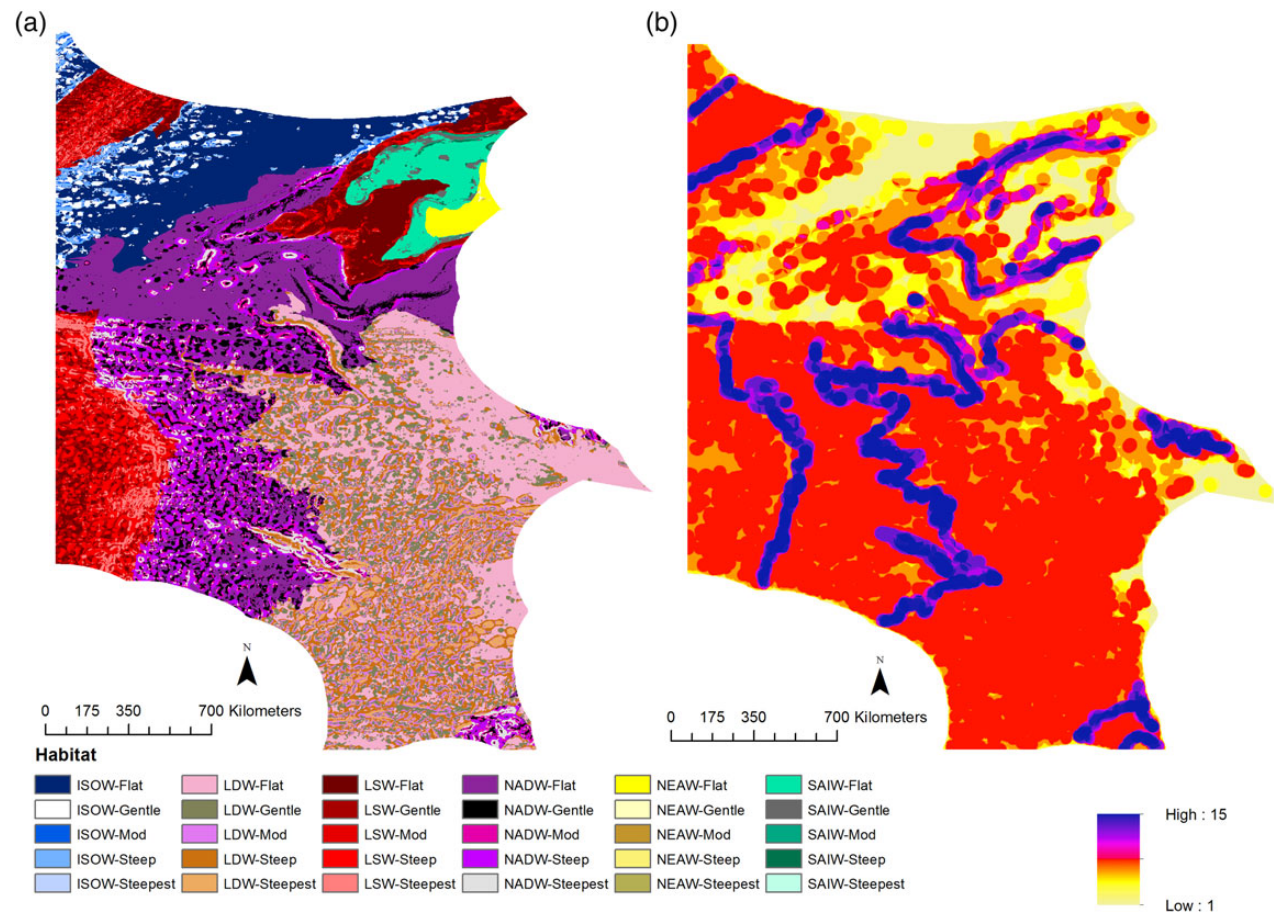
Marxan is a site selection decision support tool which is used to aid decision-makers during the formulation of conservation areas. Marxan is useful due to the large amount of spatial data it can analyse and the enormous number of possible solutions it produces. The outputs produced by Marxan will be compared alongside the focal variety output (Figure 3b) to ascertain how well each output protects biodiversity.

A basic run of Marxan requires information on the selected planning units (PUs) that cover the chosen area and a list of conservation features (habitats). User-defined variables include conservation targets for the features, the cost of using each PU, Boundary Length Modifier (BLM), penalty factor, number of runs, number of iterations, and PU status. Each individual PU can be assigned a status and can define whether a PU is locked in or out of the initial and final reserve system (Game and Grantham, 2008). Allowing the user to include or exclude the existing protected areas within an analysis.

Marxan uses its systematic annealing algorithm to select a subset of these PUs that meet the user-defined conservation objectives at the lowest possible cost (Ban, 2009). A score is then produced for each set of reserves which incorporates the cost of the reserve system and any penalty factors are applied for not achieving conservation targets (Hansen *et al.*, 2011). A higher penalty factor will place more emphasis on meeting all conservation targets to avoiding large penalties to the score of that run. Marxan uses a stochastic algorithm to search for reserve systems so that multiple runs do not return the same solutions (Ball *et al.*, 2009). It produces two main outputs: the “best” solution and solution frequency. The “best” solution shows the reserve system with the lowest cost while the frequency selection highlights PUs that are regularly selected.

