THE IRISH SEA PILOT

Report on the identification of nationally important marine areas in the Irish Sea

Louise M. Lieberknecht, Josie Carwardine, David W. Connor, Malcolm A. Vincent, Steve M. Atkins and Chris M. Lumb

March 2004

Lieberknecht, L M, Carwardine, J, Connor, D W, Vincent, M A, Atkins, S M and Lumb, C M (2004) *The Irish Sea Pilot - Report on the identification of nationally important marine areas in the Irish Sea*. JNCC report no. 347. Available online at www.jncc.gov.uk/irishseapilot.

Table of contents

Acknowledgements

The authors wish to thank all individuals and institutions who provided feedback on the consultation draft of this report, published on the Irish Sea Pilot website in August 2003, and members of the RMNC criteria group (Joe Breen, Alison Champion, Paul Gilliland, Duncan Huggett, Charlotte Johnston, Dan Laffoley, Kirsten Ramsay, Matt Shardlow, Sam Fanshawe, Jean-Luc Solandt) who participated in discussions and provided feedback throughout the process of developing and testing the criteria.

Thanks are due to Hannah Betts and Andrew Cottam for help in developing database queries and using ArcView, Caroline Turnbull for advice on Habitats Directive Annex I potential habitat, Neil Golding for advice on Marine Landscapes, Andy Webb for advice on SPAs, Jon Davies for discussions on biodiversity measures, and Matt Davies and Mike Webster for generating map templates.

Many thanks are also due to Hugh Possingham and Ian Ball for providing help and feedback on Marxan queries, to Romola Stewart and Emily Nicholson for providing help and guidance on incorporating multiple factors into the cost of planning units, and Wayne Richardson for providing guidance on generating Marxan input files.

1 Executive Summary

1.1 Introduction

This report details the results of testing the draft criteria for the identification of nationally important marine areas (Connor *et al.*, 2002), within the framework of the Irish Sea Pilot. Under the criteria, areas may qualify as nationally important based on their typicalness, naturalness, biodiversity, size, and whether they are a critical area for a mobile species or an important area for a nationally important marine feature (as defined in Lieberknecht *et al.*, 2004). "Nationally important marine areas", in the context of this report, refers to areas of importance under biological criteria. Areas of importance under geological criteria (nationally important marine earth heritage areas) are discussed in chapter 10 of Vincent *et al.* (2004).

Two approaches to applying the criteria were tested. The first main section of this report (part A) outlines the initial approach, which was to apply the criteria directly at the marine landscape scale, making use of the marine landscape classification developed by Golding *et al.* (2004). The second approach tested (part B) was to examine the use of the reserve selection software, Marxan, in aiding the process of identifying nationally important marine areas at the regional sea scale.

1.2 Part A: testing the criteria through direct application

The approach tested initially was to identify the "best examples" of each marine landscape at the regional sea scale. It was assumed that marine landscapes would act as surrogates for smaller levels of scale (species, habitats), and identifying representative examples of each type would ensure the full representation of biodiversity within the final set of areas. Two marine landscapes were selected for testing the direct application of the criteria within the Irish Sea, one inshore physiographic unit (estuaries), and one offshore type (coarse lag deposits, subsequently split into high-bed stress coarse sediment plains and low bed-stress coarse sediment plains).

A full "estuaries comparison" was carried out, using methods described in Connor & Hill (1998) to score and rank each estuary against the first four criteria (typicalness, naturalness, biodiversity, size). Estuaries occur within inshore areas, where there is good data coverage and a lot of additional information readily available. They also form distinct, comparable spatial units for assessment. Because of these reasons, it was possible to apply the first four criteria to estuaries, and determine a set of representative estuaries within the Irish Sea.

It was found that criteria 5 and 6 (critical area for a mobile species, important area for a nationally important marine feature) would better be applied at the whole regional sea scale, instead of using them to help determine "best representative" areas for each of the marine landscapes. Because large areas could potentially qualify under these criteria, some degree of prioritisation between areas will be necessary. The approach described in the Marxan trial (part B) could be used to help this process.

The approach used for applying criteria 1-4 to estuaries did not work well for offshore areas, as there was insufficient information available to carry out the assessment. It was concluded that the initial approach of identifying "best examples" of each marine landscape should be used only in regions and for marine landscapes where there is sufficient data coverage to reach sound decisions. Alternative methods were explored in the Marxan trial (part B).

1.3 Part B: Testing the use of Marxan for applying the criteria

The aim of this study was to test whether and how the criteria can be incorporated into Marxan, using real data from the Irish Sea, to determine whether Marxan could be a useful tool to aid identification of nationally important areas, particularly in data-poor offshore regions.

Marxan is a tool to select a suite of areas that meets given conservation targets efficiently. The area of study is divided into small spatial planning units, some or all of which contain conservation features, e.g. records of species, or areas of habitats. Targets are set for each conservation feature, e.g. a minimum number of records of a species, or a minimum area of a habitat, to be represented within the selected areas. Each planning unit has a cost, which may simply be a measure of its size, or may incorporate other factors (economic, social or environmental). Marxan attempts to meet the targets while minimising the overall cost of the selected planning units. A boundary length modifier can be set to minimise the overall boundary length of the set of selected areas, leading to it forming clumps instead of consisting of widely scattered small areas. Areas known to be important can be locked in, and undesirable areas can be locked out. Marxan can be run multiple times to provide alternative solutions to meeting targets. From these, a selection frequency or irreplaceability value can be allocated to each planning unit, which gives an indication of the relative importance of the planning unit to meet the given targets.

A series of different scenarios were run for the Irish Sea, using progressively more information and constraints. The first scenario set targets of between 10-40% of the total area of each marine landscape, and for 2-5 representations of each benthic species and habitat on the Irish Sea provisional list (Lieberknecht *et al.*, 2004). In the second scenario, a boundary length modifier was added. For the third scenario, naturalness scores were determined for each planning unit, using trawling data collated in a GIS under work for the Pilot (Lumb *et al.*, 2004) combined with the vulnerability of each marine landscape (Golding *et al.*, 2004). These naturalness scores were used to modify the cost of planning units, such that Marxan preferentially used more natural areas to meet targets, where possible. Subsequent scenarios locked in progressively more areas: areas with high biodiversity, estuaries previously identified as nationally important (part A), and existing candidate Special Areas of Conservation and Special Protection Areas (cSACs and SPAs, designated under the EC Habitats and Birds directives).

Marxan cannot assess the criteria directly, e.g. it cannot be used to measure biodiversity and naturalness and, on the basis of that, select the most diverse and natural areas. Pre-processing of spatial data is necessary to assess biodiversity and naturalness, and develop input files containing this information. However, given the availability of some spatial information relating to each criterion, all of the criteria can be addressed within Marxan, often in a number of ways. Once the input files have been developed, it is relatively simple to run a series of scenarios, each incorporating slightly different targets and constraints. This means that an iterative process can be used to test different ideas and determine the best way of approaching the criteria and area identification.

Marxan is not a data modelling tool, i.e. it cannot overcome a lack of data by interpolating or extrapolating between and from existing datasets to fill in gaps. However, there is no limit to the number of datasets that can be incorporated into Marxan, which means that all available spatial data can be made use of.

The Marxan trial in the Irish Sea demonstrated that the software could be used to provide a systematic, integrated step in the process of identifying nationally important marine areas. The software should be treated as an aid to decision-making, not a tool to provide the ultimate answer. Knowledge of the input data and its shortcomings, best scientific judgment, and expert knowledge, need to be used to interpret the Marxan outcome and make decisions on identifying areas. Bearing this in mind, the output from Marxan would prove extremely helpful in prioritising and choosing between potential areas, ensuring complementarity between areas and the representation of the full known range of biodiversity within the resulting suite of area. It was concluded that Marxan would be a highly useful tool to aid in the selection of nationally important marine areas.

1.4 Part C: Main Conclusions

Some minor modifications to the wording of the criteria have been suggested to make them more easily applicable. In addition, guidance text on how to apply the criteria has been developed to be read in conjunction with the criteria.

The suggested approach to applying the criteria for the identification of nationally important marine areas is a combination of the two approaches tested in parts A and B. It is recommended that the criteria should be directly applied within areas of good data coverage, such as was done for estuaries. These areas will mainly be inshore areas, where a lot more information is available than for offshore regions. The approach of using Marxan, as described in part B, should then be used to complete the identification of a full set of nationally important marine areas. Marxan provides a systematic, defensible tool to make use of best existing knowledge to aid the decision-making process. It is flexible enough to allow the exploration of a range of different scenarios, which means that a number of approaches can be tested to identify the best ones for each area.

2 Introduction

2.1 Purpose and structure of this report

This report outlines work carried out on developing, testing and applying criteria for the identification of nationally important marine areas; work carried out under Defra's Review of Marine Nature Conservation (RMNC). Following the development of draft criteria, their application and the area identification process were tested within the framework of the Irish Sea Pilot. "Nationally important marine areas", in the context of this report, refers to areas of importance under biological criteria. Areas of importance under geological criteria (nationally important marine earth heritage areas) are discussed in chapter 10 of Vincent *et al.* (2004). The testing of criteria for the identification of nationally important marine features (marine landscapes, habitats, species) is reported in Lieberknecht *et al.*, 2004.

The report contains three main parts, following the introduction. Part A (section 3) reports on work carried out to test the criteria by applying them directly to estuaries and an offshore marine landscape type, and largely contains the same information as the consultation document on this work area, published in August 2003 (Lieberknecht *et al.*, 2003). Part B (section 4) reports on work which followed on from the initial criteria test, trialling the reserve network selection software, Marxan (Ball & Possingham, 1999), to determine its potential use as tool to aid the identification of nationally important marine areas. The main conclusions drawn together from parts A and B are presented in part C (section 5), together with recommendations for modifications to the draft criteria and guidance for their applications. Parts A and B both contain a lot of detail on methodology. Readers interested primarily in the main outcomes in terms of the criteria and how to apply them should refer to part C, after reading the executive summary and the introduction.

2.2 Ecological network principles

The value of identifying areas of particular importance for biodiversity is based on the principle that these areas make such an essential contribution to meeting the objective of maintaining the range and scale of biodiversity present in the country, that, unless they are enabled to maintain this contribution in perpetuity, this objective will not be met.

Furthermore, current thinking on the role of important areas within an overall nature conservation strategy is that these areas should be seen not (or not only) in isolation as individual areas but also as components of an ecologically-coherent network of areas. Individual sites within this network should have the capability of supporting one another ecologically, and also of supporting, and being supported by, the areas of sea and seabed adjacent to them.

Marine species are a combination of highly mobile pelagic species (pelagic invertebrates, fish, seabirds, sea mammals etc) characteristically capable of moving sometimes hundreds of kilometres in a year, either under their own power or as a consequence of currents or wind, and also of seabed species which normally have a mobile larval/immature phase. The relative mobility of this larval/immature phase is dependent on species and circumstances (currents etc), but such species often have the ability to travel several tens of kilometres before they metamorphose and settle on the seabed. Since the biological component of seabed habitats is comprised of seabed species, seabed communities have the same mobility capability, though the ability of habitats to develop fully in new areas depends on the suitability of substrate, depth, temperature etc, and the relative mobility of the constituent species. Because of this mobility, marine species and communities occurring in one sea area have the potential to move to, or colonise, adjacent, and sometimes quite distant, areas of sea. A network of mutually-supporting areas, or areas capable of supporting the biodiversity of a neighbouring sea or seabed area, is, therefore, a practical ecological proposition.

As part of its work, the Pilot commissioned a review of current information and thinking on ecologically-coherent networks of important areas from the Environment Department of the University of York. The report of this work is available (Roberts *et al*, 2003).

The main principles in the development of important area networks, as set out in the contract report, can be summarised as follows:

i. networks should be designed to ensure that areas are mutually supporting (i.e. populations of animals and plants in one area should be capable of supporting, and be supported by, populations in other areas);
ii. networks should seek to incorporate the full spectrum of biological diversity (not just that subset which relates *inter alia* to rarity, endangerment, or other pre-selected importance values);
iii. examples of habitats (or concentrations of species) should be replicated in separate areas;
iv. the total area of the network, and its distribution in terms of individual component areas, should be capable of meeting the objective of sustaining species and their habitats in perpetuity;
v. the best available information should be used in site selection, but the development of the network should not be delayed pending action to collect further information.

These principles have largely been adapted from those proposed by Ballantine (1999).

2.3 The role of nationally important marine areas

One of the tasks identified by the RMNC was to develop a clear rationale and justification for a series of nationally important areas for biodiversity in the marine environment, and a suite of agreed criteria for selecting them. As part of this work, JNCC was requested to develop draft criteria. Drawing extensively upon existing and current work in other fora, notably the selection guidelines for Sites of Special Scientific Interest, the EC Habitats and Birds Directives, IUCN and OSPAR, a criteria paper (Connor *et al.*, 2002) was prepared which provided a suite of draft criteria. The paper was endorsed by the RMNC Working Group for the purpose of trialling on the Irish Sea as part of the Pilot, by applying the criteria and identifying a set of nationally important areas within the study area. The Pilot would thereby test the effectiveness of the draft criteria, recommend further refinement if necessary, and develop a recommended process for their application.

The identification of nationally important marine areas through application of the criteria is intended to contribute to the establishment by 2010 of an ecologically coherent network of well-managed marine protected areas, a critical component of any strategy for marine nature conservation. There are a number of key drivers for the establishment of networks of marine protected areas. These are:

i. the requirement to establish Special Areas of Conservation and Special Protection Areas within the Natura 2000 network out to 200n miles;

ii. the agreement reached in June 2003 under OSPAR to establish an ecologically-coherent network of well managed marine protected areas for the OSPAR maritime area by 2010;

iii. the commitment made at the World Summit on Sustainable Development in September 2002 to establish representative networks of marine protected areas by 2012 (United Nations, 2002).

The agreement reached under OSPAR is intended to lead to the establishment by 2010, of an ecologically-coherent network of well managed marine protected areas which will:

i. protect and conserve areas that best represent the range of species, habitats and ecological processes in the maritime area;

ii. protect, conserve and restore species, habitats and ecological processes which have been adversely affected by human activities;

iii. prevent degradation of, and damage to, species, habitats and ecological processes, following the precautionary approach.

The identification of an ecologically coherent network of marine protected areas may involve a range of other criteria or principles not considered here, e.g. meeting other sectoral objectives or practicality. The methods described in part B of this report (using the reserve selection software, Marxan) provide a way of identifying areas of conservation value for which there are few or no alternatives, and separate them from those where there are a number of alternative options. Note that the identification of nationally important marine areas does not pre-judge the level of protection which might need to be applied to these areas. Objectives for such areas will vary from ensuring the conservation of specific interest features to ensuring the area achieves its full biodiversity potential.

2.3 Criteria for the identification of nationally important marine areas

Nationally important areas are described by Connor *et al.* (2002) as

"… areas that best represent the range of [marine landscapes], habitats and species present in the UK – the UK's marine biodiversity heritage. Such areas are coupled with the identification of nationally important marine features, as part of an overall framework for the consistent assessment of nature conservation interest within the UK."

The draft criteria for the identification of nationally important marine areas are shown in table 2.3.1.

Table 2.3.1. Draft criteria for the identification of nationally important marine areas (Connor *et al*. 2002)

1. Typicalness:	The area contains examples of marine landscapes, habitats and ecological processes or other natural characteristics that are typical of their type in their natural state.
2. Naturalness:	The area has a high degree of naturalness, resulting from the lack of human-induced disturbance or degradation; marine landscapes, habitats and populations of species are in a near-natural state. This is reflected in the structure and function of the features being in a near-natural state to help maintain full ecosystem functioning.
3. Size:	The area holds large examples of particular marine landscapes and habitats or extensive populations of highly mobile species. The greater the extent the more the integrity of the feature can be maintained and the higher the biodiversity it is likely to support.
4. Biological diversity:	The area has a naturally high variety of habitats or species (compared to other similar areas).
5. Critical area:	The area is critical for part of the life cycle (such as breeding, nursery grounds/area for juveniles, feeding, migration, resting) of a mobile species.
6. Area important for a nationally important marine feature:	Features that qualify as special features or which are declined or threatened should contribute to the identification of these areas. The assessment should consider whether such features are present in sufficient numbers (species), extent (habitat) or quality (habitats, marine landscapes) to contribute to the conservation of the feature.

3 Part A: Testing the criteria through direct application

3.1 Initial approach

The initial approach to applying the criteria was to use them in order to identify "best examples" of each marine landscape type. In the absence of detailed information at habitat and species level, marine landscapes (Golding *et al.*, 2004) may be used as surrogate assessment units for habitats and species. Identifying "best examples" for each marine landscape is likely o ensure adequate representation of the UK's marine biodiversity. Consequently, the approach taken was to compare areas at the marine landscape level. The marine landscape classification for the Irish Sea (Golding *et al.* 2004) was being developed in parallel with the work described here. As the offshore marine landscape types were still "preliminary" at the outset, the initial focus was on the inshore type of "estuaries".

For the "estuaries" marine landscape type, examples were assessed against the six criteria, using methods based on the Marine Nature Conservation Review (MNCR) natural heritage assessment protocol (Connor & Hill, 1998). Information used for the assessment came from a variety of sources; the benthic data were from the JNCC marine database and from the Irish Sea Seabed Image Archive (ISSIA) (Allen & Rees, 1999).

Inshore marine landscape types, such as estuaries, sealochs and lagoons, are discrete spatial units which can be readily used as areas to compare. These inshore marine landscape types also tend to have relatively good data coverage, both on the JNCC marine database, and in terms of additional information sources such as the MNCR Area Summaries (Covey, 1998; Moore *et al.,* 1998; Brazier *et al.*, 1999; Dipper and Beaver, 1999) and the NCC Estuaries Review (Davidson *et al.*, 1991). For these reasons, the inshore types are more straightforward to assess than offshore marine landscape types. Offshore marine landscape types, such as the sediment plain types, tend to form large continuous areas of seabed; to enable comparison between areas of the same type, these continuous areas need to be divided up. A 10 km by 10 km grid was used to form a series of grid cells that could be compared using the same methods as for estuaries.

Because the criteria testing was carried out as part of the Pilot, it was undertaken within the Irish Sea, rather than at the whole UK level. Whilst a whole UK perspective is important, it is considered valid to work at the regional sea level as such an approach would ensure full representation of the variation in biogeographical character of features present throughout the UK. For example, rocky reefs in the Irish Sea are biologically quite distinct from those in the North Sea – selecting "best examples" in each regional sea would ensure both types are represented in the national series of important areas.

The results of this initial testing of the criteria are described in section 3.5. The approach worked well for the inshore type tested, but problems were encountered in data-poor offshore areas. These issues are addressed in section 4, which reports on work carried out to test the usefulness of the reserve design software, Marxan, in applying the criteria.

3.2 Testing the approach for inshore marine landscape types: estuaries comparison

3.2.1 Scope of the estuaries comparison

Estuaries were selected as the first marine landscape on which to test the approach for applying the criteria. They are a relatively straightforward marine landscape type for carrying out the assessment, because there is a wealth of information available about UK estuaries, both in terms of literature and data coverage on the JNCC marine database. In addition, they fall into easily comparable, convenient spatial units.

Only the first four of the six criteria for nationally important areas (typicalness, naturalness, size, biodiversity) were applied fully. The last two of the criteria (critical area, area important for nationally important feature) are also discussed in this section, but a separate approach is proposed for their application. The results of the estuaries comparison are presented for each criterion in turn. As the methods used differ for each criterion, an outline methodology is given immediately preceding the results for each criterion, rather than presenting a separate methods section.

Thirty-seven estuaries were identified in the Irish Sea (figure 3.2.1). The Pilot encompasses an area that spans international boundaries with the Republic of Ireland and the Isle of Man. However, as the criteria are intended to be applied at the national level, only UK estuaries were included in the assessment. Estuaries for which there were no data on the JNCC marine database were excluded; these were principally very small estuaries or little streams. A full list of those estuaries included in the comparison (28 in total) is shown in table 3.2.1.

3.2.2 Estuaries comparison: Criterion 1 (typicalness)

Typicalness is defined as follows: “the area contains examples of marine landscapes, habitats and ecological processes that are typical of their type in their natural state” (Connor *et al.* 2002).

In applying the typicalness criterion, the aim was to look for estuaries that reflected the features of the estuaries marine landscape type. This was tested in several ways.

Firstly, estuaries were assessed against the recent biological typology developed for the Water Framework Directive (Rogers *et al.* 2003). Within this, UK estuaries have been assigned to one of five biologically-defined types. All typed estuaries in the Pilot area fell within types C, D or E (sandy, muddy, or muddy sand estuaries). For each type, a profile of biological character is given by listing the characterising biotope complexes (level 4 in the national habitat classification, Connor *et al.* 2003), together with their percentage contribution to similarity of that type (determined using the SIMPER routine in the PRIMER software package; Clarke & Warwick, 2001).

For each of the three biological WFD types present in the Pilot area, the best representative example(s) were identified by comparing the biotope complexes recorded within each estuary to the biological profile for the type, checking which estuaries contained all the characterising biotope complexes, and in similar relative proportions. The most similar estuaries to each of the WFD types were determined as follows:

WFD type C: Mawddach; Nyfer; Teifi
WFD type D: Mersey
WFD type E: Ribble; Esk, Mite & Ir

However, estuaries already assigned to the same WFD type did not seem to be particularly similar to each other, or similar to the description of the type to which they had been assigned. So, it was concluded that using the WFD typology in this way was questionable, and that an alternative approach should be tried.

Secondly, a general "estuaries" characterisation was derived from a SIMPER analysis, using all the data available for estuaries in the Pilot area. The results (table 8.1) show percentage contributions to similarity of each biotope complex. Comparisons were carried out between the general profile and data for individual estuaries, to determine those estuaries most similar to the general estuaries type. Using this method, the estuaries found to be most similar to the general estuaries marine landscape type were as follows:

Mawddach estuary
Nyfer estuary
Teifi estuary
Esk, Mite & Ir estuary system

These four estuaries ranked highest for typicalness, however, they lack certain biotope complexes which are characteristic of Irish Sea estuaries. Consequently, additional estuaries were identified so as to best represent the full range of estuarine biotope complexes:

Solway Firth (representing FVS, LMus, IFiSa, IMuSa, EstSa, ISaMu)
Cresswell & Carew (Milford Haven) (representing EstMx)
E & W Cleddau (Milford Haven) (representing K, KT)

It was concluded that a valid assessment of typicalness can be derived from identifying the characterising biotope complexes for a marine landscape feature and selecting specific examples to fully encompass the range of biological character (assessed here at biotope complex level).

It should be noted that, in applying this criterion, the estuaries with the most data available ranked highest. Improved data coverage for other estuaries may thus alter the overall assessment.

3.2.3 Estuaries comparison: Criterion 2 (naturalness)

Naturalness is defined as: "The area has a high degree of naturalness, resulting from the lack of human-induced disturbance or degradation; marine landscapes, habitats and populations of species are in a near-natural state. This is reflected in the structure and function of these features being in a near-natural state to help maintain full ecosystem functioning."

The application of this criterion has focused on the degree of physical disturbance or modification to the natural features and processes in the estuaries. The Estuaries Review (Davidson *et al.*, 1991) and MNCR Area Summaries (Covey, 1998; Moore *et al.*, 1998; Brazier *et al.*, 1999; Dipper and Beaver, 1999) provide information for most of the estuaries on the degree of artificial shoreline modification, the degree to which artificial substrata make up the shoreline, and of the main anthropogenic influences. Naturalness scores were allocated to each estuary, where the information was available, according to the guidelines in the Natural Heritage Assessment Protocol (Connor & Hill, 1998). The highest ranking (most natural) estuaries are the following:

Malltraeth Sands (Afon Cefni)
Water of Fleet
Afon Mawddach
Rivers Esk, Mite & Ir
W & E Cleddau
Afon Dyfi (River Dovey)
Pilanton Burn & Water of Luce
Traeth Bach (Glaslyn & Dwryryd)
Afon Teifi
Cree & Bladnoch estuaries

3.2.4 Estuaries comparison: Criterion 3 (size)

Size is defined as follows: "The area holds large examples of particular marine landscapes and habitats or extensive populations of highly mobile species. The greater the extent the more the integrity of the feature can be maintained and the higher the biodiversity it is likely to support."