#### Preparing data for Marxan

In ArcGIS, the study area was divided into 1546 hexagon shaped PUs, the majority of which had an average area of 2000 km<sup>2</sup> with certain PUs clipped at the boundaries having a smaller area. This value was selected as it is approximately the smallest size of an ICES statistical rectangle, a widely used unit in the management of



**Figure 3.** (a) Combined classification of benthic habitats in the study area. (b) Focal variety analysis of the combined classification showing physical diversity within a circle of 50 cells.

fisheries. ICES statistical rectangles measure 30 min latitude by 1 degree longitude and thus the exact area in km<sup>2</sup> varies with longitude. The biophysical habitat class (conservation feature) contained in each PU were identified and the PU area calculated using the “Tabulate Areas” function in ArcGIS.

*Specifying the user-defined settings*

To assess the efficiency of the existing network, it is necessary to specify a percentage area target to assess the network against. The Convention on Biological Diversity (CBD, 2004) suggests an area target of at least 10% of global coastal and marine habitats to be protected by 2020 (Levy and Ban, 2013). However, a second target of 30% was also put forward at the 2003 World Parks Congress (IUCN, 2005). In addition, recent evidence suggests that to capture ~75% of species in the deep-sea within an MPA network 30–40% of the area would be needed (Foster et al., 2013). In this study, both the percentage area targets of 10 and 30% were used. It is important to note that Marxan will attempt to capture 10 and 30% of each individual conservation feature (biophysical habitat class) and not 10 and 30% of the study area. This inevitably results in a larger overall area being selected.

In addition, the user is required to specify the BLM to be used. The BLM determines how much emphasis should be placed on the overall compactness of the reserve boundaries: lower values generate smaller, fragmented solutions, whereas higher values generate

**Table 2.** User-defined variables for each scenario used in the two analyses run by Marxan.

Scenario	Conservation target (%)	BLM	Penalty factor	Number of runs
1	10	0.15	10	200
2	30	0.15	10	200
3	10	1	10	200
4	30	1	10	200
5	10	5	10	200
6	30	5	10	200

fewer, more clumped solutions (Levy and Ban, 2013). In this study, three BLM setting were used to ensure a good spread of possible outcomes.

*Marxan runs*

Two different portfolios of the study area were created using Marxan, each with six individual scenarios using the variables depicted in Table 2. The first portfolio (P1) ignored the presence of the existing MPA network within the study area allowing a non-biased selection of PUs to be chosen. This portfolio was then directly compared with the second portfolio (P2) in which the existing MPA network was “locked-in” forcing Marxan to include them in every run. Each scenario conducted 200 runs, with 100 000 iterations.



For all Marxan runs, PUs were assigned a cost equivalent to their area and the penalty factor was set to 10. All factors, variables and files were created, calibrated and defined following the principles set out in the Marxan User Manual (v1.8.10; [Game and Grantham, 2008](#)) and Marxan Good Practices Handbook (v2; [Ardron \*et al.\*, 2010](#)).

Output Marxan portfolios were compared to assess the efficiency of the current MPA network in the study area. Efficiency was measured as the difference in the percentage area contained within the “best scenario” MPAs from the un-bias run (P1) compared with the run where the existing MPA network was “locked-in” (P2).

Representativity of the existing network was assessed through the investigation of the properties of PU included within MPAs in the “best scenario” Marxan output of P2 that lay outside the existing MPA network.

## Results

### Biophysical habitat mapping

The BWM layer (Figure 2a) outlines the location of six major water masses in the Northeast Atlantic, using 17 polygons. The bottom waters are dominated by two deep water masses; the Lower Deep Water (LDW) and the Northeast Atlantic Deep Water (NADW) which occupies 40.36 and 31.58% of the study, respectively. These water masses are both cold (1–3°C) and have similar salinities, but it is the difference in nutrients and oxygen levels that make them distinctive ([Van Aken, 2000a](#)). The remaining water masses, apart from the Iceland-Scotland Overflow Water (ISOW), are intermediate and surface waters present over shallower regions of the map, mainly the Reykjavik Ridge, Rockall- Hatton Bank, MAR, and Icelandic Basin. The Sub-Arctic Intermediate Waters (SAIW) and Northeast Atlantic Water (NEAW) only represent 3.5% of the study area combined which means that Marxan will have less flexibility when fulfilling targets regarding habitats defined by these two water masses.

The seabed topography layer (Figure 2b) depicts five benthic environments using 2048 polygons produced using the “Iso Cluster Unsupervised Classification” tool. The majority of these polygons are very small and hard to distinguish individually; the magnified square in Figure 2b illustrates the complexity of the layer. Large expanses of the study area are occupied by abyssal plains (i.e. flat) which account for 42.64% of the study area. Areas with the steepest topography which would identify seamounts and canyons form 6.74% of the area (Supplementary Table B.1).

Figure 3a illustrates the final habitat map for the Northeast Atlantic and provides the first step in assisting the design of representative MPA networks. The final combination of biophysical features is far more complex and includes 52 937 spatial objects. These polygons represent 30 hypothetically distinct habitats using the six water masses and five benthic environments.

The LDW-Flat and NADW-Flat categories represent 28.5% of the study area. Many of the 30 individual habitats occupy very small areas; with 22 habitats individually representing less than 5% of the study area and of those, 12 individually represent less than 1% of the area (Supplementary Table B.2).

### Marxan analysis

#### Focal variety analysis

Areas of high biophysical habitat diversity occurred mainly where the flat abyssal plains met steeper areas of topography. These hot-spots illustrate areas where maximum biophysical habitat diversity can be conserved within the smallest area. Within the context of this study, the Focal Variety Analysis essentially identifies habitat “edges” and transition regions. The narrow ribbons of apparent highest diversity occur along the boundaries between regions based on different water masses. These narrow ribbons need to be viewed with caution as the use of categorical classification systems will produce “hard edges” where natural boundaries are rarely solid.

#### Assessment of efficiency

Comparison of P1 and P2 Marxan portfolios suggests that the current MPA network is not efficient. With the existing MPAs locked-in Marxan has far less freedom when selecting the remaining PUs to achieve its percentage inclusion target (Table 3). Having the existing reserve system locked-in means that 10–24% of the study area is already conserved and reduces the percentage Marxan has left to allocate when analysing the study area; especially when the conservation feature target is set at 10%. To keep the score as low as possible, Marxan will often clump areas together according to the chosen BLM. Thus, locking-in such areas causes Marxan to include far fewer PUs in its output. In fact, in P2, Marxan includes ~75% of the PUs within its analysis zero times during its 200 runs (Figure E.2). This situation mainly affects the scenarios where the conservation factor is 10%. When the conservation factor is increased to 30% Marxan still has the freedom to select many of the areas frequently selected in P1. This constraint is reflected in the difference in the average protected area for comparable scenarios

**Table 3.** Showing the results from the “best” run of each scenario produced by Marxan.

Scenario	Target	BLM	Score	Cost	Connectivity	Penalty	Average protected (%)
Portfolio 1 (P1): no PUs locked-in							
1	10	0.15	190.50	159	207.26	0	15.26
3	10	1	254.16	161	93.16	0	17.91
5	10	5	358.98	185	39.76	0	28.57
2	30	0.15	542.35	471	474.80	0	38.45
4	30	1	607.06	473	133.80	0	41.09
6	30	5	809.00	515	58.97	0	45.64
Portfolio 2 (P2): PUs locked-in							
1	10	0.15	250.43	226	162.87	0	26.76
3	10	1	331.31	228	103.31	0	26.91
5	10	5	630.29	278	70.45	0	36.61
2	30	0.15	534.64	474	404.28	0	39.40
4	30	1	630.45	480	150.22	0	42.00
6	30	5	856.52	541	63.10	0	49.12

for P1 and P2. This difference is larger where the 10% target is set, than when the 30% target is set (Table 3).

In P2, Marxan has linked many of the existing MPAs together in an attempt to keep the score down, but at the same time has increased the number of PUs selected. A number of PUs within the existing reserve network will not contribute to Marxan achieving its specified targets. Therefore, including them in the final reserve network requires Marxan to include extra PUs within the final reserve to meet the conservation targets. For example, scenario 3 (P2) contains 67 more PUs than scenario 3 (P1) and scenario 4 (P2) contains 7 more PUs than its counterpart. This illustrates the limiting effect of locking-in the existing PAs.

### Assessment of representativity

Comparison of appropriate scenarios of P1 and P2 clearly demonstrates that when representation of a set percentage of all habitats is the primary aim of the network, Marxan will choose a partially different reserve system to the existing system, rarely choosing PUs that fall within the existing protected areas. Examination of the P2 outputs suggests that the current network is not representative as additional PU are selected outside the current network. In P1, the percentage of selected cells chosen in each scenario that also intersected any of the protected areas ranged between 2.5 and 19.5%. The percentage of each habitat type contained in both portfolios

suggests an underrepresentation of flat classes and an over representation of moderate, steep, and steepest classes (Tables 4 and 5).

### Effect of the BLM

Scenarios 1 and 2 in each portfolio had the lowest score and the highest value for connectivity (Table 3), implying that they achieved the conservation targets using the smallest area and had an equal coverage across the study area. The BLM of 0.15 allowed Marxan to select many individual or small clumps of PU across the entire study area. Increasing the BLM to 1 in scenarios 3 and 4 still allowed individual PUs to be selected but generally clustered the majority of PUs together, especially in scenario 4.

Scenarios 5 and 6 had the highest BLM of 5, which ensured that all selected PUs were part of large clusters. These large clusters have an extremely low connectivity and achieved the highest scores (lowest connectivity, largest area) from the three sets of runs in both portfolios (Table 3); as they required a greater number of PUs to achieve the conservation targets. Due to this clustering, both scenarios 5 and 6 showed the greatest difference between the two portfolios. In P1, the clustering occurs around the PUs chosen the highest number of times, whereas in P2 the clustering occurs around the existing MPAs (locked in PUs).

Setting a BLM of 5 causes Marxan to neglect considerable parts of the study area, and the MPAs produced are unrealistically large. The network requires a larger number of PUs to meet the specified