This was straightforward to assess - the figures for size were calculated from the GIS layer containing the marine landscapes polygons. The polygons in the GIS are based on the estuary boundaries used for assessing the extent in the UK for the Habitats Directive Estuary Annex I type. The highest ranking (largest) estuaries are the following:

Solway Firth
River Dee
River Mersey, inc. Alt
River Ribble
Cree & Bladnoch estuaries
Clyde estuary
Duddon Sands
River Kent
River Leven
Afon Dyfi (River Dovey)

3.2.5 Estuaries comparison: Criterion 4 (biological diversity)

Biological diversity is defined as follows: the area has a naturally high variety of habitats or species (compared to other similar areas). The criterion has been addressed at three levels of scale: diversity of biotope complexes, diversity of biotopes and diversity of species. Biotope complexes and biotopes refer to levels 4 and 5 in the national marine habitat classification (Connor *et al.*, 2003).

Biological Diversity scores were derived using the Banded Ranked Relative Richness (BRRR) method (Connor & Hill, 1998), which ranks the areas according to the number of species (or biotopes, or biotope complexes) recorded in each, and then splits the ranks into five bands of equal width. The highest ranking areas receive a BRRR score of 5, the lowest ones a score of 1.

The application of the biological diversity criterion, at all three levels of scale, is strongly influenced by sampling effort. For some areas data coverage is highly inadequate, e.g. for the Clyde Estuary, for which JNCC holds only three data points. Whilst the results provide a reasonable indication of which estuaries support the greatest biodiversity (based on available data), future work needs to explore the use of methods to overcome uneven sampling effort, such as taxonomic distinctness (Clarke & Warwick, 2001) or cumulative species curves.

Table 3.2.1. BRRR scores for each estuary, for biodiversity at three levels of scale (biotope complex, biotope and species).

Estuary	Biotope complex diversity BRRR score	Biotope diversity BRRR score	Species diversity BRRR score
Afon Teifi	5	5	5
Solway Firth	5	5	5
Afon Mawddach	5	5	5
Rivers Esk, Mite & Ir	5	5	5
Duddon Sands	5	5	4
Water of Fleet	4	4	4
River Dee	4	4	4
Afon Nyfer	4	4	4
Afon Dyfi (River Dovey)	4	4	4
Traeth Bach (Glaslyn & Dwryryd)	4	4	4
Cresswell & Carew Rivers	3	3	5
Cree & Bladnoch estuaries	3	3	3
River Lune	3	3	3
River Ribble	3	3	3
River Leven	3	3	2
Malltraeth Sands (Afon Cefni)	3	2	2
River Kent	3	2	2
Mochras Lagoon (Artro estuary)	2	2	3
W & E Cleddau	2	2	3
Afon Reidol & Ystwyth	2	2	2
Afon Dysynni (Broad Water)	2	2	2
River Mersey, inc. Alt	2	2	2
Clyde estuary	1	1	3
Nefern estuary	1	1	1
Ffraw estuary	1	1	1
Pilanton Burn & Water of Luce	1	1	1
Dwyfor estuary	1	1	1
Aeron estuary	1	1	1

3.2.6 Estuaries comparison: Criteria 5 and 6

Criterion 5 (critical area for a mobile species) was partially addressed through checking whether any of the estuaries overlap with seabird SPAs, in which case they have been rated as “critical areas” for the birds for which the SPA was designated. In order to try and address criterion 6 (important area for a nationally important marine feature), the number of features on the Irish Sea provisional list (Lieberknecht *et al.*, 2004) was counted within each of the estuaries. Table 3.2.2 shows the results of both these partial assessments in the final two columns.

It became clear that criteria 5 and 6 would be better approached in a different way, and suggestions on how to do this are presented in section 3.3.

3.2.8 Estuaries comparison: Overall results

Table 3.2.2 provides an overview of the rankings allocated against each of the estuaries for each of the criteria. The order of estuaries in this table is not significant, i.e. no overall ranking of estuaries is suggested. Only those estuaries included in the comparison are shown.

The overview table has been used to draw conclusions on the estuaries which should be considered as nationally important. This was done bearing in mind a number of caveats, particularly the problems encountered with uneven sample distribution, which may have led to significant bias in the criteria assessments, especially the biodiversity assessment. In addition, criteria 5 and 6 were not fully assessed for estuaries, and were therefore not taken into consideration in this instance.

Not all criteria were given equal weighting. It was considered that naturalness and size should be considered after assessing other criteria. Where there are a number of areas which score equally on the other criteria, size and naturalness may be used as a factor to prioritise between these areas. Larger areas tend to support greater biodiversity and are likely to be more robust in supporting ecosystem function. All other things being equal, the most natural areas should be preferred over more degraded areas.

The conclusions were drawn on the following basis:

- Include sufficient examples to fully represent the biological character (biotope complexes) characteristic of the marine landscape feature.
- Include those examples which appear to support the highest biodiversity.
- Check the examples identified are the most natural available, and of sufficient size.

Based on this approach, and bearing in mind the caveats, the following estuaries in the Irish Sea (listed from north to south) may be considered as nationally important: Solway Firth; Rivers Esk, Mite & Ir; Afon Mawddach; Afon Teifi; Afon Nyfer; W & E Cleddau; Cresswell & Carew Rivers.

Table 3.2.2. Overview of rankings allocated to each estuary for each criterion. Abbreviations: Typicalness (C, D and E refer to WFD types; G to general estuaries marine landscape; * refers to additional areas required to fully represent estuarine complexes). The critical area column indicates overlap (y) or partial overlap (y*) with SPAs.

Estuary	Diversity – biotope complexes	Diversity - biotopes	Diversity - species	Typicalness	Naturalness	Size	Critical area – birds (SPA)	Area important for nationally important feature
Water of Fleet	4	4	4		5	3		4
Afon Teifi	5	5	5	C; G	4	3		3
Malltraeth Sands (Afon Cefni)	3	2	2		5	3		2
Rivers Esk, Mite & Ir	5	5	5	E; G	4.7	2		6
Mochras Lagoon (Artro estuary)	2	2	3		3.7	2		3
River Dee	4	4	4		2	5	y	3
Cree & Bladnoch estuaries	3	3	3		4	5		1
River Lune	3	3	3		3	3	y*	2
Afon Nyfer	4	4	4	C; G		2		
Duddon Sands	5	5	4		2.7	4	y	3
Solway Firth	5	5	5	*	3.3	5	y	10
Clyde estuary	1	1	3		1.3	4	y	1
River Leven	3	3	2		3	4	y*	1
Cresswell & Carew Rivers	3	3	5	*		2		4
Afon Mawddach	5	5	5	C; G	4.7	3		4
Afon Dyfi (River Dovey)	4	4	4		4.3	4	y	2
Nefern estuary	1	1	1			1		
Ffraw estuary	1	1	1			1		
Traeth Bach (Glaslyn & Dwryryd)	4	4	4		4.3	4		2
Pilanton Burn & Water of Luce	1	1	1		4.3	2	y *	
W & E Cleddau	2	2	3	*	4.5	3		2
River Ribble	3	3	3	E	2.3	5	y	3
Afon Reidol & Ystwyth	2	2	2		2.7	1		
River Kent	3	2	2		3	4	y*	1
Afon Dysynni (Broad Water)	2	2	2			2		1
Aeron estuary	1	1	1			1		
Dwyfor estuary	1	1	1			1		1
River Mersey, inc. Alt	2	2	2	D	2	5	y	2

3.3 Applying criteria 5 and 6

3.3.1 Suggested approach

Criterion 5 ("critical area for a mobile species") and criterion 6 ("area important for a nationally important marine feature") both serve to identify areas that are important for specific features (marine landscapes, habitats, species). Criterion 5 is focused on all mobile features, irrespective of whether they qualify as nationally important features under the process described in Lieberknecht *et al.* (2004). Criterion 6 focuses on all nationally important features, irrespective of whether they are mobile or not.

The two criteria weren't fully applied within the estuaries comparison. It is suggested that the approach taken for these two criteria should differ from the approach of identifying "best areas" for each marine landscape. It would be more appropriate to identify areas unrelated to the boundaries of the marine landscape types, because critical areas for mobile features, as well as important areas for some nationally important features, may span across a range of seabed types. Section 4 reports on a trial of the reserve design software tool, Marxan, within the Irish Sea. Areas identified under criteria 5 and 6 could be incorporated into an integrated assessment at the regional sea scale, using methods tested in the Marxan trial.

3.3.2 Criterion 5: Critical area

Criterion 5 is worded as follows: "Critical area: the area is critical for part of the life cycle (such as breeding, nursery grounds/area for juveniles, feeding, migration, resting) of a mobile species" (Connor *et al.*, 2002).

The approach taken should be to identify mobile species that need protection in a site-based management approach and then to identify those areas that are critical to their survival. Some work has been carried out that may help to identify areas which are critical for some mobile species, though no thorough inventory of mobile species requiring site-based management has been completed. The number of species for which critical areas can be identified in practice will be strongly influenced by data availability.

Work to identify nationally and internationally-important localities for intertidal non-breeding waterfowl populations, and also for seabird breeding colonies, has been ongoing for many years, and guidelines for the selection of these as Sites of Special Scientific Interest in Great Britain, and as Special Protection Areas (SPAs) in the United Kingdom, have been published respectively by the Nature Conservancy Council (1989) and the Joint Nature Conservation Committee (1999). Detailed population figures for all major sites in the United Kingdom, including intertidal areas, are provided annually through the Wetland Bird Survey (Pollitt *et al*, 2003). A similar scheme (I-WeBS) is operated in the Republic of Ireland. A census of most of the important seabird colonies in Britain and Ireland was undertaken between 1999-2002 and the results will be published during 2004.

Work to identify important marine resting and feeding sites for assemblages of seabirds (including seaduck, divers and grebes) as a component of the UK network of Special Protection Areas is currently being undertaken by JNCC and the country nature conservation agencies. Methods are based on the statistical analysis of recorded seabird densities in conjunction with the published SPA selection guidelines (Joint Nature Conservation Committee, 1999). To date, sites have been selected for black scoter at Carmarthen Bay (just outside the Pilot area), and are being considered for black scoter and red-throated diver at Liverpool Bay.

Guidelines for the identification of important areas for seals have been published by the Nature Conservancy Council (1989) for Sites of Special Scientific Interest, and by the Joint Nature Conservation Committee (McLeod *et al.* 2002), for Special Areas of Conservation. Data on the distribution of cetaceans in British and Irish waters has been compiled and the results published (Reid *et al.*, 2003). A statistical approach is being taken to investigate the appropriateness of selecting Special Areas of Conservation for harbour porpoise.

The distribution of Basking Shark, as well as mobile seabird and cetacean species on the provisional list of nationally important marine features (Lieberknecht *et al.*, 2004) was mapped using data provided by JNCC Aberdeen and the Marine Conservation Society, indicating areas with clusters of records of those species. These maps may help to identify critical areas for these species, though further work would be necessary to take account of additional existing knowledge (e.g. consultation of experts and scientific literature). Information collated on commercial fish species for the Pilot (Lumb *et al.*, 2004) was used to map important nursery and feeding grounds for a small number of commercial fish.

It has become clear from the work carried out so far that not all areas of importance for mobile species can qualify as nationally important, as the area taken up by commercial fish feeding and nursery grounds alone takes up a very large proportion of the Irish Sea. It is necessary to narrow down the definition of “critical area”, and it will be necessary to prioritise between areas. The critical area criterion has been amended, and generic guidance produced, in order to reflect this (section 5).

3.3.3 Criterion 6: Important area for nationally important marine feature

Criterion 6 is worded as follows in Connor *et al.* (2002): “Area important for a nationally important marine feature: Features that qualify as special features or which are declined or threatened should contribute to the identification of these areas. The assessment should consider whether such features are present in sufficient numbers (species), extent (habitat) or quality (habitats, marine landscapes) to contribute to the conservation of the feature.”

Areas that may qualify under this criterion include areas containing high densities of a single nationally important marine feature, as well as areas containing a large number of different nationally important marine features. Using the records on the JNCC marine database, the number of benthic species and habitats on the Irish Sea provisional list was mapped on a 5km by 5km grid. The resulting map is shown in figure 3.3.1 (section 6). Areas containing large numbers of features were incorporated into the Marxan trial (section 4).

3.4 Testing the approach for offshore marine landscapes

The offshore marine landscape types mostly cover large, continuous areas, and there is far poorer data coverage than for the inshore types. Ideally, however, the criteria should be applicable to all marine landscape types. The offshore marine landscape selected at the time of the testing was "coarse lag deposits", which was subsequently split into "high bed stress coarse sediment plains" and "low bed stress coarse sediment plains". The coarse sediment plains needed to be divided into suitable areas that could be compared with each other and ranked against the criteria, in a similar way to the estuaries. A 10 km x 10 km grid was overlaid onto the Pilot study area, and the grid cells were treated as units to compare. Figure 3.4.1 (section 6) shows the grid, the distribution of JNCC marine database data, and the marine landscapes (Golding *et al.* 2004), illustrating the poor data coverage for offshore areas. For the western part of the Irish Sea, there is relatively good ISSIA data coverage (Allen and Rees, 1999), however, these records lack species, biotope or physical information.

Given that most of the 10 km x 10 km grid cells in the offshore areas contain no or very few records, it was felt that to carry out a comparison between the grid cells would yield few useful results. The offshore grid cell comparison for the coarse sediment plains was therefore not pursued further. Our conclusion was that the methods used to apply the criteria in the estuaries comparison cannot be used for data-poor offshore marine landscape types with any degree of confidence, unless sufficient data becomes available.

3.5 Conclusions from testing the direct application of the criteria

The direct application of the criteria at the marine landscape level proved effective for criteria 1-4 within data-rich inshore areas. However, unevenness in the coverage of biological sample data means that better techniques are needed to reduce bias in the data, and alternative techniques are needed for the data-poor offshore areas.

The assumption was made at the outset (section 3.1) that marine landscapes may be used as a surrogate for benthic species and habitats. There remains the broad question as to whether we can be sure that by focussing on the selection of "best examples" of the marine landscapes, adequate coverage of the entire UK marine biodiversity resource is provided. However, in the absence of detailed information at smaller scales, this approach is considered to make best use of existing information.

Some of the criteria should receive priority over others; particularly size and naturalness should be considered after the other criteria have been assessed. It is recommended that the first four criteria be applied at the marine landscape level, as was done for the estuaries, and the last two criteria (critical area and important area for nationally important feature) be considered in a separate process at the regional sea scale.

The Marxan trial (part B, section 4) has tested a methodology for applying all of the criteria at the regional sea scale. This methodology is recommended for criteria 5 and 6 in all instances, and for offshore regions where data coverage poor. Areas identified as nationally important in data-rich inshore regions, using the process described for the estuaries, can be incorporated into the process described in part B.

4 Part B Testing the use of Marxan for applying the criteria

4.1 Introduction to the Marxan trial

4.1.1 Background

Because data coverage is not sufficient in offshore areas to apply the criteria directly at the marine landscape scale, an alternative approach to identifying nationally important marine areas based on best existing knowledge was sought. Recent work has focussed on determining the use of the software tool Marxan to aid the identification of nationally important marine areas at the whole sea scale, making use of the marine landscape classification, biological species and habitats records on the JNCC marine database, and newly collated human use data (Lumb *et al.*, 2004). Marxan is a software tool designed for aiding the selection of networks of protected areas, which was developed in Australia by Ball & Possingham (1999). It is freely available on the world wide web, and has been used successfully for identifying suitable areas for marine reserve networks in Australia (Stewart *et al.*, 2003) and in Canada (Ardron *et al.*, 2002).

The aim of the work described in the current section of this report was to determine the use of the reserve network selection software, Marxan (Ball & Possingham, 1999), to aid the process of applying the criteria to identify a series of nationally important marine areas.

4.1.2 Terminology

In literature relating to reserve selection algorithms and software tools such as Marxan, terminology is sometimes used that could potentially give rise to confusion. In particular, readers should note that the terms “reserve system” or “reserve network” are often used to refer to the results of running an algorithm, and do not mean the same as “marine protected areas” or “marine protected area networks”. “Reserve systems” are the spatial solutions suggested by software tools, to meet certain targets under given constraints. Although Marxan can incorporate some aspects of reserve network design into its algorithm, whether this is done depends on the input parameters that are set for each scenario. A “reserve system” or “network” resulting from running Marxan is therefore not the same as an “ecologically coherent network”, such as described by Vincent *et al.* (2004) as adapted from Roberts *et al.* (2003).

Another term with the potential to be misinterpreted is “site”. In the literature relating to Marxan, “site” is used to mean the same as “planning unit”. Planning units are the spatial units into which the study area is divided before running the software. Usually, these spatial units are relatively small, and they can be totally arbitrary (e.g. based on a grid). The term “site” in this context, therefore, should not be interpreted in the same sense as when discussing sites for protection or a site of importance.

The term “conservation feature” usually applies to species, habitats or broader ecological units (e.g. marine landscapes). Marxan is given a target to meet for each conservation feature, e.g. to represent a given number of records for species or a given area of a marine landscape within the output. Any entity for which spatial data are available may be treated as a "conservation feature", e.g. targets could be set for a given amount of highly pristine area, or important nursery and feeding area of a mobile species.

4.1.3 Marxan: the basics

Marxan is a reserve selection tool that can identify sets of areas that will satisfy a number of ecological, social or economic criteria. The process initially requires the study region to be divided into spatial planning units, each of which will contain differing amounts of conservation features. Planning units can be based on an arbitrary grid, or take into account existing ecological or administrative boundaries. They may differ in shape and size, but must not overlap and should cover the entire region of study.

The user sets targets to be met for conservation features within the area of study, e.g. to represent three records of a species or 15% of the total area of a marine landscape. Marxan identifies sets of planning units that meet these targets. Each planning unit has a cost, which in the simplest case will be a measure of its size, but which may take account of other factors (e.g. social or economic factors). Marxan is designed to find ways of meeting the targets whilst minimising overall cost of the areas selected. In the simplest case, this would mean meeting the targets whilst keeping the overall size of the selected area to a minimum. In most cases, it will also be important to minimise the overall boundary length of the areas selected – otherwise, Marxan is likely to select planning units which are highly scattered across the area of study. This can be done by adjusting a boundary length modifier (BLM), which leads to the clumping of selected planning units.

The process works by using an optimising algorithm, where an initial set of planning units is either randomly selected or set by the user. In an iterative process, additional planning units are randomly selected, and added or removed from the current selection according to which move would improve the set of selected areas. The set of selected areas is measured by an objective function value which the algorithm strives to minimise. In its simplest form, the pseudo-equation for the objective function is:

$$\text{Objective Function} = \sum \text{cost} + \text{BLM} \sum \text{boundary} + \sum \text{penalty}$$

Here, "cost" refers to the total cost of all planning units in the selected areas (which might be their combined area, an economic or social cost, or any combination of these). The "boundary" is the length (or cost) of the boundary surrounding the selected areas. The BLM controls the importance of minimising the boundary length relative to minimising the cost of the selected areas. If it is zero then the boundary length is not considered. The penalty term is added for any conservation feature where its target is not met. As more planning units are selected the cost and boundary length are likely to increase, but the penalty term decreases as each target is met.

Marxan can be set to answer very simple or more complicated questions. There is no limit on the number of data layers that can be incorporated, so targets can be set for any species, habitats, or any ecological or other entities for which spatial data are available. For example, a target could be set to represent a given percentage of known fish spawning grounds, or known pristine areas, within the selected areas. In addition, the user can lock favourable areas into the solution, and lock undesirable areas out.

Each time it is run, Marxan provides one of many possible solutions to meeting the targets while meeting any other requirements set by the user. Because there is a random element in the algorithm, each run will result in a slightly different solution. By running Marxan many times, it is possible to come up both with a “best solution” (the solution with the lowest objective function value), and a measure of irreplaceability of each planning unit (i.e. the percentage of solutions each planning unit is selected in). Irreplaceability can be used as a relative measure of the conservation or biodiversity importance of each planning unit in the dataset Ferrier *et al.*(2000). For more details on the use of Marxan see Ball and Possingham (2000).

4.1.4 Aims and objectives of the Marxan trial

The aims of the work reported here were to determine the usefulness of Marxan in helping to overcome some of the problems encountered when applying the criteria for nationally important marine areas directly and at the marine landscape scale (section 3).

The specific objectives were as follows:

- To determine the level of data pre-processing required to create input files for Marxan from datasets collated for the Irish Sea Pilot project, including biological point sample data, geographical coverage data for marine landscapes, and additional data on human use patterns in the Irish Sea collated in a GIS since the initial testing of the criteria was carried out (Lumb *et al.*, 2004).

- To determine if and how the existing criteria for the identification of nationally important marine areas may be incorporated into Marxan.

- To demonstrate the process of preparing a dataset and applying Marxan to the Irish Sea region, with the incorporation of selected aspects of the draft criteria.

4.2 Incorporating the criteria into Marxan

4.2.1 Possible ways of incorporating the criteria into Marxan

Marxan's principal use is in identifying suites of planning units that could make a potential network of Marine Protected Areas (MPAs). In relation to the aims of the nationally important areas work this equates to identifying a series of areas which represent the range of ecological character in the Irish Sea. The approach is to work at marine landscape scale, i.e. to identify a set of areas representing each marine landscape, but to use habitat and species data to support the evaluation. To identify the best areas we can apply the criteria. The issue here, in using Marxan, is to what extent we can use available data within Marxan to apply all or some of the criteria, and move from identifying any set of areas representing all marine landscapes to identifying the best set. Other considerations such as minimising the number of sites, accounting for existing MPAs or excluding areas set aside for certain human activities can also be incorporated into the Marxan process.

This section details how the criteria can be dealt with in Marxan in general terms, while section 4.2.2 describes the methods used during the trial. There are a number of possible approaches to including the criteria in Marxan, which can be used according to the availability of data and the specifics of the question at hand.

4.2.1(i) Typicalness

Areas which are particularly typical can be given targets, e.g. a certain amount of typical area can be forced to be included in the set of planning units selected. This target could be the total extent of typical areas, or it could be any given proportion of the total amount. Alternatively, typical areas can be locked in, requiring Marxan to meet its other targets using these areas as much as possible. If sufficient data were available, a measure of typicalness could be used to alter the cost of planning units, similar to using naturalness to alter planning unit costs, as described in section 4.2.1(ii) for naturalness.

4.2.1(ii) Naturalness

As for typical areas, an area target can be set for areas known to be highly natural. The target could equate to any proportion of the total area of 'natural' areas identified. Highly pristine areas could be locked in. Conversely, areas considered to be significantly altered from their natural state could be locked out of the process. Alternatively, or in addition to this, naturalness could be used to alter the cost of selecting a planning unit. Planning units with intensive trawling, for example, could be made more expensive for Marxan to select than areas with low trawling intensity. It would then be more likely for Marxan to select natural areas to meet its targets, but it would not preclude non-natural areas from being selected if they are required to meet targets. This may be more appropriate as there may be degraded areas where recovery of biodiversity/natural status is a key objective.

4.2.1(iii) Size

Marxan can be set to select aggregated sets of planning units to meet its targets. This is done using the boundary length modifier, which controls the importance of the cost of the total boundary length of the selected areas relative to its area. If no BLM is set, the most efficient way for Marxan to meet its targets normally is to select a set of highly scattered, small areas. Setting a BLM tends to create a network of fewer, larger areas, but it does not set a minimum patch size. Small areas which are still required to meet targets may still be selected, but at a greater cost. A description of the application of the boundary length modifier can be found in section 4.3.3.

For any individual conservation feature (e.g. a species or a habitat) a minimum clump size can be set, below which a clump of planning units containing the feature does not count towards meeting the target for that feature. For example, a group of adjacent units might be required to contain 500 ha of a marine landscape in order for that group of planning units to count towards the target for that marine landscape. This does not preclude small areas being selected, but it does mean that conservation features which are area sensitive are always “protected” in sufficiently large areas. Setting a minimum clump size for all features will preclude small areas being selected, but this is likely to make targets unable to be met.

4.2.1(iv) Biological diversity

Marxan is given targets for conservation features, such as number of occurrences or area of species, biotopes, marine landscapes to be represented within a set of planning units. These conservation features are the features on which biodiversity measures are based (e.g. species diversity, habitat diversity). Therefore, in order to meet its targets using the minimal amount of area, Marxan is likely to select high biodiversity planning units, as these planning units will contribute to meeting targets more efficiently. However, this will not necessarily happen, and Marxan is not meant to be used to directly identify areas of high biodiversity. Assuming targets have been set for a number of different species, theoretically, a planning unit containing one single species can be selected just as often as a planning unit with 10 species. This is will depend on the targets set for each species relative to the occurrences of the species. In Marxan a planning unit is valued by whether it is needed or not (or, if using irreplaceability, by how often it is needed), not by how many features it is needed for.

If the users wish to ensure that certain high biodiversity planning units are included then these can be locked into the solution. Alternatively, they could be given a lower cost than less diverse areas, or a target could be set to represent any given proportion of the diverse areas in the Marxan output.

4.2.1(v) Critical area

An area based target could be set for each type of critical area. For example, we could ask Marxan to include x hectares of breeding grounds for each species, or the amount of hectares required could be species specific. As with other area based features, all or some critical areas could be locked in, which will require Marxan to meet its other targets using these critical areas as much as possible.

4.2.1(vi) Area important for a nationally important marine feature

Targets can be set for each nationally important marine feature, e.g. to represent an amount of each feature (area or number of occurrences). This will ensure records of each nationally important marine feature are represented. Areas with high numbers of nationally important marine features will tend to be favoured, though that is not necessarily the case, as the same argument as explained under "biological diversity" (section 4.2.1(iv)) applies.

If information is available on which areas are specifically important for nationally important marine features, then Marxan can be asked to include all of these areas, or a certain amount of area, or a given number of occurrences of the features. Additionally, areas which are important for more than a certain number of nationally important marine features can be locked into the solution.

4.2.2 Using Marxan to apply the criteria – pre-processing of data

It is apparent from the above that Marxan cannot be used to directly apply most of the criteria – e.g. it cannot directly measure typicalness, naturalness and biodiversity of different areas in order to identify those areas which score highest in a combination of all these factors. It is necessary to pre-process data for the region of study, in order to determine values or scores for different areas against each of the criteria, using existing spatial biological and human use data. Once this has been achieved, each of the criteria can be incorporated into Marxan in a number of different ways, as described above.

If spatial data are available for areas of importance for nationally important marine features or critical areas for mobile species, then those data may be directly usable (e.g. by setting targets or locking those areas in). Typicalness, naturalness and biodiversity of different areas have to be measured in some way, which may be a complex process in itself. Naturalness, for example, may depend on a range of human activities, and a way of combining data on fishing intensity, dredging, offshore energy developments, shipping activity etc. would ideally be used, as well as taking into account the vulnerability of different areas to each of these activities. In most cases, the assessment will be limited by the quality and coverage of available data. For the Pilot, insufficient information was available to carry out an assessment for typicalness, but areas were assessed for biodiversity and naturalness (section 4.3).

As described above, there are a number of ways to incorporate the criteria into Marxan: setting targets, locking favourable areas in, unfavourable areas out, and/or scaling the cost of "intermediate" areas. Any combination of these options is possible. It is also possible to combine a number of different factors (e.g. typicalness and naturalness) to scale the cost of planning units. However, it may not be advisable to combine too many cost factors at the same time, as this may involve very complex data processing (especially if naturalness scores in themselves are derived from a number of different human use data sets). It could also potentially make the interpretation of the Marxan results more difficult, in that it may be more difficult to see what factors cause some areas to be favoured over others.

The best way of incorporating the criteria into Marxan will depend partly on the relative weighting that the criteria are given. It may vary between different regions of study, because to some extent it will depend on what datasets are available, and on factors affecting regions differently. For example, in a region where only small areas have been completely destroyed, it may be best to lock out those areas – however, in a region with high levels of human impact throughout, using the same approach could mean that conservation targets cannot be met. Determining the most suitable approach should be an iterative process: it is possible to run Marxan on any number of different "scenarios". The approach taken during the Pilot was to start with a simple scenario, and then build it up into a more complex picture by incorporating additional criteria and data layers.

4.3 Approach taken to apply the criteria during the Marxan trial

4.3.1 Establishing the initial dataset

Planning units for the purpose of using Marxan over the Irish Sea were based on the marine landscape map from Golding *et al.* (2004) (see figure 4.3.1, section 6). With the exception of physiographic types (estuaries, rias, sounds etc.), all areas of a single marine landscape bigger than 2500 ha on the marine landscape map were intersected with a 5km by 5km grid. In this process we divided large areas while avoiding breaking up very small areas, although we did not prevent small areas from being created during the division.

Each planning unit falls entirely within a single marine landscape type, with its size providing a measure of the amount of the marine landscape present within it. The distribution of JNCC marine database records of nationally important benthic species and habitats[1] were linked to the planning unit layer, creating a summary of planning units in relation to the occurrences of species and habitats provisionally identified as nationally important. For each planning unit, the presence (though not abundance) of habitat and species records was used. The first scenario incorporated no further information, but subsequent scenarios incorporated progressively more data layers and constraints, each described in sections below.

4.3.2 Scenario 1: setting targets

The first scenario (scenario 1) demonstrates the results of setting targets for marine landscapes and nationally important benthic features. None of the criteria are addressed in this scenario except for criterion 6, in that by setting targets for nationally important features and habitats, it is likely that some areas of importance for these features will be picked up.

Targets were set for features at three levels of scale: nationally important marine species, habitats, and marine landscapes. Targets for each marine landscape (table 4.3.1) were set with consideration of their rarity (judged from the marine landscapes map in figure 4.3.1) and the guidelines in Roberts *et al.* (2003). Each nationally important benthic species was required to be represented within at least three planning units, or all occurrences were required where it was recorded in fewer than three. Each habitat was required to be represented in at least five planning units, or all occurrences were required if there were less than five in total.

The cost of each planning unit was its size (ha), therefore Marxan selected sets of planning units that minimised the total area while still meeting all of the targets. The best solution and the irreplaceability values of each planning unit over 100 runs are shown in figures 4.4.1(i) and 4.4.1(ii).

[1] Note that "nationally important marine features" (habitats, species or marine landscapes) in the context of this report refers to benthic features on the Irish Sea provisional list (Lieberknecht *et al.*, 2003a). Biotope complexes and pelagic species on the list were not considered.

Table 4.3.1. Area based targets set for marine landscapes in the Irish Sea. Rarity was assessed by eye for each marine landscape within the Irish Sea, using the marine landscapes map in figure 4.3.1.

Marine Landscape	Target (% total extent)	Justification
Estuary	35	Nationally important
Ria	30	Locally rare (possibly N imp)
Saline Lagoons	40	Extreme rarity
Sea Lochs	35	Nationally important
Sound	30	Locally rare (possibly N imp)
Gas structures	30	Locally rare (possibly N imp)
Photic Reefs	40	Rare
Aphotic Reefs	20	Moderately common
Deep Water	20	Moderately common
Irish sea mounds	40	Extreme rarity
Sand/Gravel banks	20	Moderately common
Sediment waves	10	Common
High bed stress	10	Common
Low bed stress	10	Common
Fine sediment plains	10	Common
Coastal sediment	10	Common
Deepwater mud banks	20	Moderately common
Shallow water mud banks	20	Moderately common

4.3.3 Scenario 2: incorporating a boundary length modifier

We demonstrate the use of a boundary length modifier (BLM) in scenario 2. This relates to criterion 3, size, in that the boundary length modifier encourages Marxan to select large contiguous areas rather than small isolated areas to meet its targets. The BLM is pre-set by the user before running Marxan. It controls the relative importance of minimising the boundary length of the selected areas relative to minimising its cost. As the BLM is increased, the boundary length of the selected areas decreases, and the area correspondingly increases. Figure 4.3.2 shows this trade-off effect using the targets established in scenario 1 which we ran with a range of BLM values. The values used in this graph are an average of the cost (area in ha) and the boundary (in km) of the five best runs in each scenario, i.e. the five solutions with the lowest overall objective function value.

The optimal BLM will depend on the specific issues being addressed by the user and should be determined by running variations, producing a graph like figure 4.3.2, and also viewing maps of the results of each BLM value. As a general rule, an optimal BLM should the point at which the boundary lengths of the solutions are significantly lowered, but the cost (in this case, area required) has not yet increased sharply. In figure 4.3.2, a BLM value of 1 would be optimal, if minimising area was the most important priority. We used a BLM value of 5, as viewing the maps showed that this level resulted in sufficiently few small clumps and we decided this was more important than minimising the overall area. For some later scenarios, a BLM of 5 was too high and a BLM of 2 was used. This is fully discussed in section 4.4.

Maps of the irreplaceability values and the best solution generated from 100 runs, using a BLM value of 5 in addition to the targets in scenario 1, are shown in figures 4.4.2(i) and 4.4.2(ii).

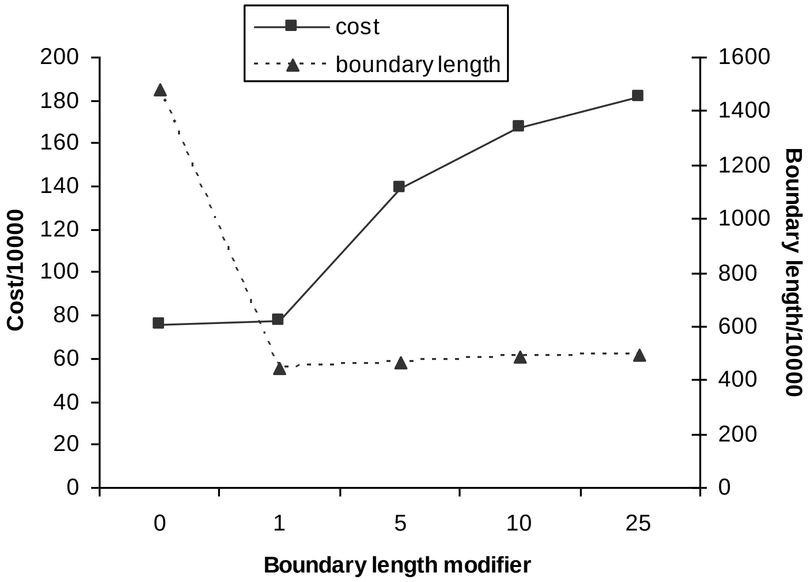

Figure 4.3.2: the relationship between cost and boundary length as boundary length modifier is increased using targets from scenario 1.

4.3.4 Scenario 3: incorporating naturalness

4.3.4(i) Methods used to determine naturalness

Using data collated for the Pilot by Lumb *et al.* (2004), we used English and Scottish overflight data on trawling intensity, recorded in the ICES sub rectangular grid, supplied by the Scottish Fisheries Protection Agency (SFPA) and the Centre for Environment, Fisheries and Aquaculture Science (CEFAS). The number of fishing vessels with mobile fishing gear in use was recorded for each quarter of the year in each grid cell. The values were standardised by the number of flights undertaken in that grid cell. The English data differentiated between beam trawling and “other trawling”, whereas the Scottish data combined all trawling except that for *Nephrops norvegicus*. To achieve comparable datasets, we combined the values for all types of trawling in both the English and Scottish datasets. The trawling intensity values therefore include some pelagic as well as benthic trawling. We then determined four trawling intensity categories (low, medium, high and very high), based on the average number of boats sighted per flight in each grid cell. Each planning unit was allocated to one of the four trawling intensity categories, by overlaying the planning units and the trawling intensity layer. Planning units that were outside the range of trawling data available were allocated to a “no data” category (note that this was a significant amount of area).

Levels of trawling intensity are likely to vary in their effect on the naturalness of different marine landscape types, depending on the vulnerability of the marine landscape. Each planning unit contains one single marine landscape type, and was given a “vulnerability” score based on the estimated vulnerability of its marine landscape to the effects of trawling. These vulnerability scores and their derivation are based on Tyler-Walters *et al.* (2003) and Gilliland (2001), as explained in Golding *et al.* (2004). Finally, each planning unit was allocated one of six naturalness ratings, determined by combining vulnerability scores with trawling intensity scores. Table 4.3.2 shows how the naturalness ratings were derived, and figure 4.3.3 (section 6) shows a map of the naturalness ratings.

Planning units in areas without trawling data were allocated to the most common naturalness category for their marine landscape. This meant that when Marxan was run, these planning units had an “average” cost, i.e. they were neither favoured nor disfavoured compared to other planning units of the same marine landscape type.

This method of deriving naturalness ratings meant that high levels of trawling resulted in lower naturalness levels in highly vulnerable marine landscape types, compared with the same level of trawling intensity in less vulnerable marine landscapes. It also helped to refine the coarse nature of the grid upon which fishing intensity was recorded. Where a grid cell with high trawling intensity intersects a boundary between a high and a low vulnerability marine landscape, a direct utilisation of the trawling intensity values would place all planning units within that grid cell into a low naturalness category, irrespective of their marine landscape type. Areas of rocky seafloor (where there is unlikely to be a lot of bottom trawling activity), for example, may be placed in a low naturalness category if they happen to occur adjacent to an area of soft sediment with heavy trawling activity.

Table 4.3.2: Derivation of six naturalness ratings, based on trawling intensity and vulnerability of each planning unit. A higher value indicates lower naturalness.

Trawling Intensity	Boats/ flight	Vulnerability			
		High	Moderate	Low	None
Very High	>30	6	5	4	1
High	>20-30	5	4	3	1
Medium	>10-20	4	3	2	1
Low	0-10	1	1	1	1
No data	No data	3	2	1	1

4.3.4(ii)Incorporating naturalness into the cost of planning units

In previous Marxan runs (scenario 1), the cost of the planning unit was simply its area. In scenario 3, we modified the cost of each planning unit by the numeric rating of its naturalness. We used the following equation, which is a modification of the formula established by Stewart and Possingham (in prep):

$$C = (1 - w)A + w(A)N$$

where:
C = overall Cost
A = Area
N = Naturalness rating
w = Weighting (if w = 0, only area is included; if w = 0.5, equal weight is on both input cost components)

After testing various “w” values, we used a value of 1 (i.e. we simply multiplied the area figure with the naturalness rating), to allow naturalness to have a significant effect on our dataset. We then ran Marxan using the targets in scenario 1, with a boundary length modifier of 5.

4.3.4(iii) Arriving at scenario 3

Two versions of scenario 3 were investigated. Very unnatural areas may be undesirable for meeting targets, as they may be poor quality examples of biodiversity features and may be difficult to protect from human use. Therefore, in scenario 3a, areas falling into naturalness categories 5 and 6 in table 4.3.2 (the "low" and "very low" categories on the map in figure 4.3.3) were locked out completely, and the equation in section 4.3.4(ii) was used to modify the cost of planning units in naturalness categories 1-4.

Locking out highly unnatural areas, however, resulted in 13 targets being impossible to meet, including two of the marine landscapes targets. The marine landscape type "gas structures" falls entirely within a low naturalness area and was therefore not able to be represented at all, and large areas of the marine landscape "Irish Sea mounds" were also locked out resulting in a shortfall in meeting its target. In light of this, we ran scenario 3b, with the cost of each planning unit altered using the equation in section 4.3.4 (ii) for all six naturalness categories, without any planning units locked out. This meant that highly unnatural areas were not prevented from being selected by Marxan, where these areas were vital in order to meet specific targets. Scenario 3, therefore, consisted of the following:

<u>Scenario 3a</u>: targets from scenario 1, BLM of 5, cost altered by naturalness and planning units in the two most unnatural categories were locked out
<u>Scenario 3b:</u> targets from scenario 1, BLM of 5, cost altered by naturalness, but with no planning units locked out

The irreplaceability and "best solution" maps generated from 100 runs in scenarios 3a and 3b are shown in figures 4.4.3a(i), 4.4.3a(ii), and 4.4.3b(i), 4.4.3b(ii).

4.3.4.(iv) Framework for incorporating multiple activities in a naturalness rating

The approach taken for the current study used only one type of human use information (trawling intensity) to generate ratings for naturalness. In reality, a range of human activities will affect naturalness. As part of earlier work for the Pilot, data on a range of human uses of the Irish Sea were acquired and mapped using GIS (Lumb *et al.*, 2004). We were unable to incorporate multiple human uses in the naturalness ratings for this trial, due to lack of time and issues with uneven or incomplete data coverage. However, a framework for incorporating multiple factors in determining naturalness was developed and is described here.

Table 4.3.3 shows a hypothetical example of how different levels of intensity in four types of human use could be combined into a single naturalness scale. The assumption in this hypothetical example is that data is available on two different types of fishing activity (one more damaging that the other), aggregate dredging, and offshore wind farms. For each of these four human use types, a naturalness assessment such as that described above (ideally, combining vulnerability and intensity) needs to be carried out for the study area. The query system in table 4.3.3 works by reading across each line in turn. Any planning unit which falls into the "wind farms present", "aggregate dredging present" or "high damaging fishing" categories is allocated the lowest naturalness rating. The query system is progressive such that only by failing to fulfil the first seven queries could an area be given the highest naturalness rating.

Please note that this is a hypothetical example to illustrate a possible framework of integrating across different human use categories. It is not meant to prescribe how the queries should be set up, e.g. wind farms do not have to result in an area being given the lowest possible naturalness rating.

Table 4.3.3: Hypothetical example to illustrate a framework for incorporating multiple activities in the determination of naturalness ratings

Naturalness	Query number	Wind farm	Aggregate dredging	Damaging Fishing (trawling)	Other fishing or human uses
Very low	1	Present			
Or	2		Present		
Or	3			Very High	
Low	4			High	
Or	5			Medium	Very High
Med	6			Low	
Or	7				High/Medium
High	8			Very Low	Very Low/Low

4.3.5 Scenario 4: Incorporating biodiversity and pre-assessed estuaries

4.3.5(i) Arriving at scenario 4

In scenario 4, we locked in the areas of highest biological diversity within each marine landscape (addressing criterion 4). We also locked in areas with more than eight nationally important species within a 5km by 5km grid cell, which contributes to applying criterion 6. In addition, estuaries identified as nationally important in section 3 were locked in. Figure 4.3.4 (section 6) shows the planning units locked in within scenario 4. Three versions of scenario 4 were tested:

<u>Scenario 4a:</u> targets from scenario 1, BLM of 5, high biodiversity areas and estuaries locked in, naturalness not taken into account
<u>Scenario 4b:</u> targets from scenario 1, BLM of 5, high biodiversity areas and estuaries locked in, with naturalness as for scenario 3a (the two most unnatural categories locked out – note that this included four high biodiversity planning units)
<u>Scenario 4c:</u> targets from scenario 1, BLM of 5, high biodiversity areas and estuaries locked in, with naturalness as for scenario 3b (no categories locked out)

The irreplaceability and “best solution” maps are shown in figures 4.4.4a(i), 4.4.4a(ii), to 4.4.4c(i), 4.4.4c(ii).

4.3.5(ii) Assessing biodiversity for the Irish Sea: species diversity

Given the paucity of data, especially in offshore areas, and the uneven distribution of samples, the number of samples within an area has a strong influence on how it scores in terms of species diversity. Areas with the highest numbers of species recorded may not be the most diverse in reality, they often simply reflect where most sampling effort has taken place. The same issue caused problems in carrying out the estuaries comparison (section 3), and it still applies here. It is not a reason to stop the use of best available information in order to assess this criterion – there will never be the perfect dataset available. However, it is important to bear it in mind whilst proceeding with the assessment and interpreting the outcome. There are methods available to overcome uneven sampling effort, e.g. the use of taxonomic indices (Clarke & Warwick, 2001) or cumulative species curves, however, time pressure meant that it was not possible to explore these possibilities further as part of this study.

Initially, the number of species recorded in each planning unit was determined, using all biological sample data available on the JNCC marine database. However, as the size of the planning units is highly variable, the largest planning units tended to score highest, as there is a higher chance of larger number of samples falling within them. It was therefore decided to divide the Irish Sea into 5km by 5 km grid cells, and determine the number of species recorded in each of these grid cells.

Species diversity varies strongly between different types of habitat, e.g. rocky substrata tend to support a higher number of species than soft substrata. By looking at the Irish Sea as a whole, and selecting the highest-diversity grid cells, there would be a bias towards selecting grid cells in rocky areas whilst failing to select areas of high diversity within sediment habitats. Some degree of stratification is required when selecting high biodiversity areas, i.e. selection of the most diverse areas within different habitats. The approach taken in this instance was to combine some of the marine landscapes into broader categories, as data coverage in offshore areas is too sparse to adequately compare biodiversity within each individual marine landscape. Table 4.3.4 shows how the high biodiversity areas that were locked in were selected.

4.3.5 (iii) Assessing biodiversity for the Irish Sea: habitat diversity

No additional areas added as the highest habitat diversity grid cells were already covered by the high species diversity areas

4.3.5(iv) Assessing biodiversity for the Irish Sea: Marine Landscape diversity

It is apparent from the map of coastal and seabed marine landscapes (figure 4.3.1), that areas of the Irish Sea differ in their variety of marine landscapes. Some areas are relatively uniform, with one or two marine landscapes, in others many more types of marine landscape are to be found. A coarse grid of 20 by 20 km grid cells was used to compare the relative diversity of marine landscape areas, and the results are shown in figure 3.4 of Golding *et al.*, 2004. It was considered that areas of high marine landscape diversity might be used to identify probable areas of high biodiversity where biological data are scarce, and this approach could be used to identify probable diversity hotspots in such areas. The grid cell approach showed areas of high marine landscape diversity off the coasts of Co Antrim and Co Down and eastwards to the Mull of Galloway, off Anglesey, off the coasts of Co Wexford, Co Waterford and Dyfed.

However, the outcome of this approach was strongly dependent upon where the boundaries for the assessment were drawn: shifting the anchor point of the coarse grid by a few kilometres would have resulted in a different outcome. Different assessment units were considered. Planning units could not be used because they only contain one marine landscape. The most appropriate way to carry out this assessment seemed to be to identify high marine landscape diversity areas by eye, looking at the marine landscape map - a method lacking objectivity. It was decided after some discussion not to include biodiversity at the marine landscape scale in the Marxan trial. In addition to the difficulties in finding a suitable method for assessment, it was considered that the seafloor substratum data on which much of the marine landscape classification is based is too coarse to allow for the use of the marine landscape classification in this way.

4.3.5(v) Areas important for high numbers of nationally important species

Planning units overlapping with 5km by 5km grid cells containing records of more than eight species from the provisional list of nationally important marine species (Lieberknecht *et al.,* 2004) were locked in.

Table 4.3.4: Methods for selecting high biodiversity planning units for each group of marine landscapes

Broad Unit	Marine Landscapes included	Methods for selecting high biodiversity grid cells within broad unit
Deep rock	Aphotic Reefs	>300 species recorded in grid cell
Shallow rock	Photic reefs	>300 species recorded in grid cell
Shallow sediment	Coastal Sediment, Shallow-water mud, Sand / Gravel banks	>100 species recorded in grid cell, and/or an average of >30 species per sample recorded in the samples within the grid cell
Deep sediment	Sedimentwave / megaripple, Fine sediment plains, Fine sediment plains, High stress coarse sediment plains, Low stress coarse seds, Deep-water mud, Deep-water channel	>100 species recorded in grid cell, and an average of >30 species per sample recorded in the samples within the grid cell (note this is different from the shallow sediment, to avoid selection of an areas with extremely dense sample points where grid cells had >100 species recorded, but only few species recorded in each sample)
	Estuary	biodiversity assessment already carried out as part of the estuaries assessment (section 3). Estuaries identified as nationally important in the estuaries assessment were locked into the Marxan runs.
	Ria	biodiversity assessment should be carried out as part of a full assessment similar to the estuaries assessment, as this is an inshore marine landscape type with sufficient information available. Within the Irish Sea, there is only a single planning unit that is a Ria (Milford Haven), which will be selected by Marxan in any case in order to meet its conservation feature targets. Consequently this planning unit was not locked in.
	Saline Lagoons	biodiversity assessment for each of these marine landscapes should be carried out as part of a full assessment similar to the estuaries assessment, as this is an inshore marine landscape type with sufficient information available.
	Sound	as for Saline Lagoons
	Sealoch	as for Saline Lagoons
	gas structures	no data
	Irish Sea mounds	no data

4.3.6 Scenario 5: Incorporating candidate SACs

Scenario 5 incorporates areas which are candidate Special Areas of Conservation (cSACs) under the EC Habitats Directive. This involved locking all planning units that intersected with cSAC areas. This scenario demonstrates the use of Marxan in incorporating pre-established important areas, as well as highlighting some conservation implications of cSAC areas. We ran three alternative scenarios with cSACs locked in:

<u>Scenario 5a:</u> targets from scenario 1, BLM of 5 (then lowered to 2), high biodiversity areas, estuaries and cSACs locked in, naturalness not taken into account
<u>Scenario 5b:</u> targets from scenario 1, BLM of 5, high biodiversity areas, estuaries and cSACs locked in, with naturalness as for scenario 3a (two most unnatural categories locked out)
<u>Scenario 5c:</u> targets from scenario 1, BLM of 5, high biodiversity areas, estuaries and cSACs locked in, with naturalness as for scenario 3b (no categories locked out)

The irreplaceability and "best solution" maps generated from 100 runs are shown in figures 4.4a(i), 4.4a(ii), to 4.4c(i), 4.4c(ii). The maps shown for scenario 5a are those generated using a BLM of 2 instead of 5. Note that locking areas out was set to over-ride locking areas in (it may have been preferable to do the reverse). As a result, four high biodiversity planning units were locked out in scenario 4b, and four high biodiversity planning units and five planning units overlapping with cSACs were locked out in scenario 5b.