**Table 4.** Percentage of each habitat type contained within the Marxan un-bias network (P1).

	Scenario 1	Scenario 3	Scenario 5	Scenario 2	Scenario 4	Scenario 6
BLM	0.15	1.00	5.00	0.15	1.00	5.00
Conservation target (%)	10.00	10.00	10.00	30.00	30.00	30.00
Habitat (%)						
ISOW-Gentle	10.32	10.12	26.55	30.10	32.18	30.63
ISOW-Steep	12.20	11.37	31.71	30.24	30.17	34.63
ISOW-Mod	11.70	10.65	34.58	30.31	32.19	34.60
ISOW-Flat	10.05	10.21	10.20	30.10	30.02	30.01
ISOW-Steepest	11.96	15.37	54.08	37.58	33.09	54.08
LSW-Gentle	10.94	10.27	13.73	30.35	30.26	35.38
LSW-Flat	10.16	10.63	12.19	30.07	30.25	30.01
LSW-Steep	9.98	10.19	10.06	30.28	30.31	32.12
LSW-Mod	10.03	10.55	14.26	30.10	29.99	31.14
LSW-Steepest	10.28	10.44	10.81	30.03	30.06	30.19
SAIW-Flat	10.07	10.15	11.34	30.26	30.99	30.03
SAIW-Gentle	9.90	14.03	22.60	32.30	30.32	39.29
SAIW-Steep	11.05	22.92	25.26	47.36	41.04	43.38
SAIW-Mod	25.74	45.64	23.74	33.24	53.23	66.59
SAIW-Steepest	20.80	19.84	16.64	47.84	51.04	43.84
NEAW-Flat	11.39	11.83	53.45	30.64	31.84	59.17
NADW-Steepest	10.51	10.07	14.33	30.26	30.23	30.00
NADW-Mod	10.04	10.12	11.77	30.15	30.05	32.30
NADW-Steep	10.01	10.53	10.04	30.05	30.10	33.58
NADW-Gentle	10.01	10.17	10.14	30.04	30.32	30.00
NADW-Flat	10.00	10.12	10.06	30.02	30.01	30.32
NEAW-Gentle	11.07	52.87	91.28	34.45	84.16	98.39
NEAW-Steep	10.81	10.81	94.59	94.59	100.00	100.00
NEAW-Mod	37.93	37.93	92.34	92.34	100.00	100.00
NEAW-Steepest	100.00	100.00	100.00	100.00	100.00	100.00
LDW-Flat	10.04	10.05	10.03	30.00	30.18	30.11
LDW-Steep	10.20	10.19	10.20	30.12	30.05	37.86
LDW-Mod	10.20	10.07	10.81	30.30	30.13	42.41
LDW-Steepest	10.15	10.18	10.41	30.33	30.07	46.40
LDW-Gentle	10.18	10.00	10.00	30.02	30.43	32.81
Average (%)	15.26	17.91	28.57	38.45	41.09	45.64



**Table 5.** Percentage of each habitat type contained within the Marxan biased network (P2).

	Scenario 1	Scenario 3	Scenario 5	Scenario 2	Scenario 4	Scenario 6
BLM	0.15	1.00	5.00	0.15	1.00	5.00
Conservation target (%)	10.00	10.00	10.00	30.00	30.00	30.00
Habitat (%)						
ISOW-Gentle	10.08	10.19	10.06	30.02	30.05	30.01
ISOW-Steep	10.19	10.28	13.21	30.02	31.26	39.82
ISOW-Mod	10.33	10.15	11.55	30.12	30.11	37.94
ISOW-Flat	10.04	10.06	11.45	30.03	30.03	34.34
ISOW-Steepest	10.07	10.05	10.01	30.05	30.00	30.02
LSW-Gentle	10.94	10.27	13.73	30.35	30.26	35.38
LSW-Flat	92.34	92.34	92.34	92.34	92.34	92.34
LSW-Steep	94.59	94.59	94.59	94.59	94.59	94.59
LSW-Mod	34.45	34.45	91.28	40.75	86.81	96.56
LSW-Steepest	16.35	16.35	16.55	30.08	30.02	30.01
SAIW-Flat	19.08	19.18	19.60	30.14	30.11	30.31
SAIW-Gentle	25.42	25.61	26.58	30.01	31.78	40.42
SAIW-Steep	27.08	28.01	28.96	30.90	33.02	39.82
SAIW-Mod	33.38	34.00	35.44	36.02	37.19	46.96
SAIW-Steepest	25.80	25.80	49.82	31.34	34.60	66.87
NEAW-Flat	21.12	21.12	21.12	38.72	38.72	38.72
NADW-Steepest	54.87	54.87	66.68	66.47	70.23	77.99
NADW-Mod	36.42	36.95	55.76	45.36	48.17	60.19
NADW-Steep	15.87	16.53	23.76	31.45	31.50	32.59
NADW-Gentle	25.71	26.03	43.57	30.47	30.78	47.73
NADW-Flat	13.37	13.64	25.77	30.38	30.43	31.51
NEAW-Gentle	13.30	13.27	23.63	30.33	31.66	38.02
NEAW-Steep	11.37	12.44	19.33	30.08	30.06	39.13
NEAW-Mod	10.03	10.10	13.32	30.04	30.21	30.02
NEAW-Steepest	10.07	10.54	15.91	30.57	30.00	37.38
LDW-Flat	17.96	17.96	61.75	30.10	37.35	68.78
LDW-Steep	10.39	10.36	14.87	30.08	30.09	32.24
LDW-Mod	12.71	12.53	38.10	30.27	33.24	44.99
LDW-Steepest	15.23	14.89	33.37	30.14	32.86	43.11
LDW-Gentle	15.07	15.01	29.81	31.02	32.89	41.15
Average (%)	23.79	23.92	33.73	37.08	39.68	46.96

targets, which therefore increases the cost and lowers the connectivity of the network.

## Discussion

### Is the existing MPA network efficient?

All scenarios of P1 required less of the total area to be contained within an MPA network to meet the objective of being representative. Therefore, when assessed based on representation alone, the current network is not the most efficient solution. Locking-in the existing reserves to always appear in the final reserve system made a significant difference to the final outcome. This is because Marxan uses the existing reserve sites as hubs around which to build its solution and substantially lowers the number of possible solutions (Game and Grantham, 2008). It is not uncommon for current reserve systems to be inefficient in terms of meeting broader network objectives (Ardrone *et al.*, 2010); however, it is often politically and practically easier to expand or alter existing MPA systems than to create new ones (Game and Grantham, 2008).