4.3.7 Scenario 6: incorporating Annex I habitat and SPAs

In our final scenario (6), we aimed to include as much information as possible, including locking in all existing designated areas. In addition to the cSACs, we locked in planning units that overlapped with Special Protection Areas for birds (SPAs), designated under the Birds Directive. While these sites do not relate directly to the benthic dataset, they may contribute to some targets for the benthos and should be included since they are already protected.

Three Annex I habitats (listed on Annex I of the EC Habitats directive) occur in the UK offshore area - reefs, sandbanks and gas structures. These will require the designation of SACs. Areas of potential Annex I habitat have been identified and mapped in the UK offshore region. These are 'sandy sediment in less than 20m', 'gas structures' and 'potential reefs', shown for the Irish Sea in figure 4.3.5. Somewhere between 20-60% of Annex I habitat has been used as a target for cSACs in the past. We set targets for 20% of area of Annex I habitat to be included in each run. This demonstrates the potential of using Marxan in an integrated approach for selecting a network of areas, though whether it would be feasible to integrate the process of selecting offshore cSACs with the identification of nationally important marine areas in this way is questionable, given the advanced status of the offshore cSAC work.

We ran this scenario with the original targets for species, habitats and marine landscapes, along with the Annex I targets, a BLM of 5 (then lowered to 2 for scenario 6a), and areas of high biodiversity, nationally important estuaries, cSACs and SPAs locked in. We used naturalness as for scenario 3b, i.e. using naturalness ratings to alter the cost of each planning unit but not locking any areas out. This allows Marxan to select planning units in natural areas where possible but to meet targets in unnatural areas if necessary. Three versions of scenario 6 were run:

Scenario 6a: targets from scenario 1, Annex I targets, BLM of 5 (then lowered to 2), high biodiversity areas and estuaries, cSACs and SPAs locked in
Scenario 6b: targets from scenario 1, Annex I targets, BLM of 5, high biodiversity areas and estuaries, cSACs and SPAs locked in, with naturalness as for scenario 3b (no categories locked out)

The third scenario involved trialling a set of lower targets for marine landscapes. This was undertaken to see which areas were selected as most important if a lower overall area of the Irish Sea could hypothetically be protected. Most targets were reduced to 5-10% of total area for each marine landscape, except for rare types (see table 4.3.5). This scenario was:

Scenario 6c: new low targets for marine landscapes (all others as for scenario 1), Annex I targets, BLM of 2, high biodiversity areas and estuaries, cSACs and SPAs locked in

Maps of the irreplaceability values and 'best solution' for scenario 6, generated from 100 runs, are shown in figures 4.4.6a(i)-4.4.6c(ii). Note that the maps shown for scenario 6a are those generated using a BLM of 2.

Table 4.3.5 Lower targets for marine landscapes, used in scenario 6c.

Marine Landscape	Target (% total extent)	Marine Landscape	Target (% total extent)
Estuary	10	Irish sea mounds	40
Ria	10	Sand/Gravel banks	5
Saline Lagoons	40	Sediment waves	5
Sea Lochs	10	High bed stress	5
Sound	10	Low bed stress	5
Gas structures	40	Fine sediment plains	5
Photic Reefs	30	Coastal sediment	5
Aphotic Reefs	30	Deepwater mud banks	5
Deep Water	5	Shallow water mud banks	5

4.4 Results and analysis of scenarios

4.4.1 Marxan solution maps

The scenarios presented here demonstrate the application of Marxan to a real dataset, and show the effect of progressively incorporating different information. Table 8.2 gives a summary of information regarding each scenario, including targets not met by each and the amount of area required for each “best solution”.

Figures 4.4.1(i) to 4.4.6c(ii) show two maps for each scenario, which should always be viewed in conjunction: an “irreplaceability” map and a “best solution” map. The “best solution” shows the outcome with the lowest objective function value out of the 100 runs carried out for each scenario. The map highlights the amount of area necessary to meet the targets, and shows the most efficient theoretical solution under the given constraints. The “irreplaceability” map shows the percentage of runs in which each of the planning units was included in the solution. Dark green colours represent planning units that were not selected at all, or were only included in the set of selected areas in a small proportion of the runs, yellow colours indicate planning units that were selected in about 50% of the runs, and orange to red colours show the planning units that were included in most or all of the solutions. The red areas are most irreplaceable: they must be included in the solution in order for the targets to be met. The “irreplaceability” maps are very useful for prioritising between areas, as they highlight those areas which are vital for meeting conservation goals. Note that all colour plates, including the Marxan solution maps referred to here, are located in section 6 (pages 56 onwards).

This trial study was undertaken to test the usefulness of Marxan as a tool to aid identification of nationally important marine areas. The maps shown are only examples of solutions generated by Marxan under given scenarios. They are based on real datasets for the Irish Sea and therefore probably give some indications as to which areas could be considered more important that others. However, they are not intended to show areas that should be considered nationally important, or that should be protected. The setting of the targets in this study was done without any wide consultation, literature review or expert input. The level at which targets should be set would require further, wider discussion, and there would have to be further consideration of using different or additional datasets and constraints, in order to develop the best possible outcome. A description of how Marxan could be used to aid in selecting a set of nationally important areas can be found in section 4.5.4.

4.4.2 Analysis of scenarios

4.4.2(i) Scenarios 1 and 2

The irreplaceability map for scenario 1 (figure 4.4.1(i)) contains a lot of light green colours, with hardly any orange or red areas at all. Some areas (in dark green) where hardly included in any of the solutions, but most of the planning units were selected in 10-30% of the runs. This illustrates that there are many possible ways of meeting the targets for the marine landscapes efficiently, and none of the areas are highly irreplaceable. There is a small number of planning units that are selected in around 100% of the runs (dark red areas). These planning units are those which contain unique records of nationally important benthic species or habitats: where there are fewer than five occurrences of a habitat or three occurrences of a species, the target was set to represent all occurrences. This means that, where there is only a single record of a species, Marxan has to select the planning unit containing that species in every run in order to meet the target for that species.

It is evident that scenario 1, without the use of a boundary length modifier, is of little practical use, as there is very little preference between planning units. The "scattergun" design shown in the "best solution" in figure 4.4.1(ii) is also impractical and not acceptable from any future management perspective. Further data and constraints need to be incorporated in the process to generate more realistic and helpful results.

A slightly more useful outcome was achieved in scenario 2, with the addition of the BLM. While more area was required to meet the targets than in scenario 1, the "best solution" map in figure 4.4.2(ii) shows how the BLM leads to previously highly scattered areas forming fewer, larger clumps, which is desirable from any future management perspective. The "irreplaceability" map in figure 4.4.2(i) contains a lot more yellow and orange areas than the equivalent map for scenario 1, highlighting areas with a higher level of irreplaceability. The small number of planning units containing unique records of nationally important benthic species and habitats still have the same high level of irreplaceability as they did in scenario 1. Because these planning units are selected in most or all of the runs, with the addition of the BLM they effectively act as "seeds" around which further planning units are selected to form clumps. A high level of confidence in the completeness of the dataset for the benthic species and habitats would be needed if conservation decisions were to be based on the high irreplaceability values around these "seed" areas in figure 4.4.2(i). An under-recorded species could easily affect the irreplaceability values for the area around each record. In the absence of further information, however, these results would help to ensure efficient representation of known locations containing important species and habitats, as well as the full range of marine landscapes.

4.4.2(ii) Scenario 3: Incorporating naturalness

In scenario 3a we used naturalness to modify the cost of planning units in order to favour more natural areas. We locked out areas that were considered likely to suffer significantly from fishing pressures (these were categories 5 and 6 from table 4.3.2). The highly unnatural areas are concentrated around the *Nephrops norvegicus* trawling grounds in the area of the deep mud basin in the western Irish Sea. Locking out these areas resulted in 13 targets being unable to be met. Six of the features for which targets were not met were species, five were habitats, while two were marine landscapes. The marine landscapes were the Irish Sea mounds and the gas structures, the latter of which could not be represented at all, as they fall entirely within the highly trawled area (see table 4.4.2 below). Sea lochs were also reduced close to their target amount. The target for the marine landscape type “deep-water mud basin” was met, but the highly reduced area of this marine landscape type available to Marxan resulted in high irreplaceability values in the southern part of the mud basin in the western Irish Sea, shown in figure 4.4.3a(i).

We had initially considered that areas in the lowest naturalness categories should be locked out, in order to force Marxan to select areas of higher quality in order to meet its targets. However, in view of the shortfall in meeting a high number of targets, we decided to re-run the programme without locking out any areas, but simply factoring in naturalness scores into the cost of planning units for all naturalness categories. The results are shown in figures 4.4.3b(i) and 4.4.3b(ii). The irreplaceability values in figure 4.3b(i) show a shift in the yellow/orange areas away from the most unnatural areas, when compared to the irreplaceability values in scenario 2 (figure 4.4.2(i)). An exception to this are the relatively high irreplaceability values around the area of the gas structures, and around the Irish Sea mounds (cf. figure 4.3.1). This demonstrates that the effect of factoring naturalness into the cost of planning units is that Marxan favours more natural areas, except where it requires unnatural areas to meet its targets.

The outcome of scenario 3a highlighted that, unsurprisingly, some of the marine landscape types are more affected by trawling activity than others. This prompted us to investigate the level of impact that different types of human activity (high fishing pressure and potential windfarm developments) may have on different marine landscape types, in terms of the percentage of area affected. Table 4.4.2 below summarises the percentage of the total area of each marine landscape falling into naturalness categories 5 and 6 (lowest naturalness), and into areas of potential future offshore wind development, determined using data collated by Lumb *et al.* (2004).

The table illustrates the extent to which the Irish Sea mounds, gas structures and sealochs are affected by high fishing intensity. It was considered that low naturalness should not prevent targets from being met where most or all of a marine landscape type falls within low naturalness categories. Where relatively natural areas of a marine landscape exist, then these should be preferentially identified as nationally important over unnatural areas, as they will be better examples of the marine landscape, and are likely to cause less conflict of interest (e.g. between nature conservation and fisheries). However, if no natural areas exist, then unnatural areas should be allowed to be selected in order to meet the set target. For this reason, scenario 3b was run, with none of the naturalness categories locked out.

As was expected, potential wind farm areas are concentrated over areas of sand/gravel banks and the target would not be able to be met for this marine landscape if all potential wind farm areas were locked out (see table 4.4.2). The presence of windfarms does not necessarily preclude conservation goals from being met in those areas, and we are not advocating that potential windfarm areas should be locked out from the process of identifying areas of national importance. In the naturalness assessment for scenarios 3a and 3b, offshore windfarms were not incorporated at all. However, it is important to highlight how these potential future developments would impact on a single marine landscape type, with only a small proportion of that marine landscape unaffected.

Table 4.4.2: Amount of area of each marine landscape falling into the two lowest naturalness categories in scenario 3, and into areas of potential future offshore windfarms determined from data collated by Lumb *et al*. (2004). * Indicates where targets could not be met if the lowest naturalness categories or potential future windfarm categories were locked out.

Marine Landscape	Total area (ha)	Target (% total area)	% total area in categories 5 and 6	% total area in potential wind farm sites
Aphotic Reefs	123679	20	8	5
Coastal Sediment	249579	10	4	1
Deep-water channel	23384	20	0	0
Deep-water mud basins	495322	20	27	4
Estuary	92564	35	0	0
Fine sediment plains	1291760	10	12	9
Gas structures	5772	30	* 100	0
High bed-stress coarse sed.	1176013	10	1	3
Irish Sea mounds	7418	40	* 70	0
Low bed-stress coarse sed.	1511257	10	6	2
Photic Reefs	16039	40	1	0
Ria	4921	30	0	0
Saline Lagoon	790	40	0	0
Sand/Gravel banks	54041	20	0	* 83
Sealoch	59616	35	62	0
Sed. wave/megaripple field	662994	10	0	6
Shallow-water mud basins	91325	20	4	17
Sound	6868	30	0	0

4.4.2(iii) Scenario 4: Locking in important estuaries and high biodiversity areas

Our later scenarios investigated the effect of locking in progressively more area of pre-established important sites. Locking in high biodiversity areas and the estuaries assessed as nationally important in the estuaries comparison (section 3) was important for demonstrating how Marxan can be used as part of a broader framework with the criteria. Locking in this set of areas increased the overall area required to meet targets, but not by a large amount. This indicates that few of these areas were redundant in terms of the targets for our study.

Figure 4.4.4a(i) shows irreplaceability values for scenario 4a, where high biodiversity areas were locked in, but naturalness was not taken into account. The map shows how the locked in planning units (shown in purple) act as "seeds", similarly to the planning units with unique species records in earlier scenarios. The area of high irreplaceability to the south-west of the Isle of Man is a result of the presence of survey records in that area for the "deep sediment" broad unit (table 4.3.4). There is a lack of data for other areas in the "deep sediment" broad unit, which means that the area to the southwest of the Isle of Man came out as the most diverse within that unit, and was consequently locked in. Better techniques are needed to address uneven sampling effort when assessing biodiversity, as highlighted previously. However, no technique can overcome complete lack of data, and for data-poor offshore regions, any clump of survey records is likely to result in that area being assessed as having a higher diversity than other areas. It is important to bear these issues in mind when interpreting the outcome of any biodiversity assessment, or of running a software tool such as Marxan.

Scenarios 4b and 4c locked in the same high biodiversity areas, but the incorporation of naturalness resulted in a significant shift in the areas of high irreplaceability values, and in the areas selected in the "best solution", away from areas in the lowest naturalness categories around the western/central Irish Sea, towards more natural areas further south. This is most pronounced for scenario 4b (figures 4.4.4b(i) and 4.4.4b(ii)), where the most unnatural categories were locked out. Because this resulted in the same shortfall in meeting targets as scenario 3a, scenario 4c was run, without any areas locked out.

4.4.2(iv) Scenarios 5 and 6: Locking in existing protected areas

In scenario 5, existing cSACs in the Irish Sea were locked into Marxan. This was done without incorporating naturalness (scenario 5a), and subsequently including naturalness (scenarios 5b and 5c). As in earlier scenarios, the incorporation of naturalness resulted in the areas selected shifting towards more natural areas (figures 4.4.5a(i) to 4.4.5c(ii)). Locking in cSACs in scenario 5 resulted in Marxan selecting a slightly greater total amount of area to meet all targets, depending upon other factors in the variations of the scenario. This is a result of the cSACs containing areas which are redundant in terms of meeting the targets which we set Marxan in this trial, at the same time as failing to meet other targets at all (see table 4.4.3).

Candidate SACs are concentrated inshore, particularly off the English and Welsh coasts, and hence they contain high amounts of inshore features. Table 4.4.3 below shows the percentage of the target area and total area of each marine landscape contained in cSACs. The figures indicate some redundancy and lack of complementarity in cSACs in terms of targets set for inshore marine landscapes this study. For example, over 450% of the target for the coastal sediment landscape type is captured within cSACs, while some offshore marine landscapes (e.g. deep-water channel, Irish Sea mounds) are not represented at all. This meant that the selected sets of areas resulting from running Marxan had to have a large overall area: In order to meet targets for offshore landscapes, offshore areas had to be added to the locked in areas in the inshore region, which were largely redundant for meeting targets.

The results of this trial are in no way to be interpreted as a criticism of the location and boundaries of existing cSACs. These areas were selected under a mechanism – the EC Habitats Directive – with conservation goals that do not correspond with the targets set in the process tested here. The Habitats Directive lists specific features for protection on its annexes, but does not practically address the issue of "representing the full range of known biodiversity". The apparent redundancy of cSAC areas may also partly reflect the fact that some of these areas were selected not for benthic features, but for pelagic species e.g. the Bottlenose Dolphin *Tursiops truncatus* in Cardigan Bay. In terms of the cSACs not meeting targets for offshore marine landscapes, it should also be pointed out that no offshore cSACs exist to date, though this is likely to change in the near future.

Table 4.4.3: Total area figures for each of the marine landscapes types in the Irish Sea, with targets, and the percentage of target and total areas contained in existing cSACs.

Marine Landscape	Total area (ha)	Target (% total area)	% of target met in cSACs	% total area contained in cSACs
Deep-water channel	23384	20	0	0
Gas structures	5772	30	0	0
Irish Sea mounds	7418	40	0	0
Sand/Gravel banks	54041	20	0	0
Deep-water mud basins	495322	20	0	0
Shallow-water mud basins	91325	20	33	7
Sediment wave/megaripple	662994	10	57	6
High bed-stress coarse sed.	1176013	10	80	8
Sealoch	59616	35	95	33
Aphotic Reefs	123679	20	108	22
Low bed-stress coarse sed.	1511257	10	144	14
Fine sediment plains	1291760	10	146	15
Photic Reefs	16039	40	149	60
Estuary	92564	35	204	72
Sound	6868	30	241	72
Saline Lagoon	790	40	251	100
Ria	4921	30	333	100
Coastal Sediment	249579	10	474	47

In our final scenario (scenario 6) we set targets for Habitats Directive Annex I habitat in the offshore area, and locked in all planning units that overlapped with SPAs. This did not result in a great deal more area in the solution than only locking in high biodiversity areas, important estuaries and cSACs (scenario 5). SPAs only covered a small amount of additional area, and Annex I habitat targets can probably be met in the same areas as the marine landscape targets for sand/gravel banks, photic reefs and aphotic reefs. The maps resulting from scenario 6a (no inclusion of naturalness) are shown in figures 4.4.6a(i) and 4.4.6a(ii).

Scenario 6b incorporated naturalness scores, without locking any areas out (using the same method as in scenario 3b). The maps resulting from this scenario are shown in figures 4.4.6b(i) and 4.4.6b(ii). Locking in high biodiversity areas, important estuaries, cSACs and SPAs in scenario 6b resulted in about 50% more area than the comparable scenario that had no areas locked in (scenario 3b). In an attempt to reduce the overall area, scenario 6c was run with lower targets for marine landscapes. This only resulted in a small reduction in overall area of the “best solution”, probably due to the high level of redundancy of the locked in areas for meeting the targets. The reduced area was mainly offshore, which was partly due to the coastal location of the locked in cSACs, but also because the more common marine landscapes with significantly lowered targets are mainly in offshore areas.

Scenario 6 represents the “best answer” scenario for the Irish Sea from the Marxan trial, given available data, time constraints, and in keeping with all pre-established important areas. However, further input, particularly expert knowledge, is needed to properly identify a set of nationally important marine areas. This would be particularly important at the time of deciding on the level of targets to set for conservation features, which methods to use for assessing biodiversity, and what datasets to include.

4.4.2(v) Area required to meet targets in different scenarios

Figure 4.4.7 shows the area of the “best solution” for each scenario. The same area figures are shown as a percentage of the area of the Irish Sea in table 4.4.1. Some of the scenarios lead to a very large amount of area being included and are not likely to be acceptable. The amount of area in the best solution generally increased from scenario 1 to 6, as more constraints were added, though there was some variability in this trend.

The “best solution” resulting from running Marxan is not necessarily the solution with the lowest area, even if no other factors have been used to alter the cost of planning units. The “best solution” is the solution with the lowest objective function value. The objective function (explained in section 4.1.3) takes into account factors other than area - in particular, overall boundary length of the selected set of areas. In the pseudo-equation for the objective function:

$$\sum \text{cost} + \text{BLM} \sum \text{boundary} + \sum \text{penalty},$$

the three main components work relative to each other. If no BLM is set, and the only factor affecting cost of planning units is their area, then the “best solution” will be that which meets the targets with minimum area (such as in scenario 1). When a BLM is added (such as in scenario 2), Marxan seeks to minimise the sum of the area and the total boundary length. By increasing the area, it may be able to reduce boundary length such that the overall objective function is lowered - the “best solution” is no longer the solution which meets all targets with minimum area.

Adding further constraints by locking areas in will also tend to increase the overall area of the “best solution”, as the locked in areas may be redundant for Marxan to meet its targets. This was found to be the case when locking in cSACs in scenarios 5 and 6.

Factoring in naturalness into the cost of planning units may decrease the overall area of the “best solution”, leading to some variation in the trend towards bigger reserves with added constraints in figure 4.4.7. In all scenarios without naturalness, the cost is simply the combined area of all planning units selected. When naturalness is included, the cost is the area multiplied by the naturalness factor for each planning unit (which is between 1 and 6). Hence the total cost component is larger relative to the boundary component, so the “best solution” may be a smaller reserve with a relatively greater boundary length. It is also worth noting that because in scenarios 4b and 5b, 13 targets were precluded from being met, Marxan selected a smaller reserve.

Setting a baseline BLM for comparing multiple scenarios was desirable in this study. A BLM of 5 was used, because of the way in which naturalness affected the data in this study. Figure 4.3.2 indicated that a BLM of 1 or 2 would be optimal. The figure was generated without factoring naturalness into the cost, however, and a higher baseline BLM of 5 was used. However, scenarios 5a and 6a, which do not incorporate naturalness, were inefficient with a BLM of 5, selecting area that was not contributing to the target, but was decreasing boundary length. Both scenarios were re-run with a BLM of 2, and the results are shown in figure 4.4.7. Note that the maps shown in section 4.4.1 show only the results of using a BLM of 2 for scenarios 5a and 6a. In future applications of Marxan, particularly in final runs that will be used to aid in identifying important areas, it may be helpful to assess BLM levels for individual scenarios, with the aid of figures equivalent to figure 4.3.2.

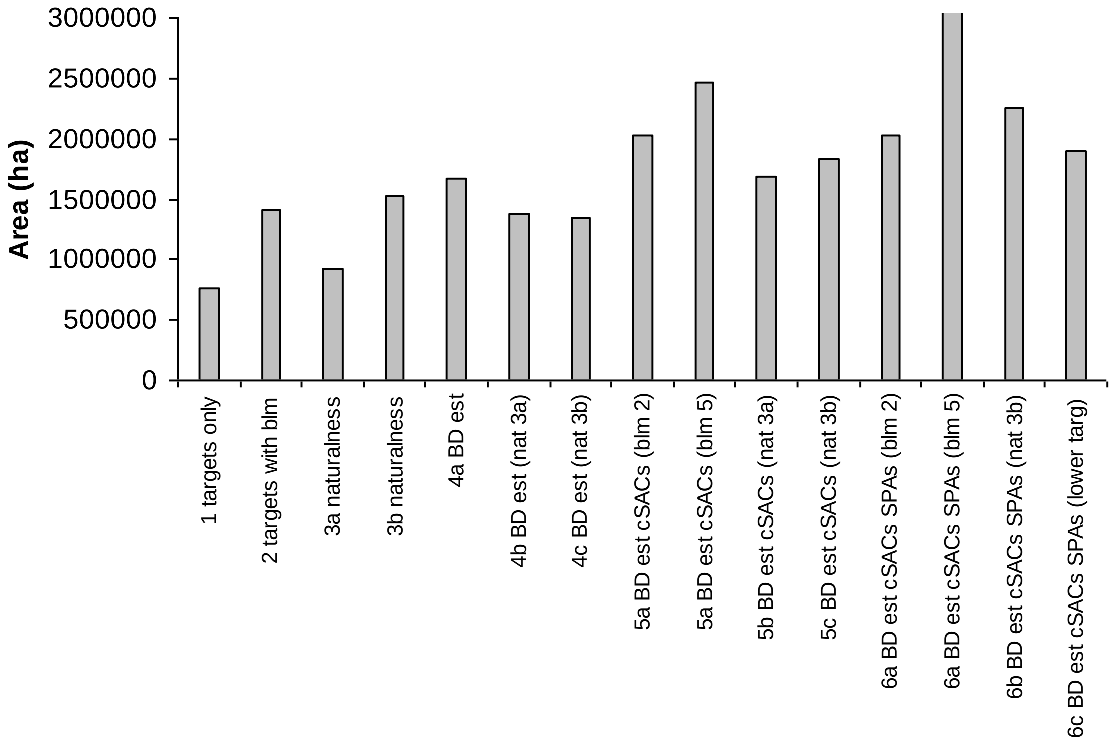

Figure 4.4.7: Area in the 'best solution' for each of the scenarios.

Table 4.4.1: Area required to meet targets for each scenario, as a percentage of the total area of the Irish Sea.

Scenario	Description	Area required as % of Irish Sea
1	targets only	13
2	targets with blm	24
3a	naturalness	16
3b	naturalness	26
4a	BD est	28
4b	BD est (nat 3a)	23
4c	BD est (nat 3b)	23
5a	BD est cSACs (blm 2)	34
5a	BD est cSACs (blm 5)	42
5b	BD est cSACs (nat 3a)	29
5c	BD est cSACs (nat 3b)	31
6a	BD est cSACs SPAs (blm 2)	35
6a	BD est cSACs SPAs (blm 5)	64
6b	BD est cSACs SPAs (nat 3b)	38
6c	BD est cSACs SPAs (lower targ)	32

4.4.3 Aspects not included in the Marxan trial

With the exception of locking in SPAs and some of the cSACs, only benthic (seafloor) data were used in the Marxan runs we conducted. We did not include any targets or considerations for pelagic (water-column) species and habitat types. This includes identifying areas for nationally important pelagic marine features and high biodiversity areas for pelagic features. We also did not incorporate human activities that might specifically affect the naturalness of pelagic areas, nor did we set targets for critical areas for mobile species. A set of "pelagic scenarios" could be used to help identify areas of importance within the pelagic realm, using the classification of water-column marine landscapes (Golding *et al.*, 2004) in the same way that the marine landscapes were used here. A separate set of scenarios could also be run for features on the water surface (seabirds). It would be possible to combine datasets and targets for all three realms in a single process, though that may not be the best approach in view of the fact that management strategies may differ between them. One of the advantages of using Marxan is that it would allow the exploration of all of these options.

Of the six criteria for the identification of nationally important marine areas, two were not assessed at all in the Marxan trial. These were criterion 1 (typicalness), and criterion 5 (critical area for a mobile species). Section 4.2 outlines a number of ways in which both of these criteria could be incorporated into Marxan. Typicalness was not included in the trial because of a lack of information. The reason for not including criterion 5 (critical area) was that this criterion was thought to apply more to pelagic species than to benthic features. In the case of nursery grounds and feeding habitats, however, it may be the benthic environment which is of critical importance to the mobile species – targets for such areas, where known, could easily be included in the scenarios described in this report.

4.4.4 General issues: data availability and distribution

This study highlighted some general problems with lack of data and uneven distribution in available data, with coastal areas much more extensively sampled than areas offshore. This affected the outcome of Marxan: for example, coastal areas were more frequently selected, particularly in scenarios where high biodiversity areas and cSACs were locked in. Also, planning units that contained species records in offshore marine landscape types were highly irreplaceable, because few other offshore planning units contained species records.

A range of human use data sets have been collated for the Irish Sea (Lumb *et al.*, 2004), including data on fisheries, aquaculture, offshore windfarms, shipping and coastal structures. However, many of them are either incomplete (i.e. there is no data available over parts of the Irish Sea), or they are extremely hard to interpret because of a lack of metadata, and we were unable to incorporate multiple human activities in the naturalness ratings used for this trial. Even the trawling data which we used had significant gaps, particularly off the coast of Ireland, and a lack of metadata made it difficult to interpret at times.

The data issues highlighted here also caused problems in the direct application of the criteria at the marine landscape level (section 3), and would probably affect any methodology used. More complete datasets would greatly assist in making the best conservation decisions. Effort therefore needs to focus on collating existing data into an available and useable GIS resource. In addition, better methods for reducing bias caused by sampling effort should be explored, e.g. in assessing biodiversity. However, in the absence of better data, these issues should not stop best use being made of existing knowledge.

4.5 Theoretical process for selecting an MPA network for the Irish Sea

The final scenario (6) in this study provides a useful indication of the amount and location of areas that might be useful for a marine protected area (MPA) network for the Irish Sea, taking into consideration existing protected areas. However, some additional input would be required to develop such a network. The general framework for applying Marxan is described in the preceding section. Specifically for the Irish Sea, we make the following recommendations:

<u>1. Evaluate and update targets:</u>
More input is required from experts to ensure appropriate targets are set. Suggestions have been made, for example, to look at setting equal baseline area targets for all marine landscapes (e.g. 5000 ha of each), which would result in higher protection levels as rarity of the marine landscapes increased. It may also be valuable to set an overall area target for the Irish Sea, which would reflect the area of the total MPA network that would be needed to include all the features in an ecologically coherent spatial design. This might be 20-40% of the Irish Sea as per Roberts *et al.* (2003). All further targets, including marine landscape area based targets, could then be set within the constraints of this total area.

<u>2. Include pelagic information</u>
As discussed in section 4.4.3, our scenarios are based on benthic data. The process of applying Marxan to the pelagic dataset would be largely similar, but with different features and targets. It could be undertaken separately or combined with benthos, or both options could be explored. Planning units may need to be reviewed with consideration of pelagic data. Water-column marine landscapes could be used as surrogate assessment units for the pelagic dataset, such as marine landscapes were for the benthos. For birds, a separate assessment equivalent to the benthic and pelagic may be advisable, as the SPAs only address some aspects of the criteria.

<u>3. Evaluate cost of planning units (naturalness and/or economic, social)</u>
More complete human use data would be beneficial as naturalness will be affected by multiple activities. More information on the location and intensity of human activities would allow planners to select planning units in areas that are least used where possible. This is beneficial in terms of choosing less damaged areas to meet conservation goals and also for ensuring that an MPA will have the least possible effect on human activities.

In addition, further expert knowledge is required to determine the level of effect that various human activities are likely to have on the naturalness of areas, and on biodiversity features (e.g. marine landscapes). We set out a framework for combining the intensity of different activities with the vulnerability of the features in each planning unit, to determine an estimated naturalness rating.

Experts should also be consulted to determine areas that might need to be locked out of the selection process, and what the most appropriate way of scaling the cost of planning units may be.

4. The selection process

The actual selection of sites for an MPA should involve interactions between experts, planners and stakeholders to ensure appropriate decisions are made. Alternative outputs and irreplaceability values from Marxan could be used to aid in this process.

Existing protected areas should form part of a marine protected area network (MPA) for the Irish Sea. A significant amount of area is already designated as candidate SACs, and more areas offshore are likely to be given this status in the future. Some areas in the Irish Sea intersect with SPAs and should also be included. Some areas would need to be added to the existing suite of protected areas to ensure the full range of biodiversity is represented in an MPA series.

It might be preferable to implement an MPA network in stages, such as initially protecting the best 5% of the Irish Sea, and then the next 5% when possible. This can be done with consideration of targets and the overall area that the MPA network is expected to be.

5. Setting protection levels for marine areas
A MPA network can contain sites with varying levels of protection, allowing appropriate activities to continue where possible as part of a sustainable development framework. Some input would be required to establish appropriate levels and type of protection on the entire network, including cSAC areas. The levels of protection relate to the biodiversity features that an area is identified as being important for.

At this stage many cSACs are protected for specific conservation purposes, such as for a single species. Part of the process of implementing a set of marine protected areas would be to establish why each additional area has been selected. This cannot be done within the Marxan program, but would be a simple process of taking the planning units selected in each region and listing the amount of each feature that is contained in the area. Appropriate management strategies can then be implemented.

4.6 Conclusions drawn from the Marxan trial

4.6.1 Limitations of Marxan

The results produced by Marxan are only a product of the data it is given. Marxan has no ability to extrapolate, interpolate, or fill gaps in datasets. It could use modelled data, but the modelling itself would have to be undertaken prior to running Marxan. It can also use surrogates for biodiversity, such as marine landscapes used in the present study, but it cannot develop such surrogates automatically from other forms of input data.

There are some aspects of the criteria that cannot be directly assessed by Marxan, e.g. the programme cannot measure biodiversity or typicalness of areas. It means that some degree of pre-processing is often necessary prior to running Marxan. This is likely to be necessary in applying most techniques to large areas, and ultimately gives solutions which better take account of important issues in identifying conservation areas.

Marxan is not a programme that the user can have up and running within minutes. Running even simple datasets requires a fair understanding of the process. A minimum of three input files is required. These have to be text files in a very specific format, with a simple structure, but potentially containing a large amount of complex information. Generating these text files from information in a GIS can be time-consuming and tedious. However, there are advantages to the process: it helps to ensure that Marxan is used appropriately, and that results are not misinterpreted. The results of running Marxan are a product of the input data, and the questions asked by the user. Generating the input text files forces the user to thoroughly assess existing datasets, their limitations, and what questions the data can sensibly be used to answer. A thorough knowledge of the input datasets will also be of great benefit when interpreting the outcome of running the software. It may prevent conservation decisions being based on results that are an artefact of low data quality, uneven data distribution, or the wrong question being asked.

Most importantly, the solutions produced by Marxan should only be used as an aid to identifying important areas – the software should not be allowed to dictate conservation decisions. Each “best solution” is only one example of many possible options, and an irreplaceability map simply gives in indication of the flexibility associated with these options. Expert judgment and best scientific knowledge can and should always be used to interpret (or over-ride) any part of Marxan the output. There may well be more information available than can be processed within Marxan, especially where this information consists of expert knowledge. The same is likely to be the case with any systematic approach to identifying important areas, and should not be a deterrent from using a systematic approach.

4.6.2 Advantages of Marxan

Marxan provides a systematic approach to conservation planning. It has been used successfully in many areas throughout the world for identifying areas of biodiversity importance and conservation priority (e.g. Ardron *et al.*, 2002; Stewart *et al.*, 2003), so has been rigorously tested over many datasets. Using a target-based, reserve design approach such as Marxan allows the user to produce many alternative, efficient solutions to meeting conservation targets. It can highlight which planning units are most important for meeting these targets (high irreplaceability values), and hence which might be most important for immediate action.

Marxan can incorporate many of the characteristics used in the criteria, but does not require as extensive information as the direct application of the criteria in order to produce usable results. Given the availability of a layer of “surrogate data” (such as the marine landscape classification), it would therefore prove a useful tool in areas with relatively poor data coverage. On the other hand, where data are available, Marxan is capable of processing a broad range of different types of data. The collation and preparation of data sets may be a time-consuming process, but the use of Marxan could potentially be a driver for organising datasets into useable GIS formats, which in turn may benefit a range of other work.

The use of Marxan ensures complementarity between selected areas, in that planning units are selected to complement the features already represented in selected planning units. It can also incorporate any number of levels of ecological scale simultaneously, from species to broad surrogates (such as marine landscapes). This ensures that the full range of known biodiversity is represented to the required amount, even over very large datasets.

Marxan has the capacity to incorporate all available data, some expert judgement, most aspects of the criteria, and existing protected areas into a single process. This is consistent with an integrated management approach. Human use data, for example may serve to scale cost relative to naturalness of areas, as was done in this trial. As well as best serving the needs of nature conservation, this may ensure minimum economic and social conflict and costs. Areas with intensive fishing activity are likely to be of economic importance – making these areas “expensive” for Marxan to select means that they will only be included in the solution if nature conservation goals cannot be met in any other way.

Marxan is flexible enough to allow the user to take account of best scientific or expert knowledge. Where areas are known to be either highly desirable or unsuitable, they can be either forced in or out of the solution. Locking in existing protected areas, or areas thought to be highly desirable, will highlight conservation “gaps” where features are not adequately represented within these areas. It will also highlight redundancy in the existing areas in terms of meeting the targets set within the programme.

Finally, once the input datasets are available and formatted, targets can be adjusted and various scenarios can be run with relative ease. This means that the programme can be used to explore various conservation goals and management options (e.g. including or excluding existing protected areas, adjusting targets), enabling the user to optimise the approach in an iterative process.

A robust, effective and defensible methodology is required to aid in the identification of nationally important areas. Overall, Marxan was found to be a useful tool to select sets of areas to meet a variety of user-defined conservation targets, capable of addressing most aspects of the criteria and thereby aiding the selection of nationally important areas. It lends itself to being part of a broader framework, in terms of locking in pre-established important areas. Where enough information exists, scientific judgement and expert knowledge can be used to identify nationally important marine areas, such as was demonstrated with estuaries in section 3. Marxan can then be used as a systematic approach to selecting sites that represent the full range of biodiversity in lesser known areas, whilst maintaining the characteristics and qualities upon which the criteria are based.

5 Part C Overall Conclusions and Recommendations

5.1 Suggested amendments to the criteria

It is considered that the wording of the criteria can largely remain as it was given in Connor *et al.* (2002), with additional text providing guidance for their application (section 5.2). The only criterion with substantial changing to the wording is the critical area criterion (5). The recommended wording of the criteria is as follows:

1. Typicalness:	The area contains examples of marine landscapes, habitats and ecological processes or other natural characteristics that are typical of their type in their natural state.
2. Naturalness:	The area has a high degree of naturalness, resulting from the lack of human-induced disturbance or degradation; marine landscapes, habitats and populations of species are in a near-natural state. This is reflected in the structure and function of the features being in a near-natural state to help maintain full ecosystem functioning.
3. Size:	The area holds large examples of particular marine landscapes and habitats or extensive populations of highly mobile species. The greater the extent the more the integrity of the feature can be maintained and the higher the biodiversity it is likely to support.
4. Biological diversity:	The area has a naturally high variety of habitats or species (compared to other similar areas).
5. Critical area:	the area is critical for part of the life cycle (such as breeding, nursery grounds/ area for juveniles, feeding, migration, resting) of a mobile species. The assessment needs to evaluate the relative importance of the area for the species. An area for which a species has no alternative should receive a greater weighting than an area where a species has a range of alternatives for that aspect of its life cycle (e.g. is a given gravel bank the only one for a herring population to spawn on?). This will vary according to species and the part of the life cycle in question.
6. Area important for a nationally important marine feature:	Features that qualify as special features or which are declined or threatened should contribute to the identification of these areas. The assessment should consider whether such features are present in sufficient numbers (species), extent (habitat) or quality (habitats, marine landscapes) to contribute to the conservation of the feature.

5.2 Guidance for the application of the criteria

5.2.1 About the guidance

This section considers how to apply the criteria, how to prioritise between them and how to bring the criteria together. The guidance allows some level of flexibility, as there may be different levels of prioritisation depending on the areas or marine landscapes in question.

Unlike the process of applying the criteria for nationally important marine features (Lieberknecht *et al.*, 2004), the criteria for nationally important marine features should not be applied in a "knock-out" fashion – i.e. "anything that meets any of the criteria is classified as nationally important". Most UK marine areas are likely to meet at least one of the criteria, but labelling almost the entire sea a "nationally important marine area" would devalue the label to the point that it would have little meaning. The ecosystem approach recognises the importance of the sea as a whole, and a functioning integrated management approach should safeguard the sea as a whole. That does not mean that the whole sea needs to be labelled "nationally important". The process of identifying areas of national importance has to first identify all areas which qualify under any of the criteria, and then prioritise between those areas.

5.2.2. Generic guidance

5.2.2(i) Pre-requisites

Before the criteria can be applied effectively, a minimum amount of data gathering and broadscale classification of the UK sea area will be necessary. In particular, the following is needed:

- Agreed regional sea boundaries with regional seas covering the entire UK marine area.

- A marine landscape classification for the entire UK sea / each regional sea.

- GIS data on ecology and human use, covering each regional sea as comprehensively as possible (e.g. such as the data collated for the Irish Sea area during the Irish Sea Pilot). Lack of data should not stop areas being identified and conservation action being taken. However, the more usable data is available, the more confidence can be had in achieving conservation goals, and achieving them efficiently.

Once these pre-requisites are fulfilled, the identification of nationally important marine areas should be carried out within each regional sea in turn, to ensure representation of all biogeographical variants of marine landscape types across the UK. In doing this, a whole UK perspective needs to be maintained, to ensure maximum complementarity and minimum redundancy in the national set of areas as a whole.

5.2.2(ii) Guidance for areas with good data coverage

For some areas of the UK sea, particularly inshore areas, there can be good data coverage, and/or a high level of knowledge (published written material, or individual expert knowledge).

For those marine landscape types which fall wholly into such regions (probably only the inshore physiographic types, such as estuaries and sealochs), it will often be possible to identify "best examples" by assessing the information available for each area and ranking each area against criteria 1-4. A method for carrying out such a ranking is described in the "estuaries comparison" (section 3). Criteria 5 and 6 should be assessed for the regional sea as a whole, not a the marine landscape scale.

A set of high-ranking areas, representative of the marine landscape and the typical biology encountered in it, should be identified. Some of the criteria may be given higher weighting than others, e.g. the most diverse and typical areas may be selected as a first step, using naturalness and size only secondarily in order to pick the "best examples". The relative weighting of the different criteria may vary between marine landscapes and regional seas.

5.2.2 (iii) Guidance for areas with sparse data coverage

In order to prioritise between areas, a minimum level of data coverage is required. In the absence of any information other than a marine landscape classification, there are few alternative ways of identifying areas other than finding an efficient way of representing a given percentage of each landscape within a regional sea. Targets for percentages to be represented within nationally important marine areas would require discussion and broad expert input.

Given some degree of data coverage, it is often possible to allocate ratings to areas against the criteria. Data-poor regions are often offshore areas, with marine landscape types covering large, continuous areas. As a first step there needs to be some subdivision of the regional sea into areas to compare and rank. This subdivision can be arbitrary (e.g. using a grid), or it can take into consideration existing boundaries e.g. those between marine landscape types.

Once the regional sea has been divided into areas for ranking, existing datasets can be used to allocate ratings to areas against the criteria. This can be done for the sea as a whole, or for each marine landscape in turn, depending on the type, amount and quality of data available. As an example, in the Marxan trial (section 4), naturalness scores were developed for areas based on a combination of trawling intensity data and vulnerability of different marine landscapes to trawling. Similarly, areas can be assessed for biodiversity and typicalness, if the relevant data are available.

Criteria 5 and 6, "critical area" and "area important for a nationally important marine feature" should usually be assessed at the regional sea level. The latter can be determined by mapping records of nationally important marine features (Lieberknecht *et al.*, 2004) and identifying areas with high densities or numbers of different features. For mobile species, enough information may be available to identify and map critical areas.

5.2.2(iv) Prioritising and choosing between areas to arrive at a national set of areas

Once areas have been allocated ratings against the criteria, or have been identified as qualifying under criteria 5 or 6, it will still be necessary to prioritise between them and identify a set of representative areas within each regional sea. A number of considerations may be taken into consideration, e.g.:

- Achieving full representation of the regional sea biodiversity
- Policy considerations: practical use / potential problems of choosing an area
- Minimising social, economic or area cost whilst achieving conservation goals
- Existing protected areas
- Potential or planned future human activity (e.g. offshore windfarms)
- quality of data on which any ratings are based

Once areas have been identified at the regional sea scale, a final step should be carried out to arrive at a national suite of areas. By approaching each regional sea in turn, a reflection of the full biogeographical variation within each marine landscape across the UK should be reflected within the full final suite of nationally important marine areas, as it should contain "best examples" from each regional sea. It may not be necessary or appropriate, however, to include areas representing every marine landscape type in every regional sea. In addition to assessments at regional sea level, the national set of areas needs some assessment to ensure full representation of biodiversity without unnecessarily including areas that are redundant in terms of meeting conservation goals.

5.2.2(v) Using Marxan to aid the process of identifying nationally important marine areas

To some extent, the process of arriving at a final set of nationally important marine areas will be iterative, and it may be useful to explore a number of scenarios (e.g. different ways of weighting criteria, excluding highly unnatural areas, including all existing protected areas, setting different targets for the percentage area of marine landscapes to be represented etc.). Such scenarios should be considered for the entire UK sea as well as at the regional sea scale.

The software tool Marxan has been trialled and was found to be very useful for assessing multiple scenarios, allowing the incorporation of as many spatial data sets as are available. It determines the irreplaceability of areas for achieving given targets, and as such is ideal for prioritising between areas. Marxan provides a defensible, systematic process for choosing between areas, whilst allowing best use to be made of existing knowledge. The use of Marxan will also help to ensure complementarily between identified areas, and that the full range of biodiversity is represented to their target levels in the full set of identified areas.

It is therefore recommended that Marxan should be used to aid the identification of nationally important marine areas, always bearing in mind the caveats highlighted in section 4 of this report. Where data availability is good, criteria can be applied directly as was done for the estuaries comparison in section 3. Marxan can then be used to complete the identification of additional areas to represent the full known range of biodiversity. It is important that there is broad expert input into some parts of the process, particularly in setting targets for conservation features. Final decisions should always take into consideration best available knowledge and expert judgement.

6 Colour plates

Figure 3.2.1. Map showing all estuaries within the Pilot area. Estuaries included in the comparison are listed in the table in section 4.9.1.

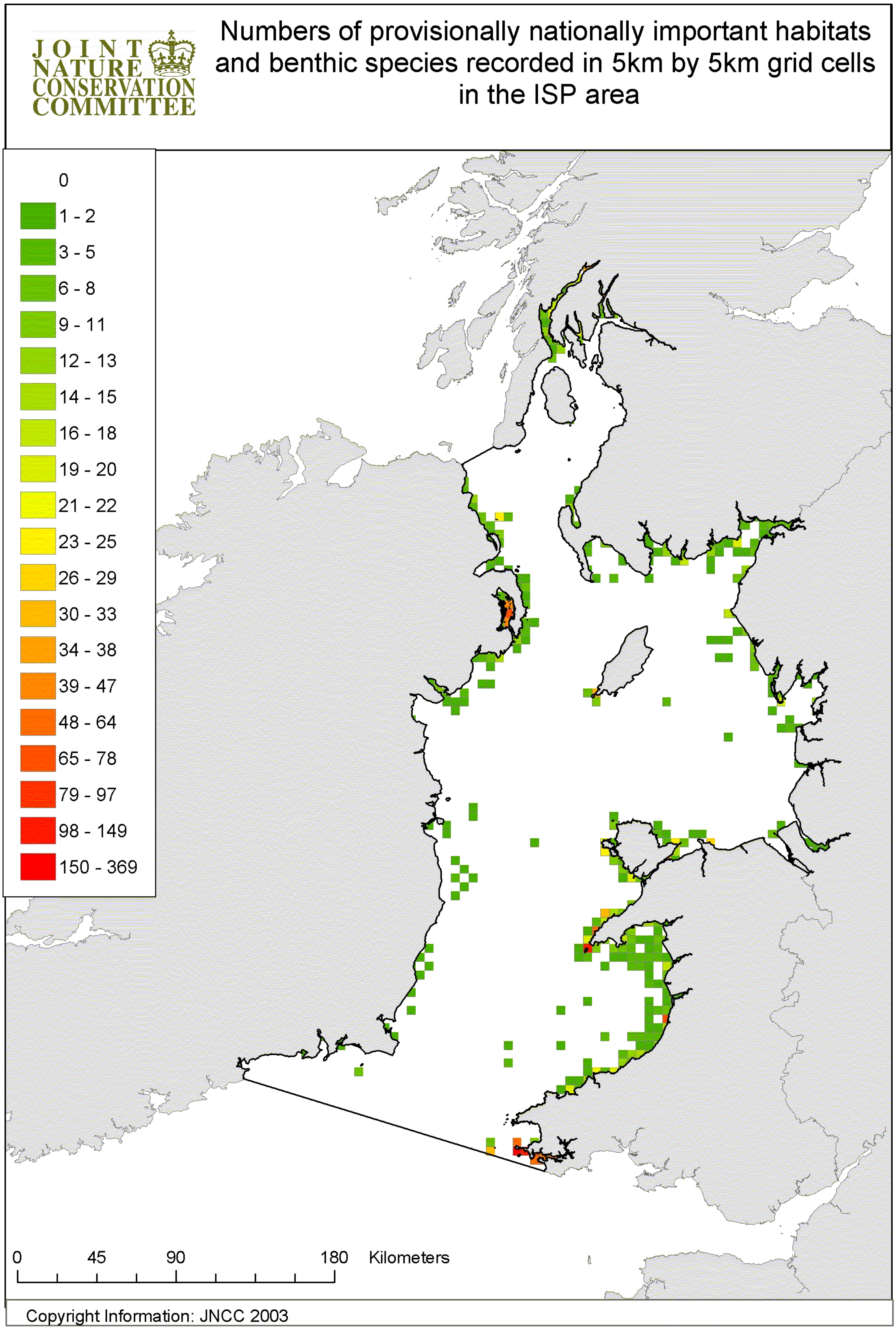

Figure 3.3.1. Numbers of features on the Irish Sea provisional list recorded in 5km by 5km grid cells in the Irish Sea, mapped from records on the JNCC marine database (data from various sources).