This study reveals that to achieve representation of habitats in P2, the resulting reserve network will be larger (in terms of percentage of seabed contained within them) than the specified targets. In P2, where a 10% target for each habitat was set the average protected

area ranged from 27 to 37%. When that target was increased to 30% of each habitat class, the average area protected ranged from 39 to 49% as well an increase in cost and decrease in connectivity (Table 3). This illustrates a common problem when attempting to expand any existing conservation areas.

A study by Stewart *et al.* (2007) suggests that systematic approaches have an important role for efficient reserve design when there is uncertainty about the target level of reservation. Often, rather than waiting for an agreed conservation factor and allowing continued environmental degradation many reserve systems are implemented with a low initial target and eventually will have to be expanded to meet conservation targets. This increase can result in the unnecessary increase in reserve size noted in P2. For example, if the initial reserve system is designed to protect 10% of every feature class then later expanded to protect 30% in subsequent years, the sites that would have efficiently encompassed 30% of all feature classes have been discarded in favour of the optimal solution to protect 10%.

However, Stewart *et al.* (2007) demonstrated that in-fact as long as systemic conservation planning methods are used to design the initial MPA network there was no loss in efficiency between incremental designed reserve systems compared with larger purpose-built reserve systems. Conversely, when a system was implemented in an *ad hoc* method, such as the OSPAR MPA network, the resulting

increase in reserve size does create a less efficient, less compact, and larger reserve system.

Using systematic conservation planning not only creates smaller and more efficient MPA networks but allows a large degree of stakeholder participation in the design process. Stakeholder acceptance of MPA networks is vital for successful implementation as MPAs are still controversial with a variety of stakeholder groups (Gleason *et al.*, 2010). The rezoning plan for the Great Barrier Reef Marine Park (Fernandes *et al.*, 2005) is a key example of a large-scale, broadly successful extension of a reserve system that extensively included stakeholders. The more recent implementation of the Marine Life Protection Act (MLPA) in California allowed stakeholders to be integrally involved in creating the reserve creating new policy and identifying potential MPAs. Stakeholders had input into the development of regional goals and objectives, evaluating existing MPAs, and developing multiple MPA network proposals (Gleason *et al.*, 2010). Demonstrating that using stakeholders not only increase the chance of success but they can often provide valuable input that improves the overall quality of the reserve system.

### Is the current MPA network representative?

Comparing the current MPA network to both Marxan portfolios suggests that the existing network misses the objective of being representative. The four OSPAR MPAs that are present in the study area all overlay regions defined by Labrador Sea Water or NADW. Although they do encompass perceived key habitats such as the Mid-Atlantic Ridge, hydrothermal vents, and regions of seamounts, many habitats identified by the habitat classification maps in this study are not represented. This is largely a reflection of the criteria on which the individual MPAs within the network were selected. OSPAR MPAs are selected using the criteria listed in Supplementary Table A.1 (OSPAR, 2010), which concentrate on habitats that are deemed important or ecologically significant, whereas the NEAFC fisheries closure zones are selected based on protecting specific Vulnerable Marine Ecosystems, most notably cold water corals. Representation of habitats at the network level has yet to be considered.

The main habitats that are not represented include abyssal areas in all regions. This may be because abyssal areas are perceived as being of less conservation value and/or currently under less threat from human activity that the use of MPAs would mitigate against. Abyssal regions are functionally highly important areas and cover more than 50% of the Earth; hypothetically making it a reservoir of biodiversity and a source of important ecosystem services. The enormity of the abyssal ecosystem allows it to exert significant influence over ecosystems services including ocean carbon cycling, calcium carbonate dissolution, and atmospheric CO<sub>2</sub> concentrations over time-scales of 100–1000 years (Smith *et al.*, 2008).

However, the size and remoteness of the abyss has led to ecosystem structure and function at the seafloor having been historically very poorly studied. For example, more than 80% of the hundreds of species of seafloor invertebrates collected at any abyssal station are new to science (Snelgrove and Smith, 2003).

The perceived lack of threat from activity that could be mitigated through the use of MPAs may well be true of the Northeast Atlantic at present. However, the exploitation of the deep-sea abyssal environment is increasing. Anthropogenic threats include; potential Manganese nodule mining, deep-sea waste disposal, pollution (e.g. persistent organic pollutants), CO<sub>2</sub> sequestration, extraction of mineral and alternative fuel resources, and oil and gas exploration. For a full review, see Glover and Smith (2003). All of these

threats have the ability to disturb the abyssal regions through sediment disturbance, habitat removal, and decrease in biodiversity.

Due to the abyss's major roles in ecological and biochemical processes on a global scale, declines in abyssal functional diversity driven by large-scale anthropogenic disturbances could influence the provision of ecosystem services from the ocean, especially over 1000-year time-scales (Glover and Smith, 2003). Therefore, it is imperative the abyssal regions are correctly represented within MPAs, while our knowledge of such regions is in its infancy and potential impact cannot be predicted; such an approach follows the precautionary principle.

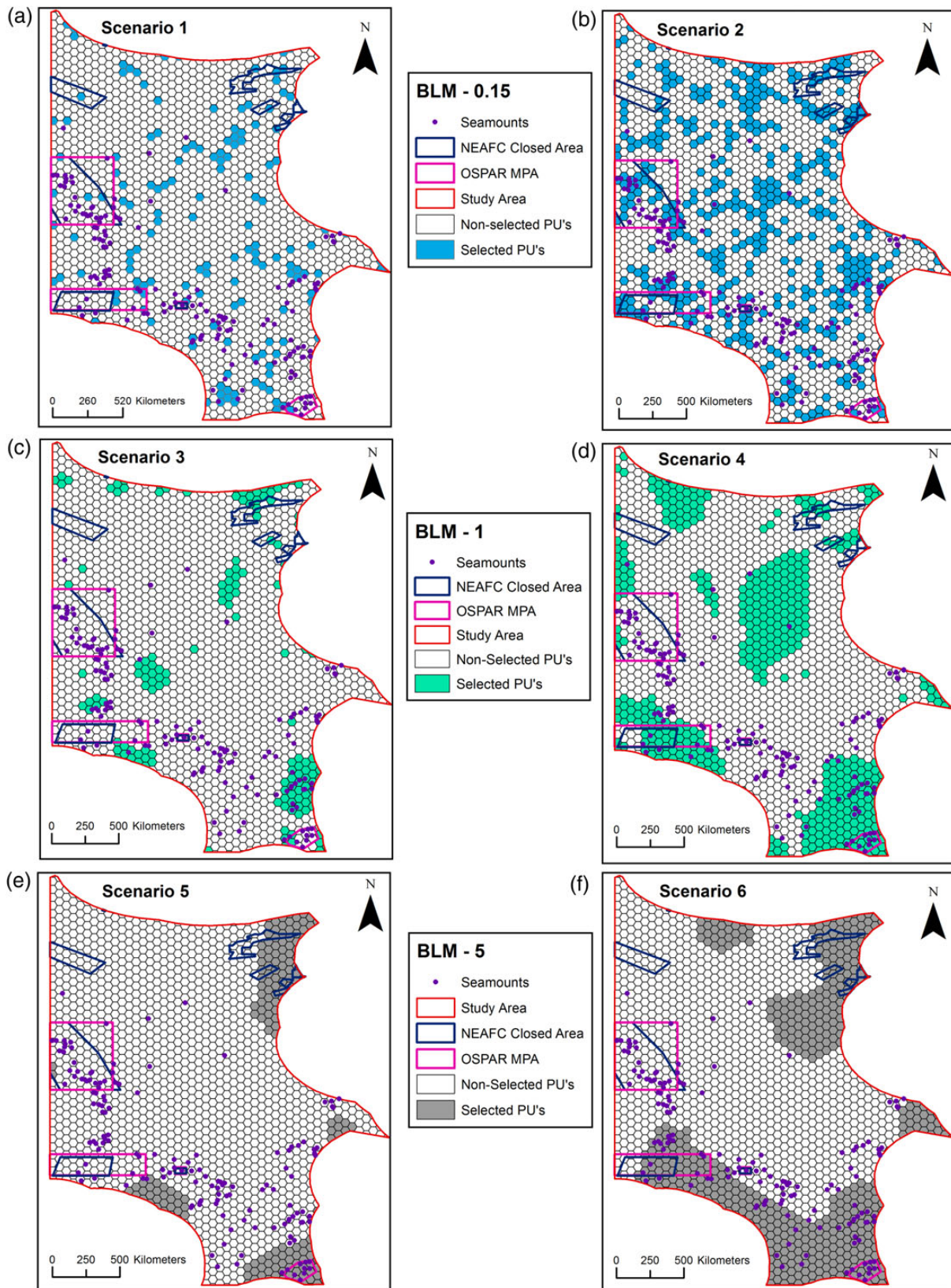
The Hatton–Rockall Plateaux is consistently selected in all scenarios, in both P1 and P2. The selection frequency output from Marxan (Figure E.1) highlights PUs that are included many times (i.e. areas that are “invaluable” to meeting the specified representation targets) again the Northeast region (Hatton–Rockall Plateaux) is frequently chosen in all scenarios and in fact two PUs in the Northeast corner of the study area are chosen over 85% of the time in all scenarios. This region contains two distinct water masses, SAIW and NEAW, and subsequently contains all five topographic “substrate” classes. Marxan therefore chooses PUs in this region the majority of the time, as it can fulfil a large proportion of its targets for SAIW and NEAW regions.

The importance of the Hatton–Rockall Plateaux in this region was recently highlighted by the plateaux being proposed as an “Ecologically and Biologically Significant Area” (EBSA) to the CBD. The Hatton–Rockall Plateaux represents an area of bathyal (200–3000 m) seabed in the Northeast Atlantic ABNJ that is distinct from the other main areas of bathyal habitat, the Mid Atlantic Ridge and Continental Slope. The banks have great habitat heterogeneity and support a wide variety of fauna. Habitats of note include deep-water corals gardens, deep-water coral reefs, reef rubble, rocky reefs, carbonate mounds, polygonal fault systems, sponge aggregations, steep, and gentle sedimented slopes. Their selection as an EBSA is a reflection of this high habitat and biological diversity. The results of our analysis suggest that this designation is also justified given the importance of this area to achieving representation in any Northeast Atlantic MPA network.

PUs within and surrounding the Josephine Seamount High Seas MPA (MPA 6) are frequently selected, as are PUs overlaying the Mid-Atlantic Ridge, Azores EEZ boundary, and areas of the Porcupine Abyssal Plain. The focal variety analysis highlights these areas as moderately biophysically diverse, although outputs of the focal analysis must be treated with caution as a result of the “hard edges” inherent in the use of a categorical classification system.