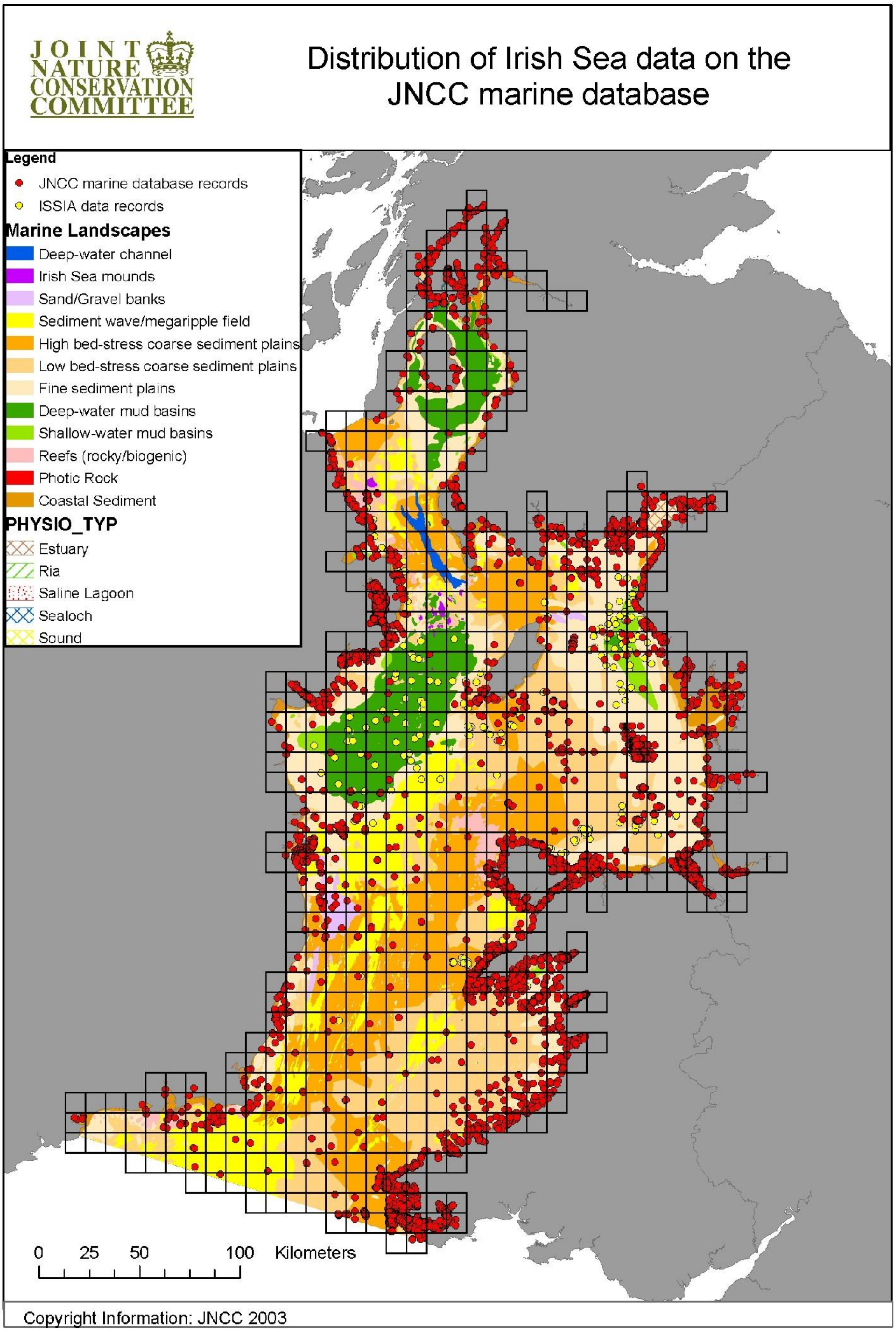

Figure 3.4.1. Map showing the distribution of JNCC marine database records (data from various sources) and ISSIA records (Allen and Rees, 1999) within the Pilot area, in relation to the 10 km x 10 km grid referred to in the text, and the marine landscape classification (Golding *et al.*, 2004).

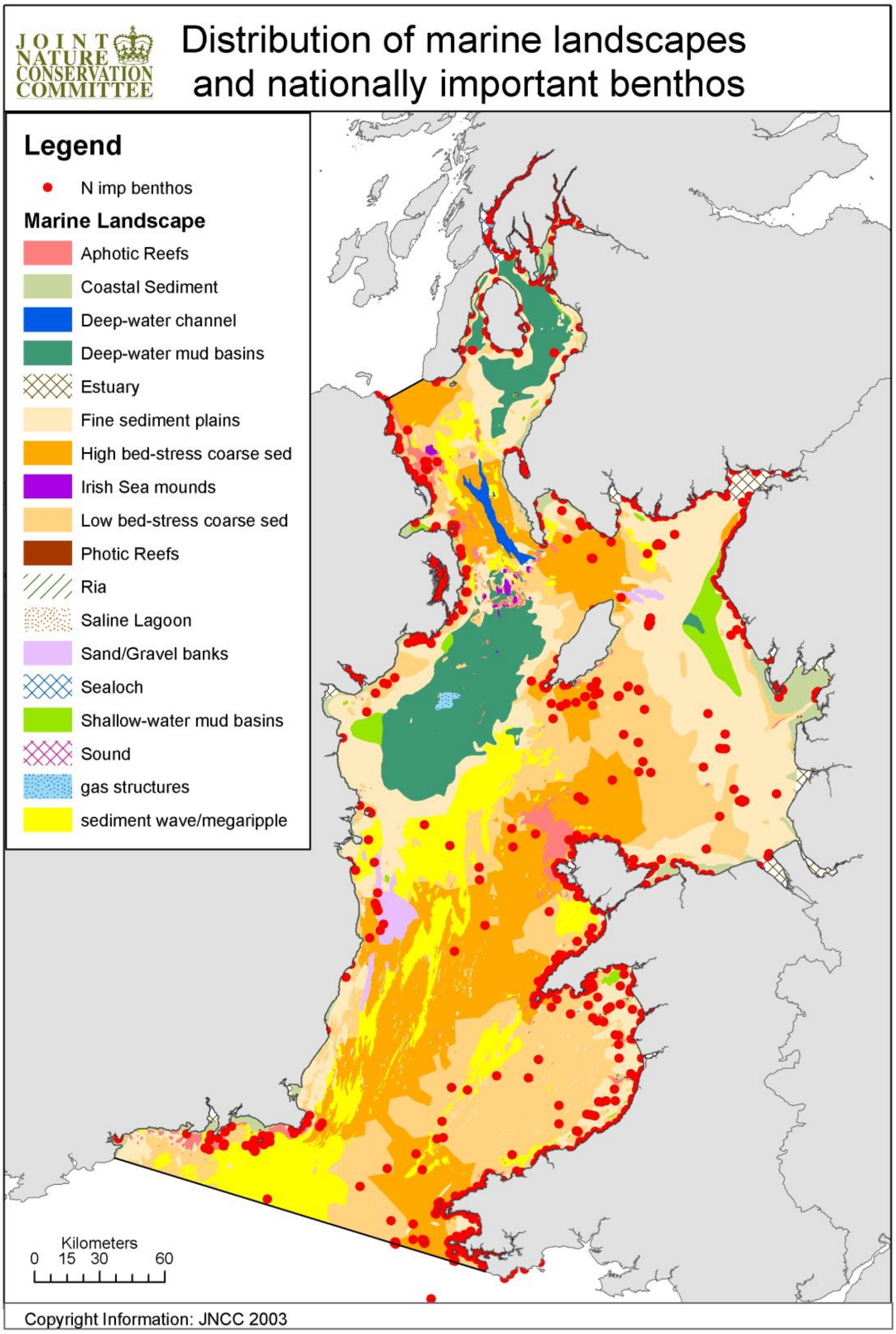

Figure 4.3.1. The Irish Sea dataset: distribution of marine landscapes (from Golding *et al.*, 2004) and records of nationally important benthic species and habitats (records from JNCC marine database, data from various sources).

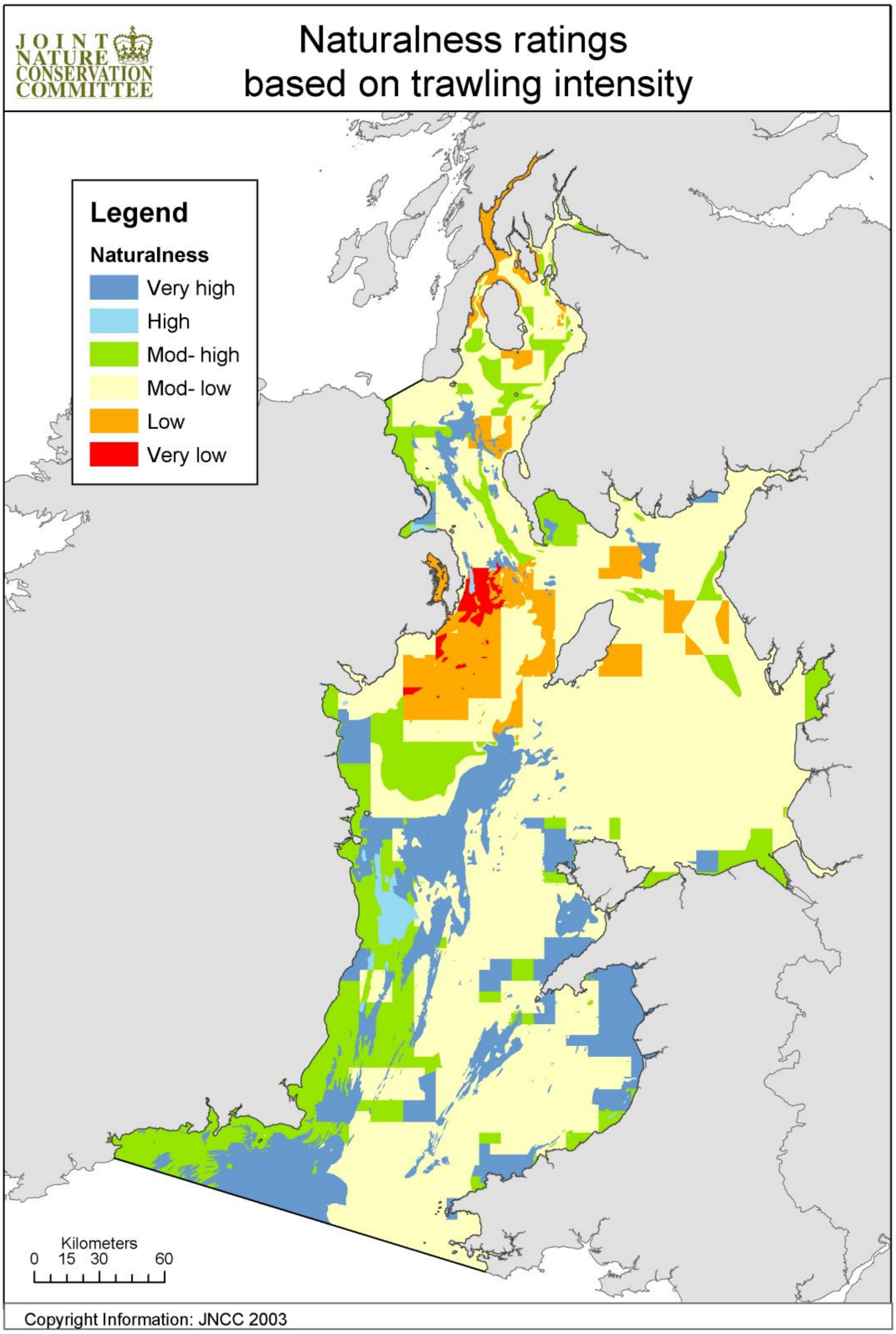

Figure 4.3.3 Naturalness ratings, based on a combination of trawling intensity figures (supplied by CEFAS and SFPA) and marine landscape vulnerability (from Golding *et al.*, 2004), used to modify costs of planning units and to lock areas out for scenario 3. The naturalness ratings relate to the figures in table 3.2 as follows: 6 = very low; 5 = low; 4 = moderate-low; 3 = moderate – high; 2 = high; 1 = very high.

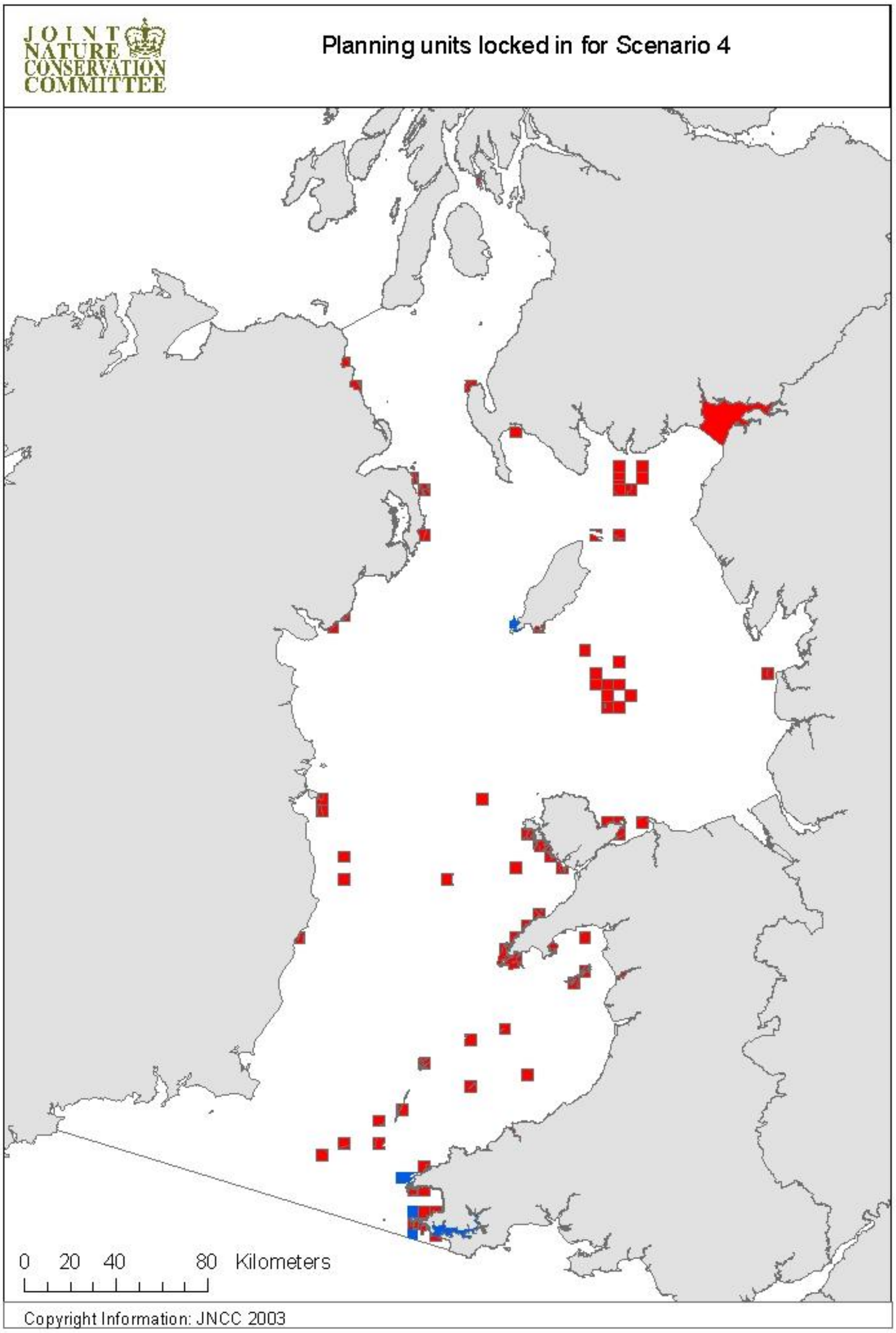

Figure 4.3.4 Planning units locked in for scenario 4. Red areas are high species diversity areas or estuaries identified as nationally important. Blue areas are those that contain records of more than eight species on the Irish Sea provisional list.

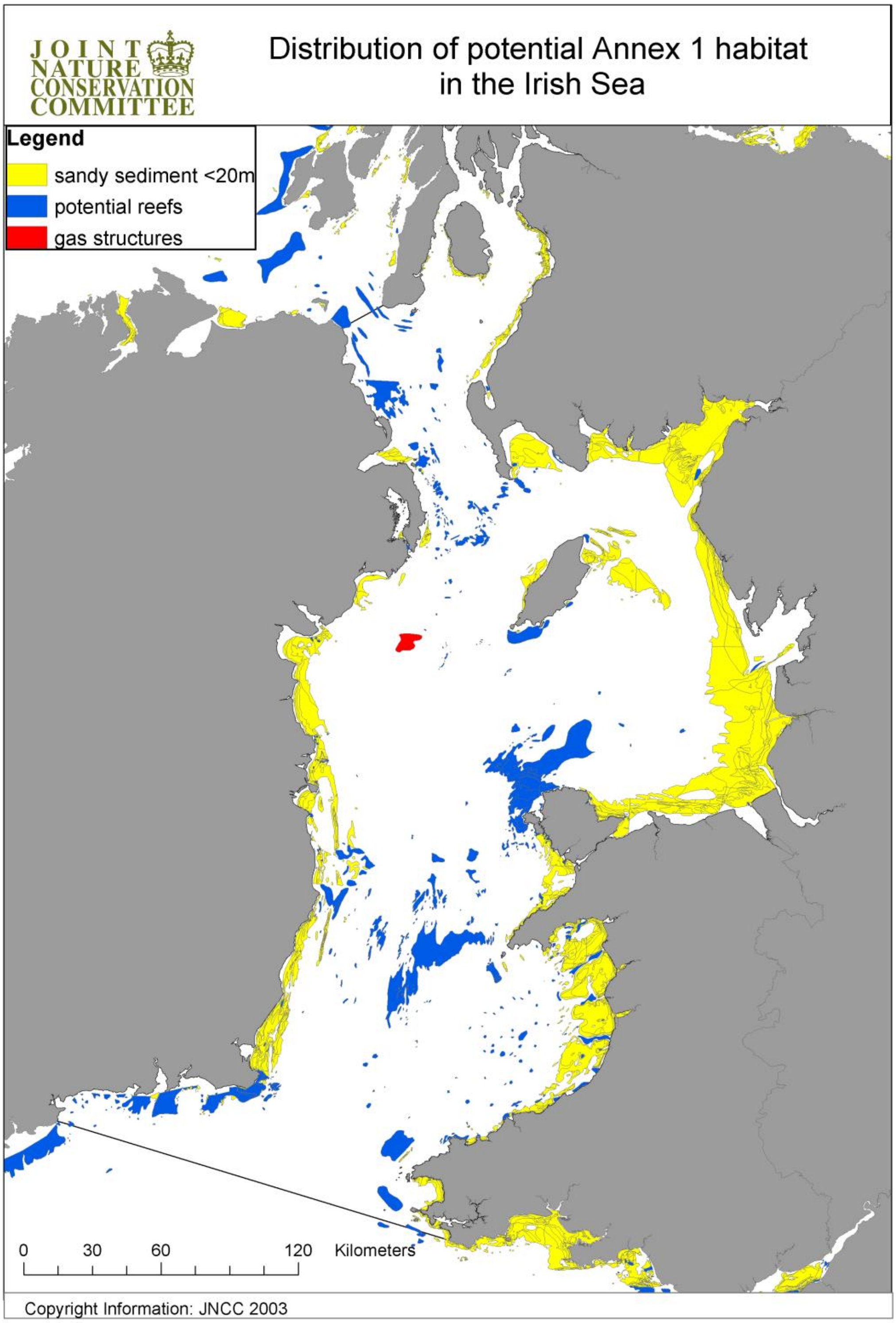

Figure 4.3.5 Areas of potential Annex I habitat in the Irish Sea. Sandy sediment layer derived from BGS 1:250,000 seabed sediment maps © NERC and SeaZone Offshore scale bathymetry © British Crown and Metoc plc 2003. Potential reef and gas structure habitat derived from BGS 1:250,000 seabed sediment maps © NERC (Licence No. 2002/85).

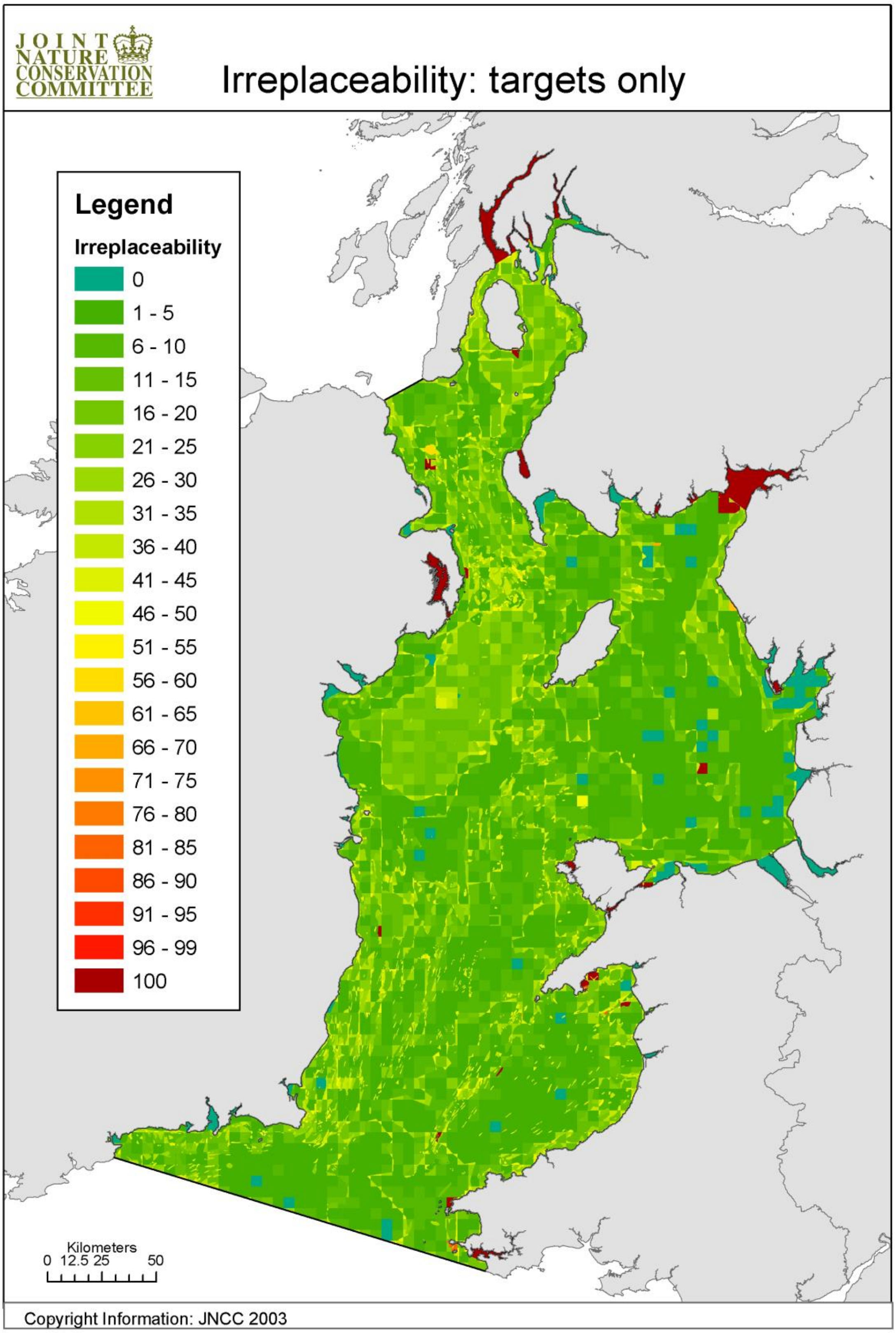

Figure 4.4.1(i). Scenario 1: The irreplaceability values of planning units for scenario 1 - targets only

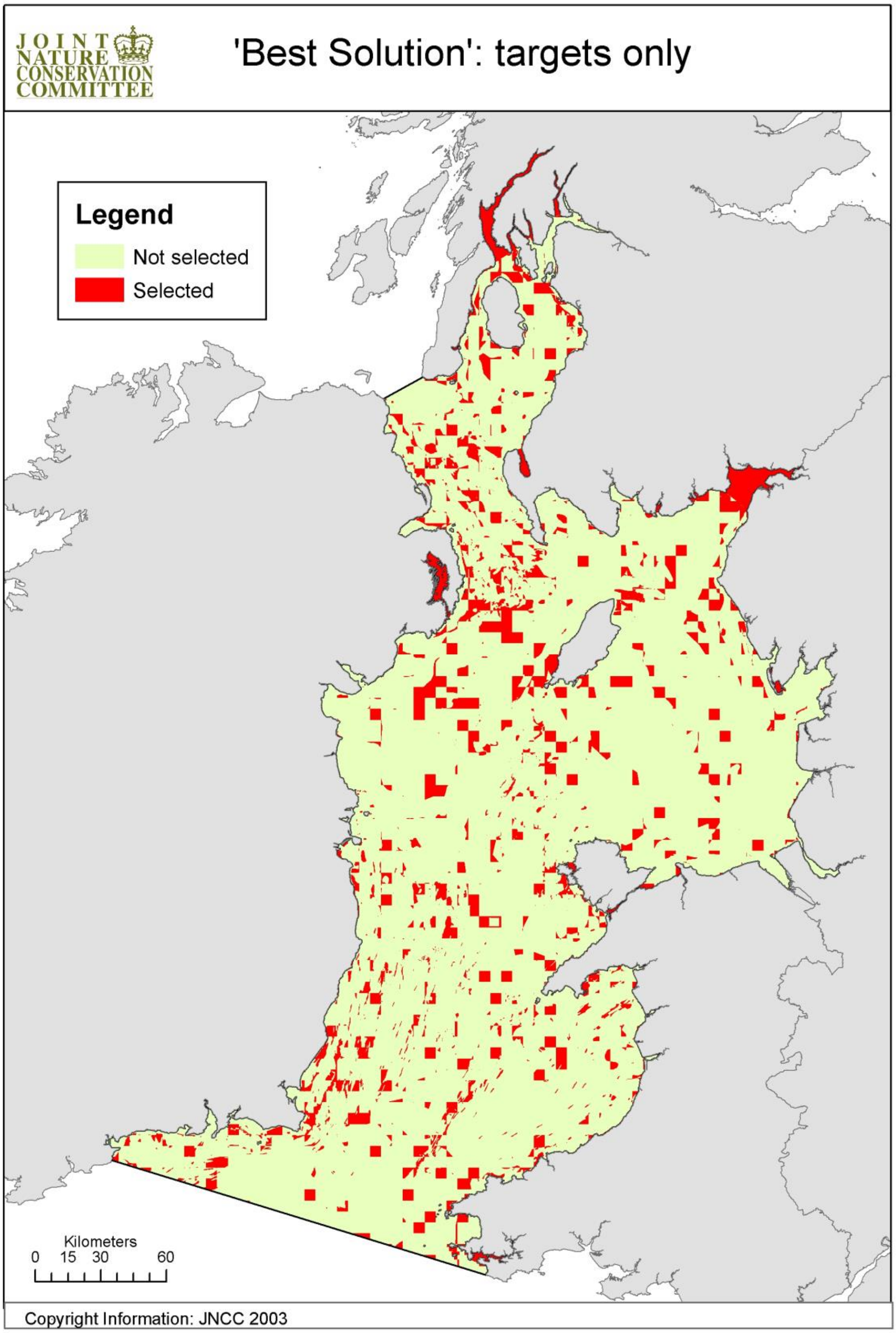

Figure 4.4.1(ii). Scenario 1: The “best solution” for scenario 1 - targets only

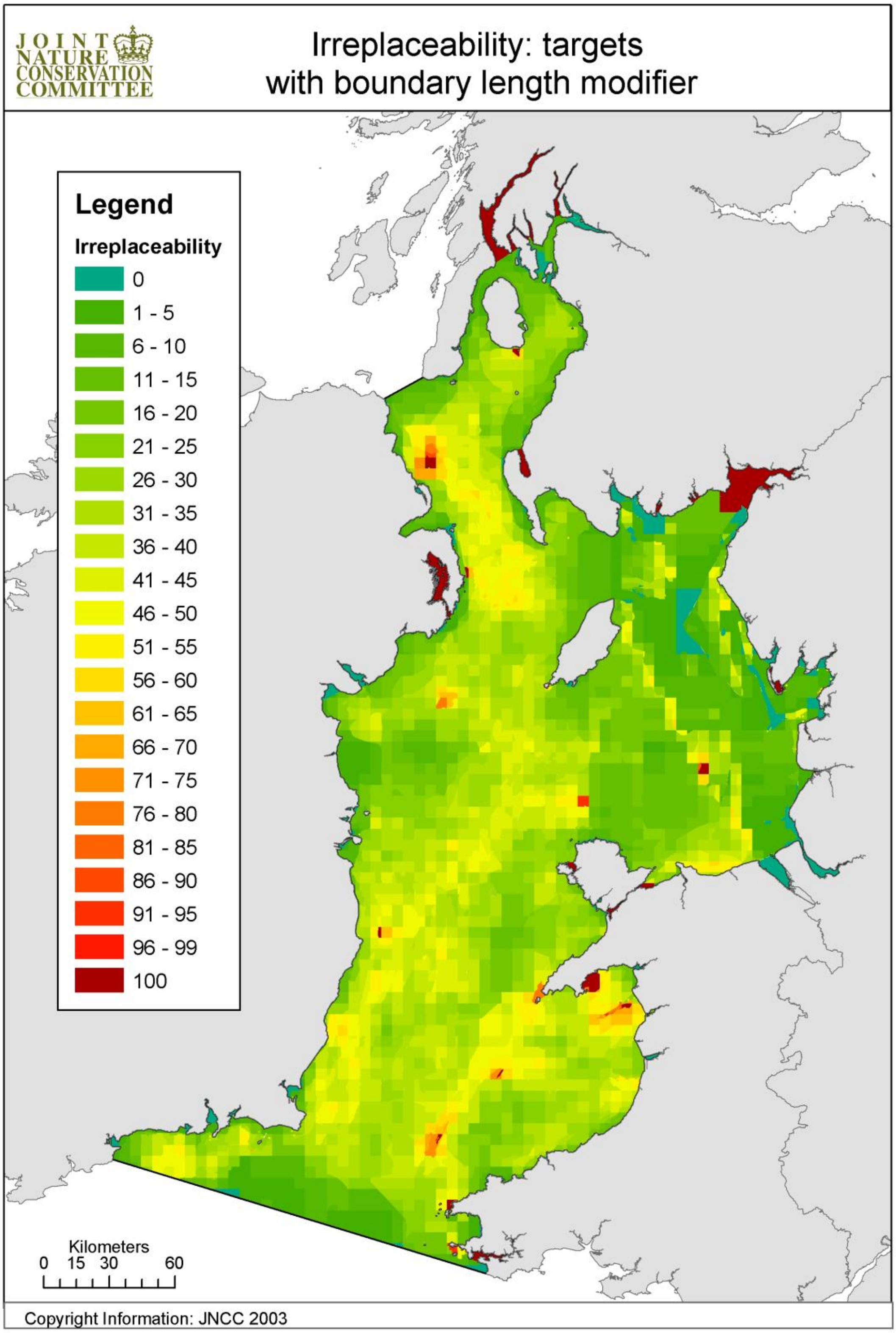

Figure 4.4.2(i). Scenario 2: The irreplaceability values of planning units for scenario 2 - targets with boundary length modifier of 5

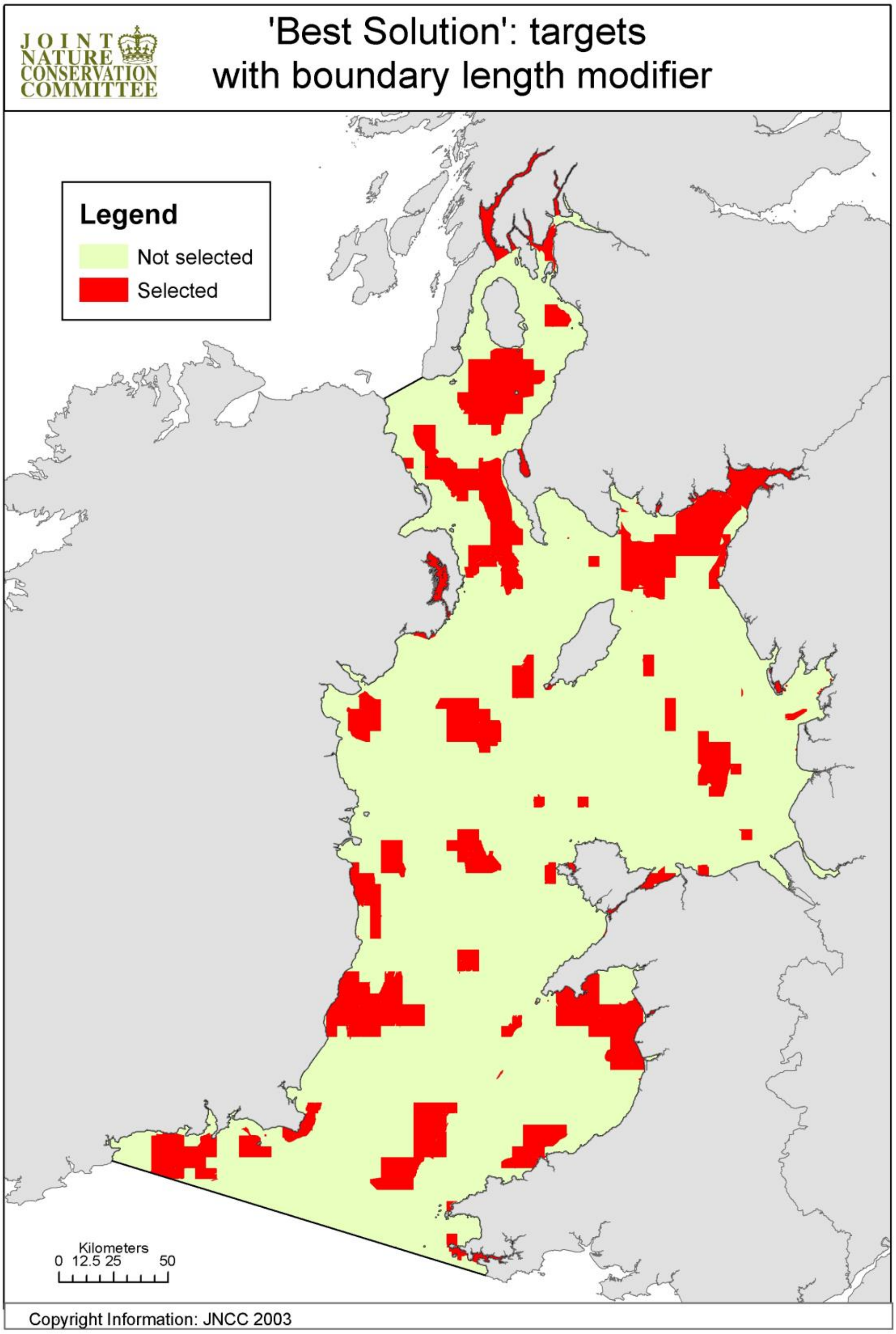

Figure 4.4.2(ii). Scenario 2: The "best solution" for scenario 2 - targets with boundary length modifier of 5

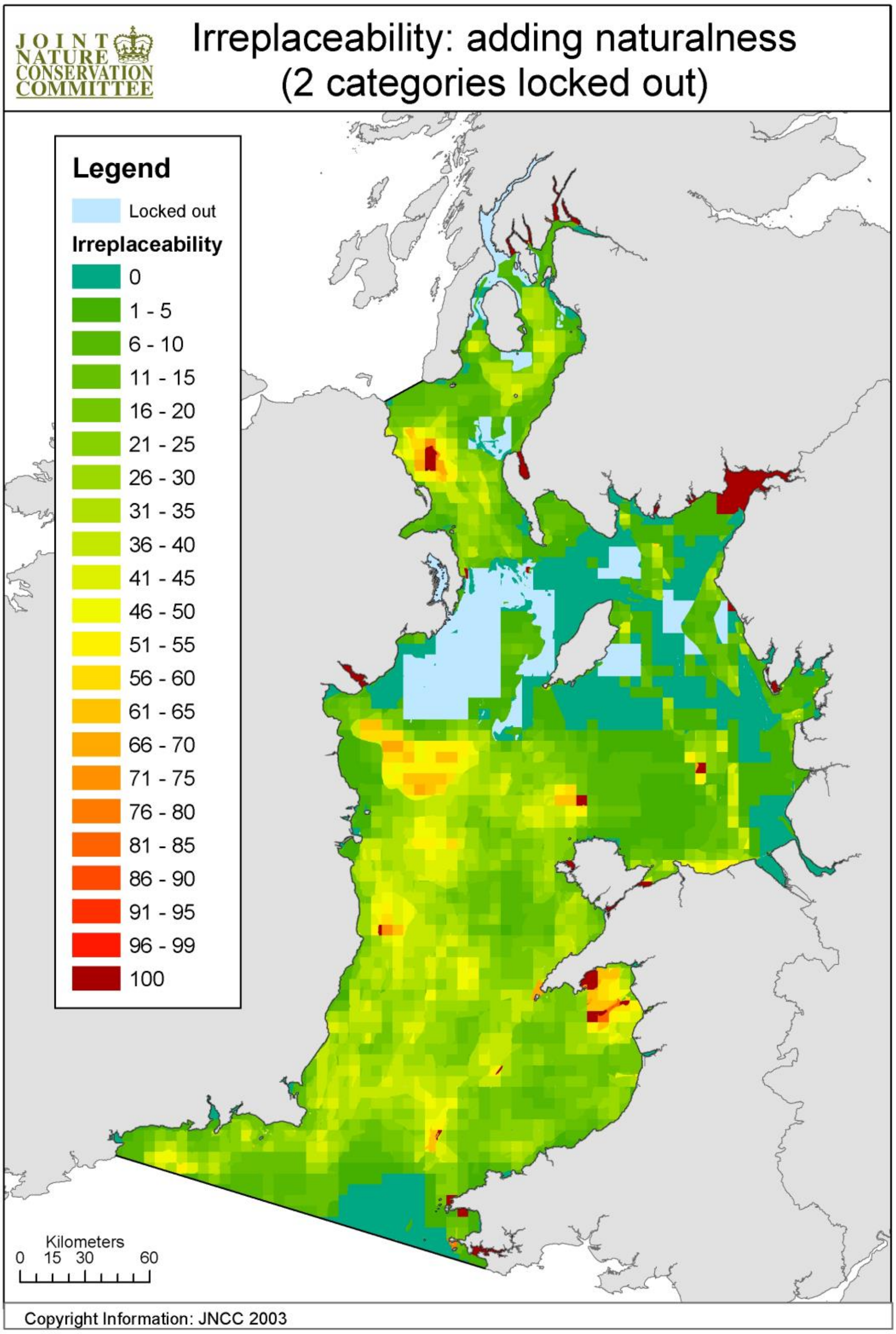

Figure 4. 4.3a(i). Scenario 3a: The irreplaceability values of planning units for scenario 3a - targets with boundary length modifier of 5 and naturalness (two most unnatural categories locked out)

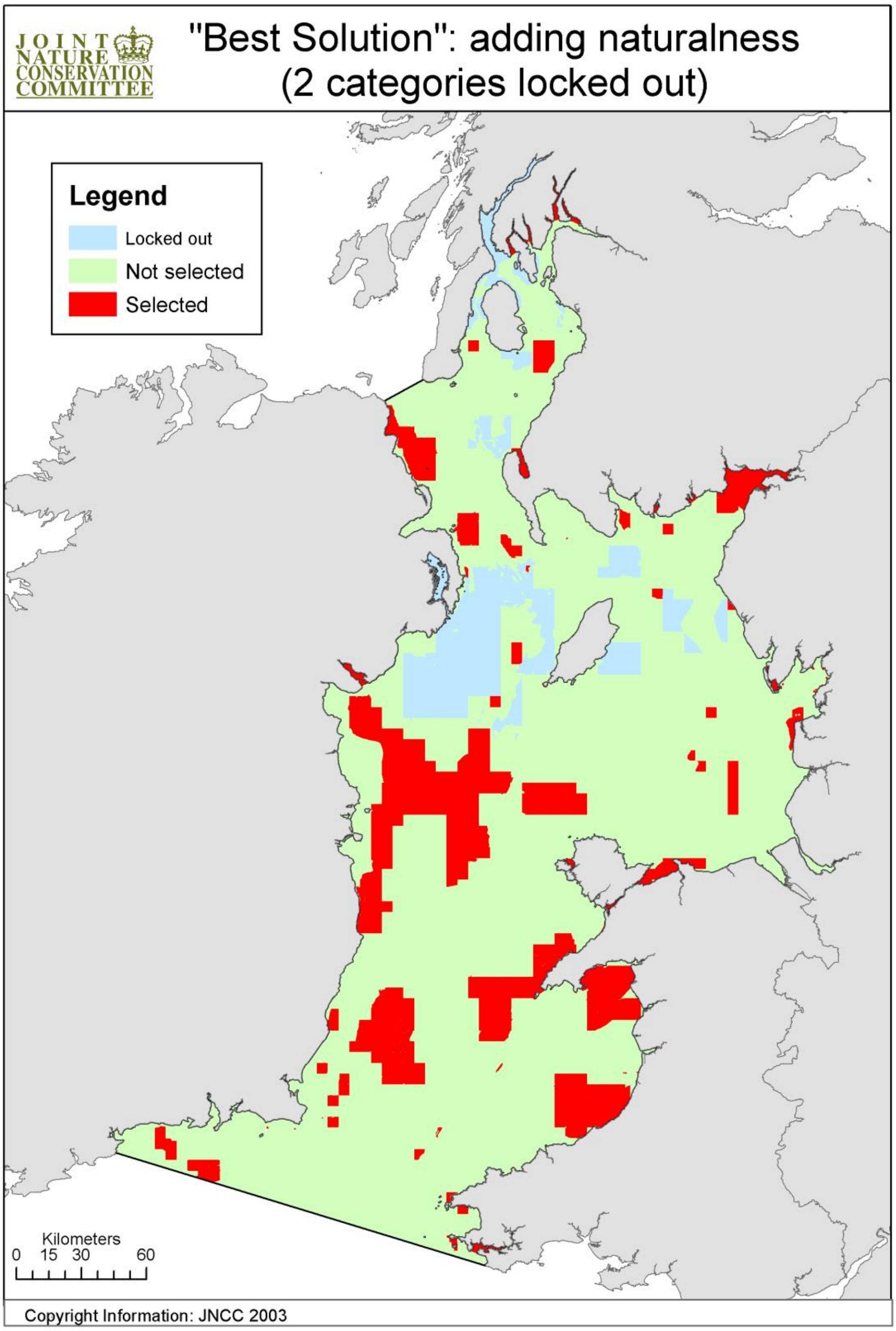

Figure 4.4.3a(ii). Scenario 3a: The "best solution" for scenario 3a: targets with boundary length modifier of 5 and naturalness (two most unnatural categories locked out)

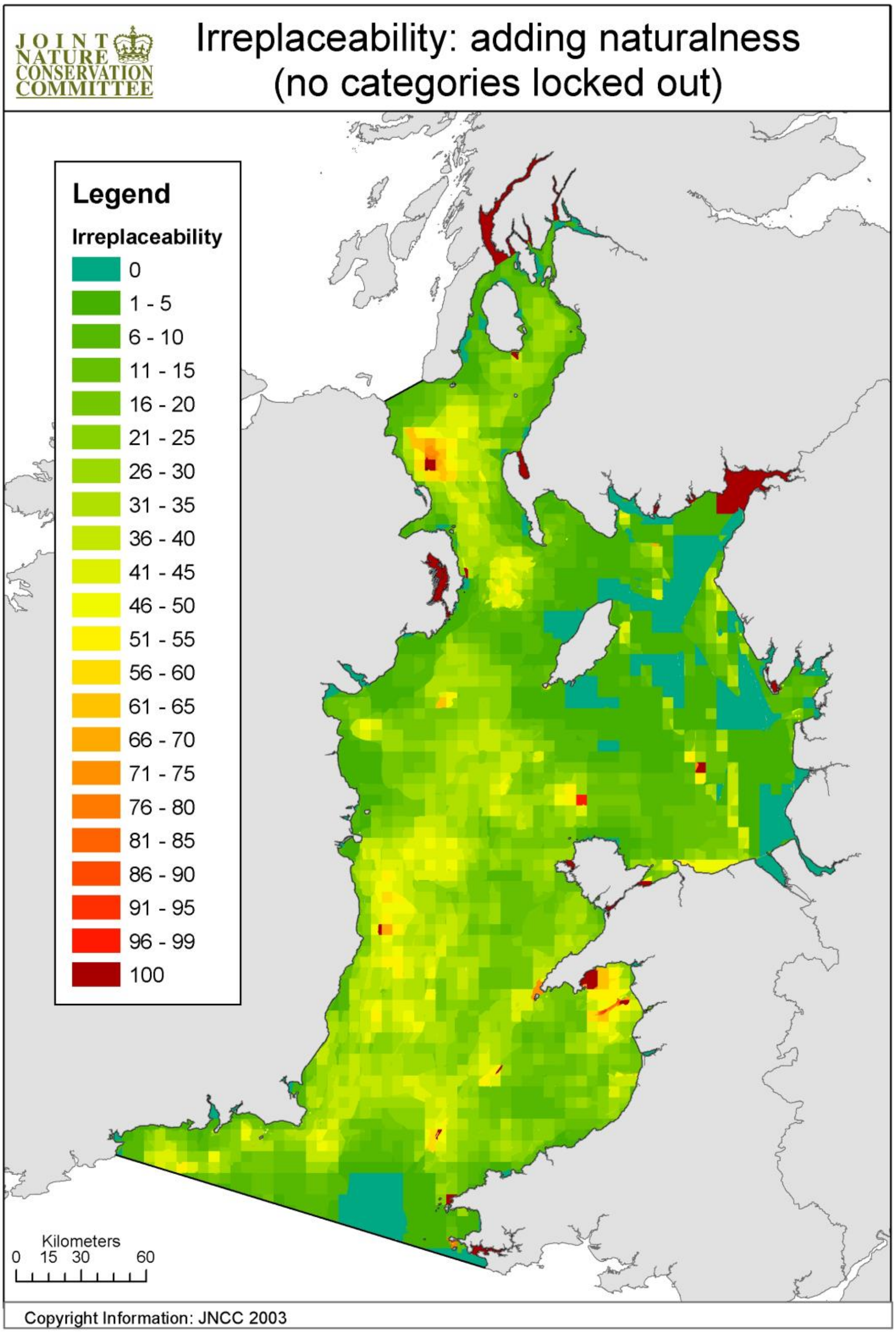

Figure 4.4.3b(i). Scenario 3b: the irreplaceability values of planning units for scenario 3b - targets with boundary length modifier of 5 and naturalness (no categories locked out)

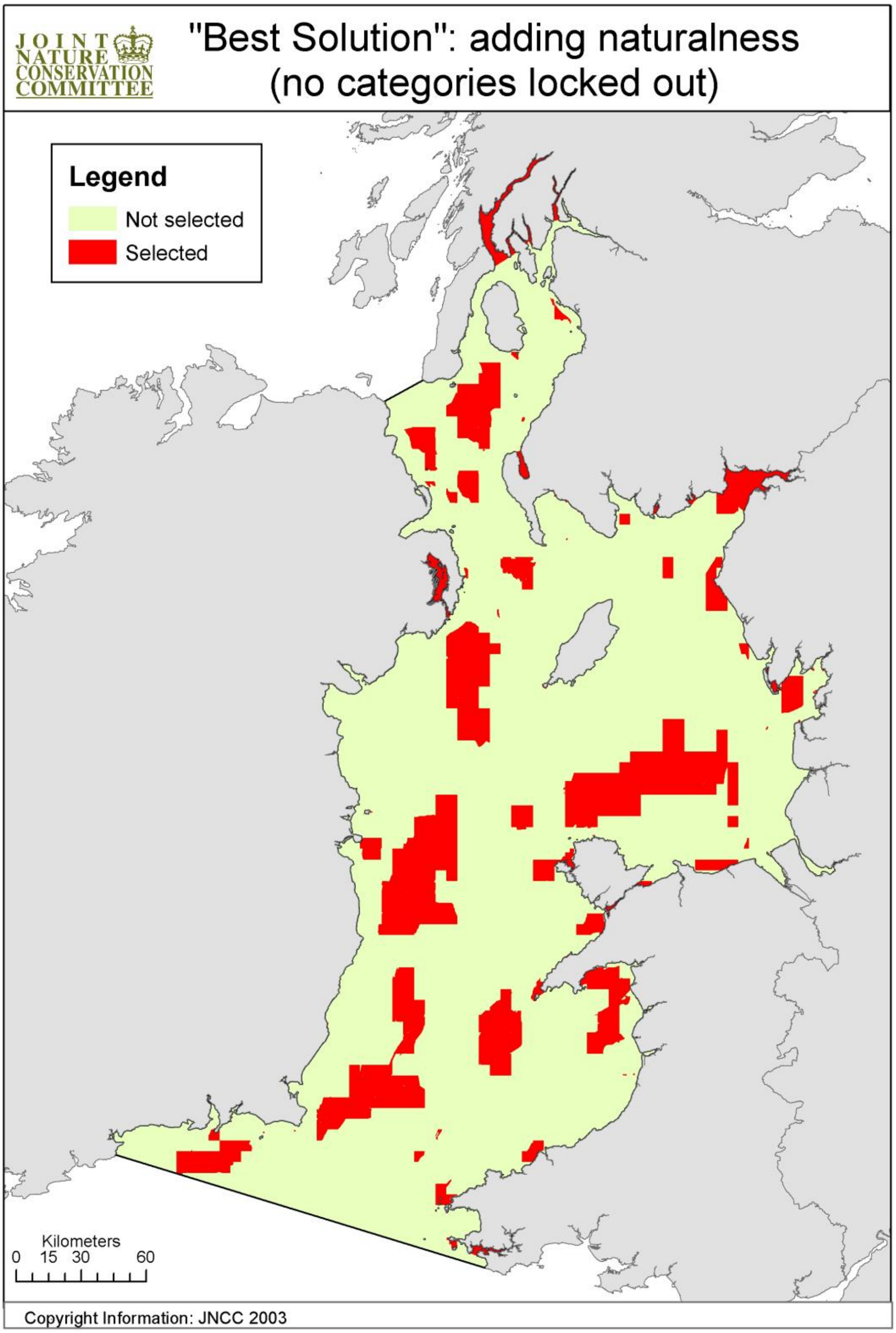

Figure 4.4.3b(ii). Scenario 3b: the “best solution” for scenario 3b - targets with boundary length modifier of 5 and naturalness (no categories locked out)