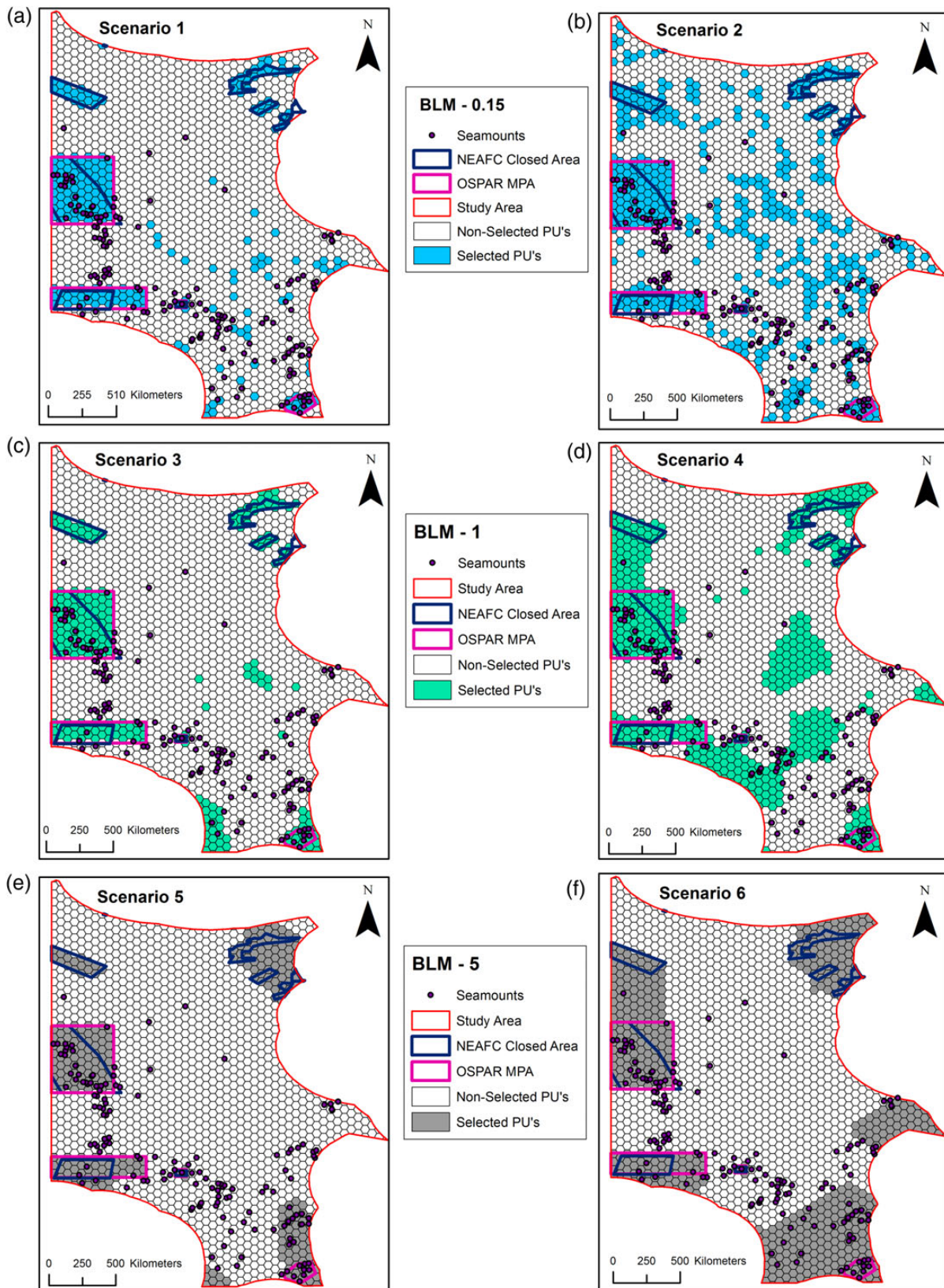
### Effect of the BLM: reserve spacing and size

Of the scenarios output by Marxan, some are more feasible for the Northeast Atlantic than others depending on the BLM used. Altering the BLM can incorporate a desired scale into MPA design, assisting in developing an optimum reserve for the region being analysed (Klein *et al.*, 2008; Ban *et al.*, 2009b). For example, the OSPAR area is extensive and has a number of anthropogenic activities occurring on a number of scales (Benn *et al.*, 2010). Having many small well-spaced MPAs (scenarios 1 and 2) would be extremely hard to implement, monitor, and enforce. Such a network of small, well-spread MPAs would be more suitable to the protection of ecosystems on a small scale, e.g. to protect a reef system in a small region of the Philippines (Ban *et al.*, 2009b). Similarly, a few larger MPAs created when using a BLM of 5 (scenarios 5 and 6) would be much easier to implement, monitor, and



**Figure 4.** (Existing reserves not locked in) (a and b) Best output from Marxan using a BLM of 0.15 and conservation targets of 10 and 30%, respectively. (c and d) Best output from Marxan using a BLM of 1 and conservation targets of 10 and 30%, respectively. (e and f) Best output from Marxan using a BLM of 5 and conservation targets of 10 and 30%, respectively.





**Figure 5.** (Existing reserves locked-in) (a and b) Best output from Marxan using a BLM of 0.15 and conservation targets of 10 and 30%, respectively. (c and d) Best output from Marxan using a BLM of 1 and conservation targets of 10% and 30% respectively. (e and f) Best output from Marxan using a BLM of 5 and conservation targets of 10% and 30% respectively.

enforce but would not be ecologically coherent. If the network is not well-distributed across the area then it is likely that it will not exhibit connectivity or truly represent unique habitats and protect biodiversity (O'Leary *et al.*, 2012). It seems that an optimal BLM is closer to 1, especially at 10%, and creates a good clustering of small and large MPAs but still gives Marxan the freedom to spread out the MPAs across the study area.

There is a definite balance to be accomplished between lowering the cost of implementing MPA networks and compromising on how equally the chosen PUs are spread geographically. A compromise is required to enable the creation of a network that is still ecologically coherent, yet politically and economically feasible. The system illustrated in scenario 3, which aims for a conservation target of 10%, originally set by the CBD (CBD, 2004), appears realistic and practical to implement soon. However, to achieve a network that is fully representative, connected, and provides areas of replication for each habitat, a conservation target of 30% needs to be reached. Although the output generated in scenario 4 is not a favourable design owing to the individual MPAs being too large, a lower BLM would be appropriate to allow less clustering when aiming for conservation targets of 30%.

Although the “best” solution for each run is displayed in Figures 4 and 5, there were ~180 similar outputs, for both portfolios, that achieved the conservation targets and ecological representation.

### Limitations of the approach

In maximizing representativeness while minimizing the area, it is highly likely that the final MPA network is biased towards the conservation of edging areas. Indeed, the “Focal Variety Analysis” highlighted hotspot areas where the maximum biophysical habitat diversity could be conserved within the smallest area which appeared as ribbons along the boundaries between habitat classes. While the edges of habitat patches may be highly diverse, they may fail to contain core species and/or reflect the core physical conditions typical of that habitat patch. Thus, focusing conservation efforts around habitat edges may fail to achieve conservation goals. However, the exclusion of edges from a reserve network may exclude edge specialist species which may be of importance to ecosystem function. Ideally, reserve networks should include examples of both edge areas and interior or core habitat areas, preferably distributed across the gradient of change that is so poorly represented by use of categorical habitat classification systems. Future studies should consider how this might be achieved within the functionality of existing spatial planning software.

In addition, patch size, patch mosaic, and distribution of patches between and among proposed conserved areas are also not considered by this method. These can have a significant influence on biotic responses in landscapes including the afore-mentioned manifestation of edge effects (Harper *et al.*, 2005) and the maintenance of connectivity (Franklin, 1993). The role of patch mosaics also remains poorly understood [Bennett *et al.*, 2006; see Lindenmayer *et al.* (2008) for a full discussion of these issues].

Although the biophysical habitat map created here to represent changes in biological diversity follows the standard approaches suggested elsewhere (Roff and Taylor, 2000; Harris and Whiteway, 2009; Howell, 2010). The map produced has not been independently validated and thus its usefulness in representing biological variation is unknown. Ideally, all modelled maps should be independently validated before use in spatial planning. However, relevant and appropriate biological datasets for use in such validation exercised are rarely available for the deep-sea and High Seas, although data

archiving initiatives such as OBIS (IOC, 2014) may serve to provide such data in future.

In addition, this study is limited to consideration of efficiency and representativeness. While key criteria in the MPA network design, there are many other criteria that may be important to consider, e.g. historical fishing effort, level of threat, economic value, habitat resistance and resilience, and rarity to name a few. The “best” solution identified here should not be taken as the way forward, but should serve to highlight the current gap in the representativeness criteria and demonstrate the application of conservation planning software in the vast and highly data poor region like the deep sea and High Seas.

### Obstacles regarding MPA implementation in ABNJ

It is important that MPA networks fulfil relevant scientific criteria, but equally important that the community that use the area under protection have a positive attitude towards conserving the resource (Ban *et al.*, 2009). OSPAR and NEAFC need the commitment from commercial industries, such as fishing and shipping, because they have limited powers to prosecute individuals and parties who do not observe and comply with their policies (Kvalvik, 2012). Research in coastal waters suggests that integrating science-based approaches and community-based approaches are the best solutions for MPA designation (Klein *et al.*, 2008; Ban *et al.*, 2009). However, ABNJ are an exception due to the open-access regime for the High Seas, where there is a limited sense of community and the prevention of overexploitation will require international co-operation (Salpin and Garmani, 2010; Ramirez-Llodra *et al.*, 2011). Using SCP is currently the most efficient way forward to protect ABNJ and it is a natural extension of ocean zoning management that stakeholders are familiar with from use in territorial waters. Ocean zoning in the form of Marine Spatial Planning (MSP), Integrated Coastal Zone Management (ICZM), and multi-use MPA management are already well developed within the adjacent European waters (Gilliland and Laffoley, 2008). If SCP can be implemented alongside MSP and ocean zoning efforts in the future, a platform for efficiently synthesizing information can be created (Agardy *et al.*, 2011). Knowledge relating to the seas ecology, resources, ecosystem services, uses, and values, in addition to threats to all the above can contribute towards the efficacy of MPA design and implementation (Foley *et al.*, 2010; Ban *et al.*, 2013).

### Conclusions

The ABNJ is one of the hardest areas to provide protection due to the lack of data, procedures, knowledge, and international cooperation in the region. Management of these areas is complex and implementation of MPAs can be slow. This study has demonstrated the use of systematic marine conservation planning alongside biophysical habitat mapping to provide a holistic, ecosystem-based approach to the design of MPA networks in regions with low levels of data (i.e. ABNJ). It has also identified several limitations to this approach that could be addressed by future studies. Ultimately, the study has highlighted the underrepresentation of abyssal regions within the current MPA network and identified areas for consideration as MPAs to achieve targets of representation. Increased use, experimentation, and improvements of these techniques is basic to promoting decision-making that can protect ABNJ.

### Supplementary data

Supplementary material is available at the ICESJMS online version of the manuscript.



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