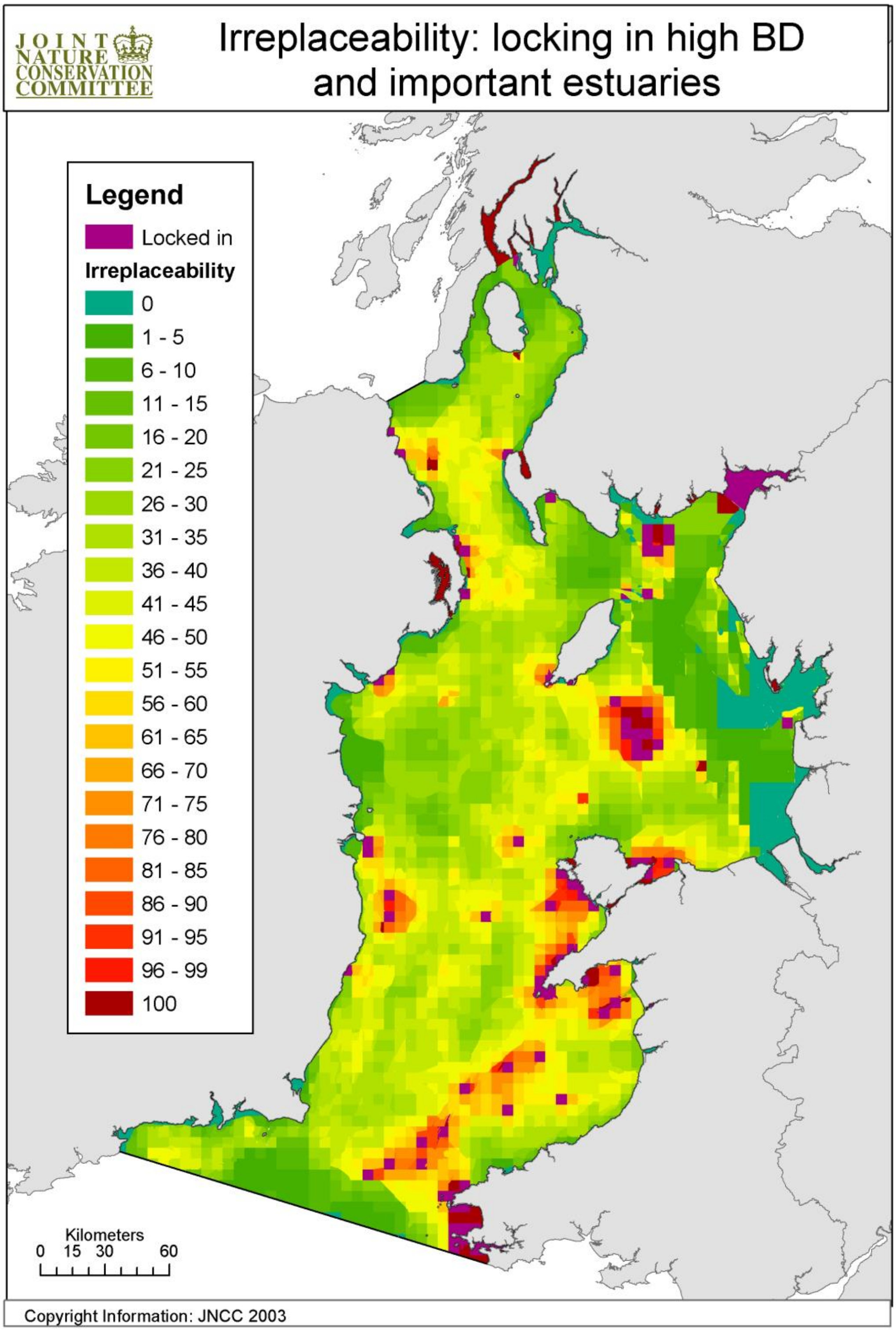

Figure 4.4.4a(i). Scenario 4a: the irreplaceability values of planning units for scenario 4a - targets with boundary length modifier of 5, and high biodiversity planning units and important estuaries locked in

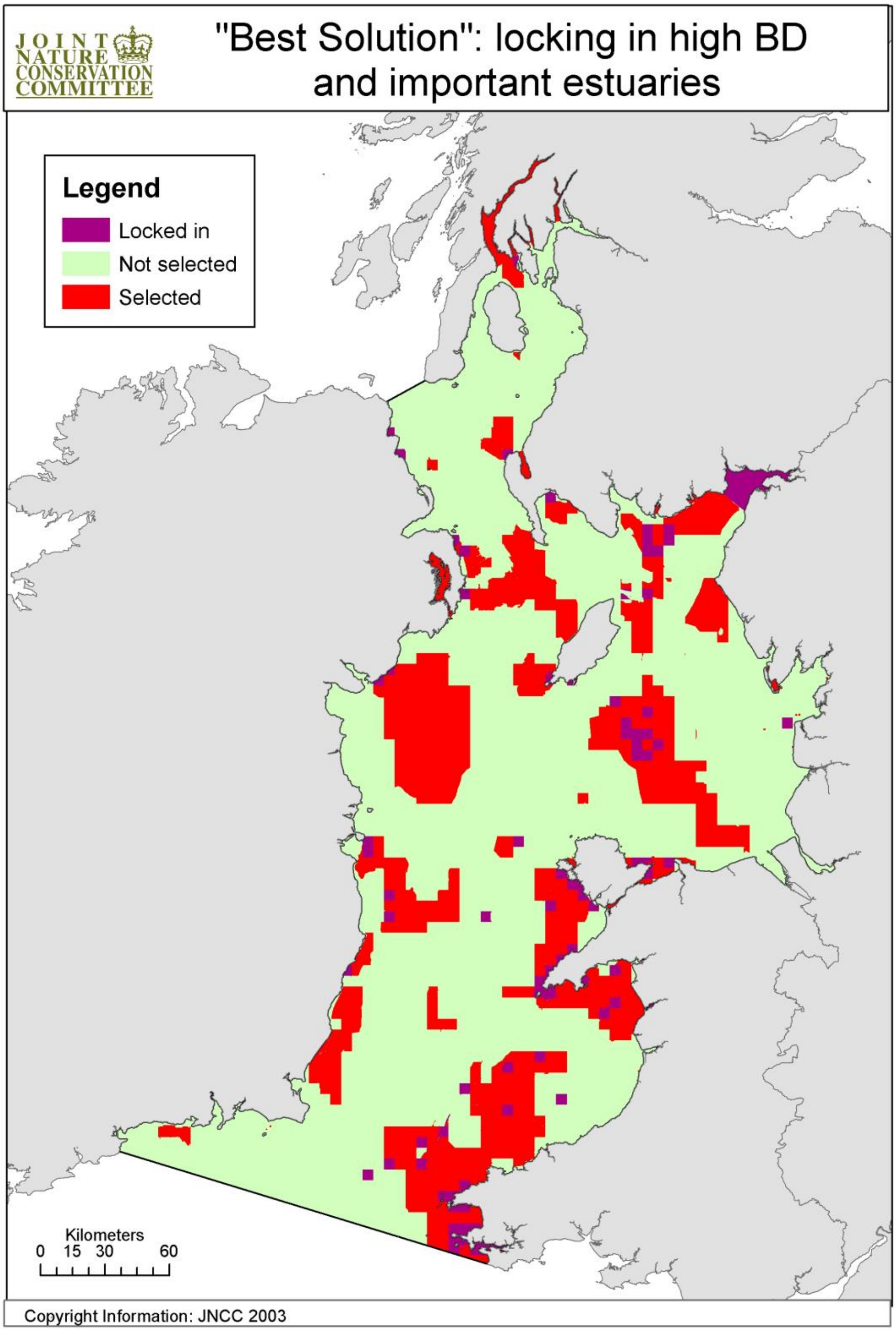

Figure 4.4.4a(ii). Scenario 4a: the "best solution" for scenario 4a - targets with boundary length modifier of 5, and high biodiversity planning units and important estuaries locked in

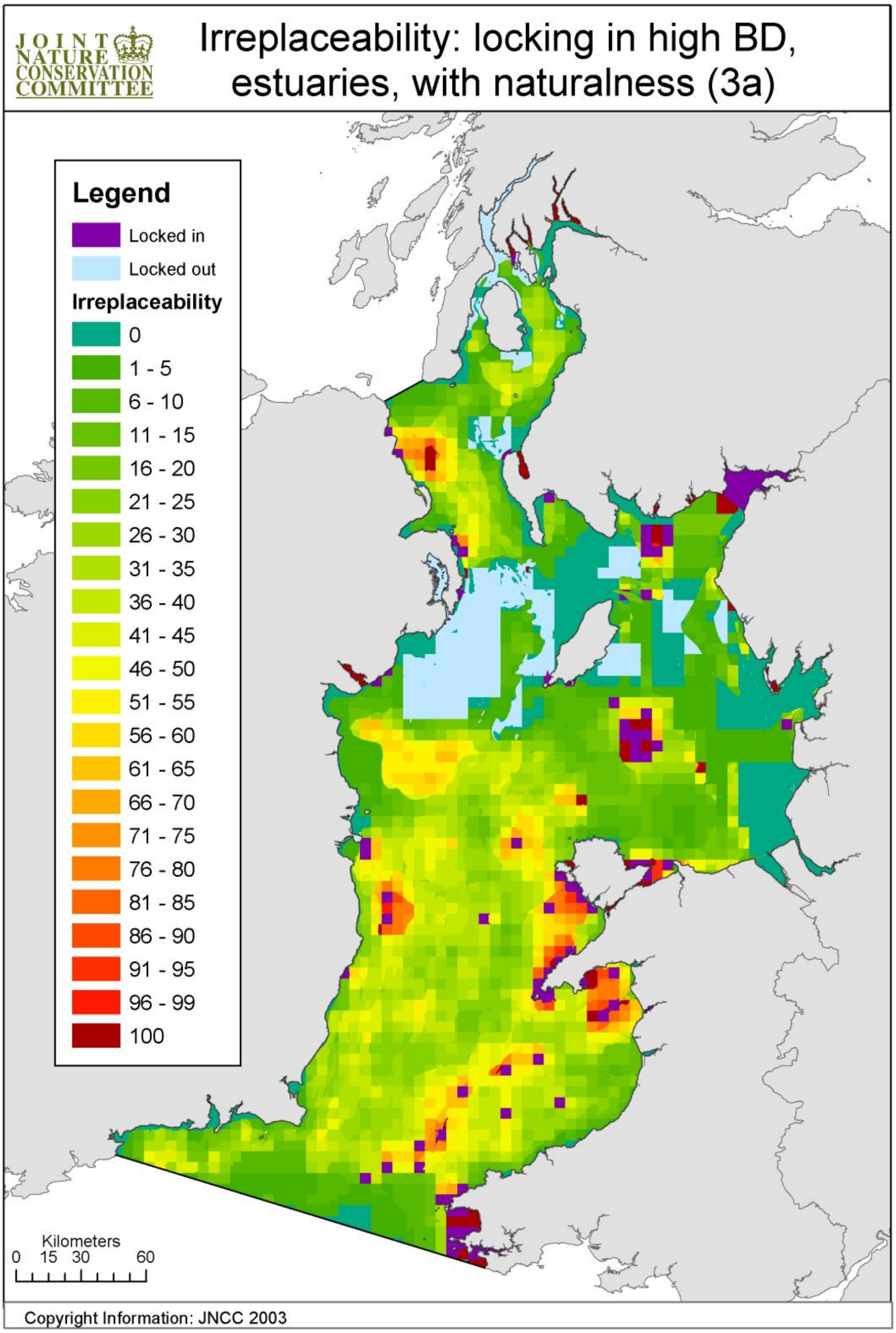

Figure 4.4.4b(i). Scenario 4b: the irreplaceability values of planning units for scenario 4b - targets with boundary length modifier of 5, and high biodiversity planning units and important estuaries locked in, with naturalness as for scenario 3a (two most unnatural categories locked out)

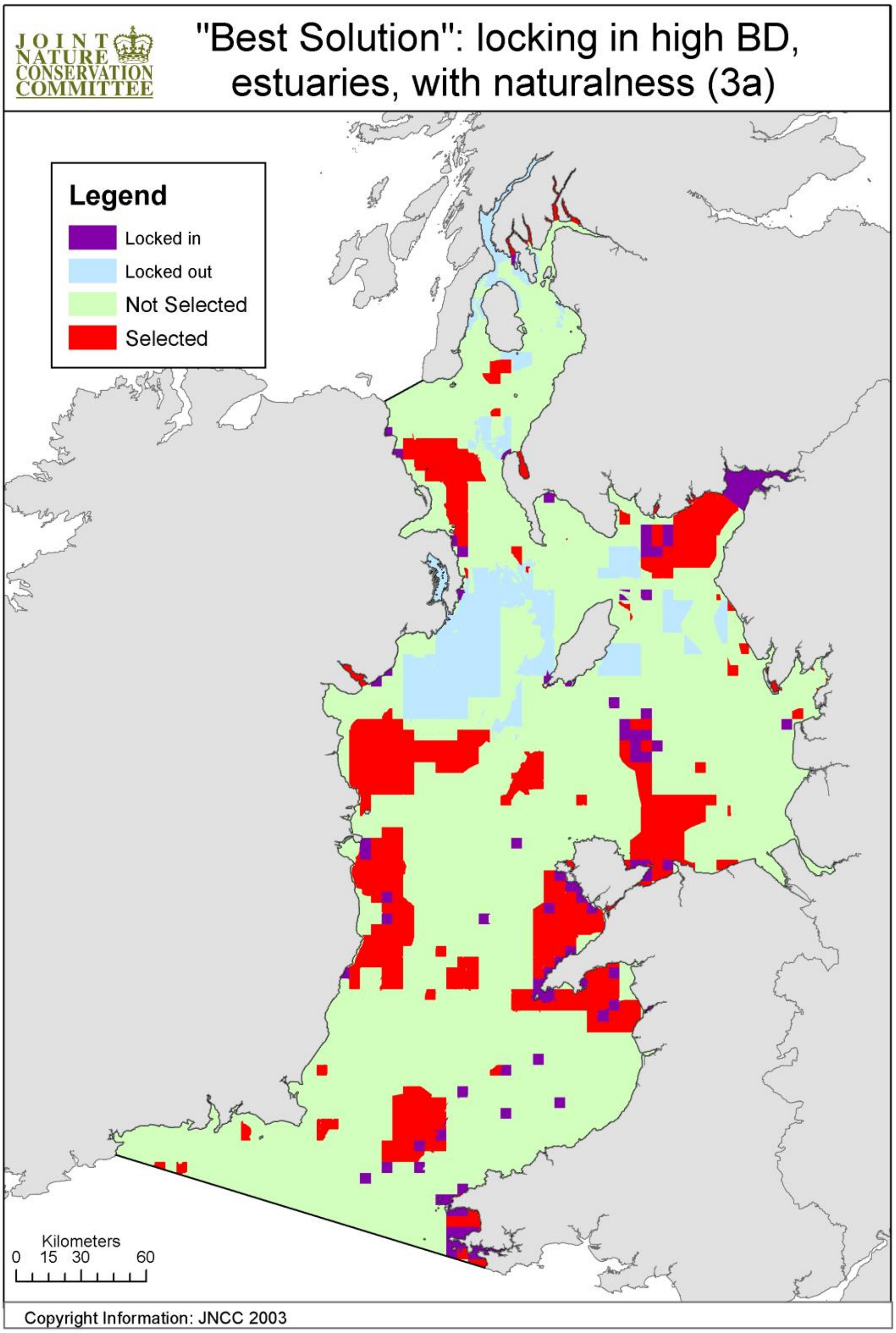

Figure 4.4.4b(ii). Scenario 4b: the “best solution” for scenario 4b - targets with boundary length modifier of 5, and high biodiversity planning units and important estuaries locked in, with naturalness as for scenario 3a (two most unnatural categories locked out)

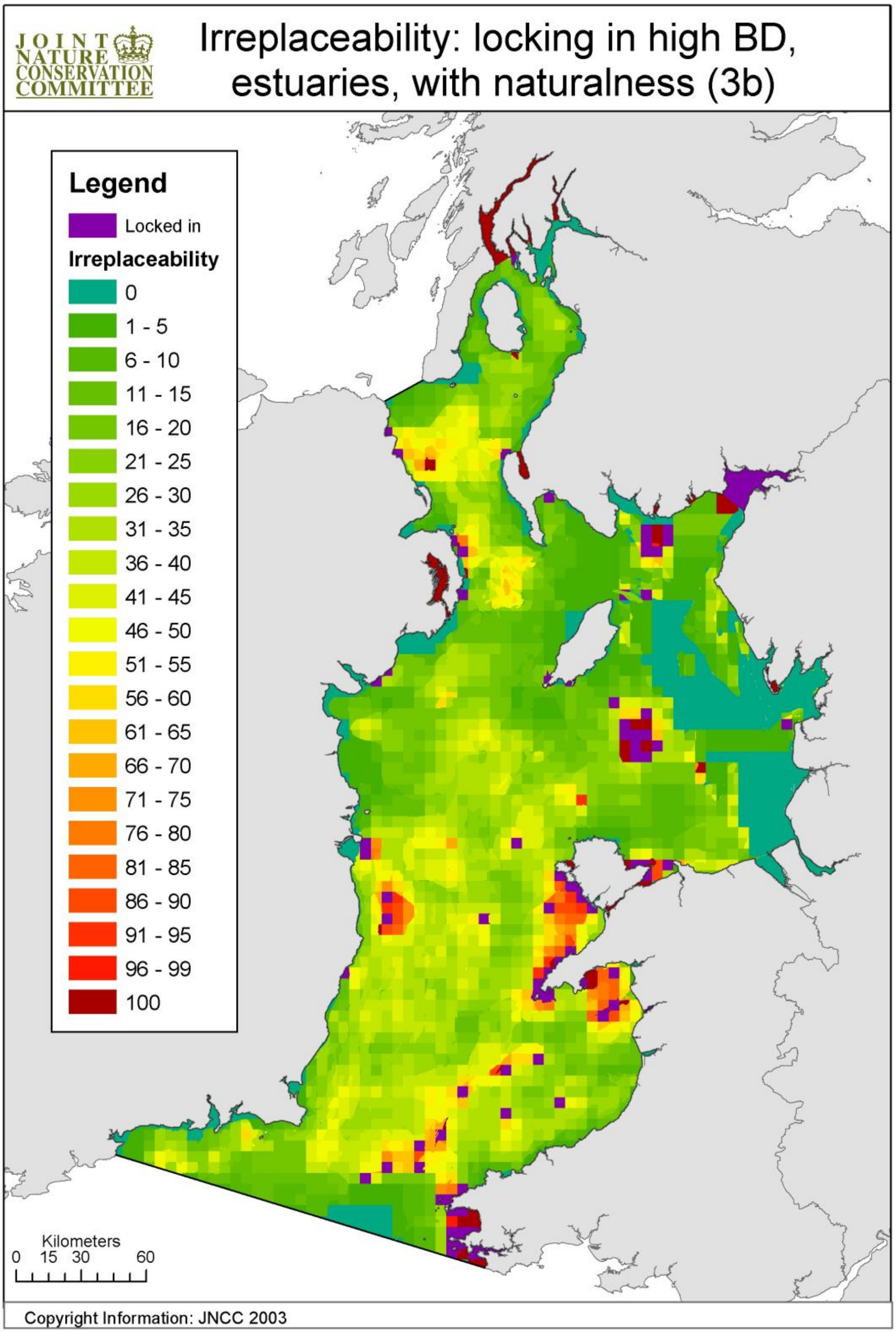

Figure 4.4.4c(i). Scenario 4c: the irreplaceability values of planning units for scenario 4c - targets with boundary length modifier of 5, and high biodiversity planning units and important estuaries locked in, with naturalness (no categories locked out)

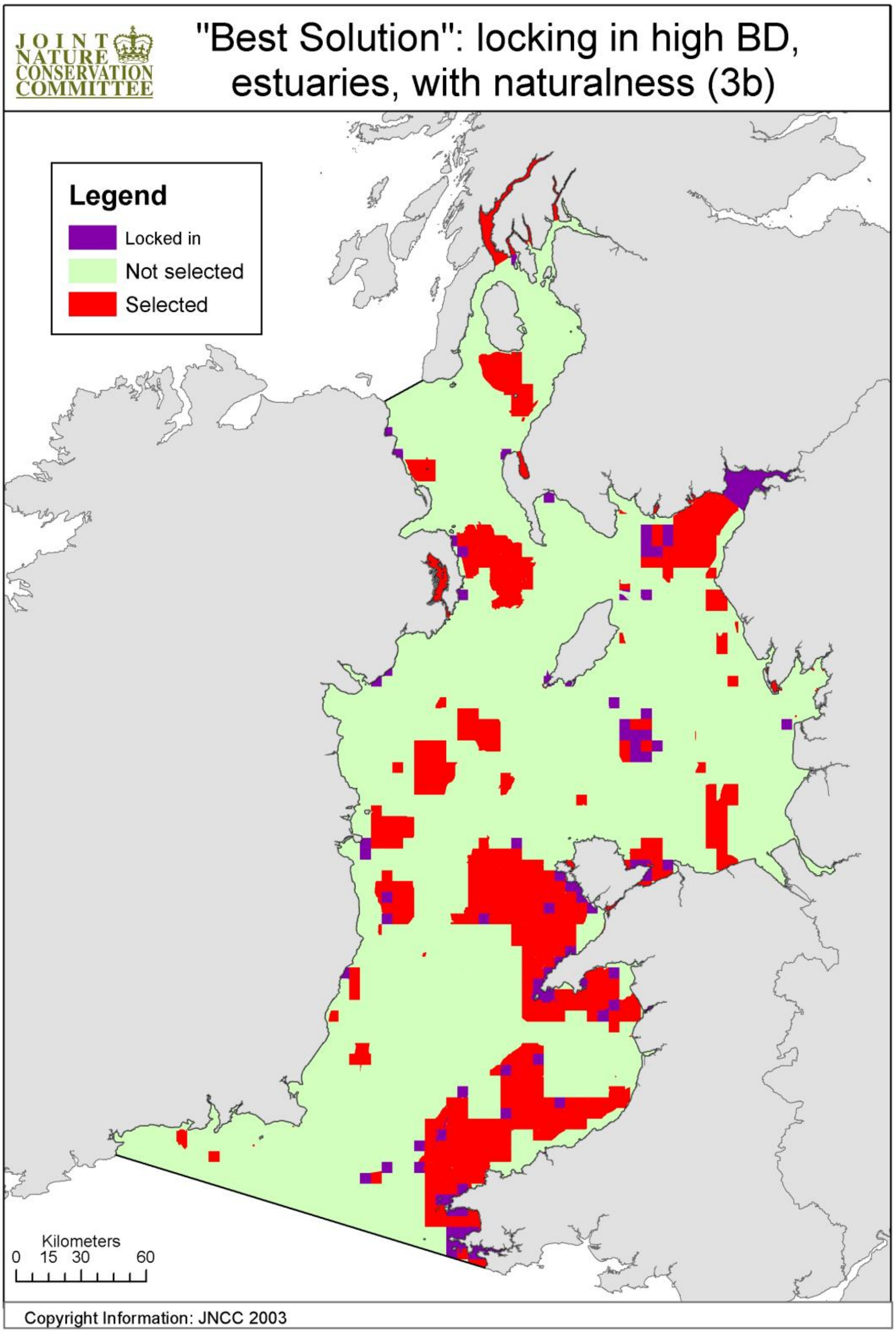

Figure 4.4.4c(ii). Scenario 4c: the "best solution" for scenario 4c - targets with boundary length modifier of 5, and high biodiversity planning units and important estuaries locked in, with naturalness (no categories locked out)

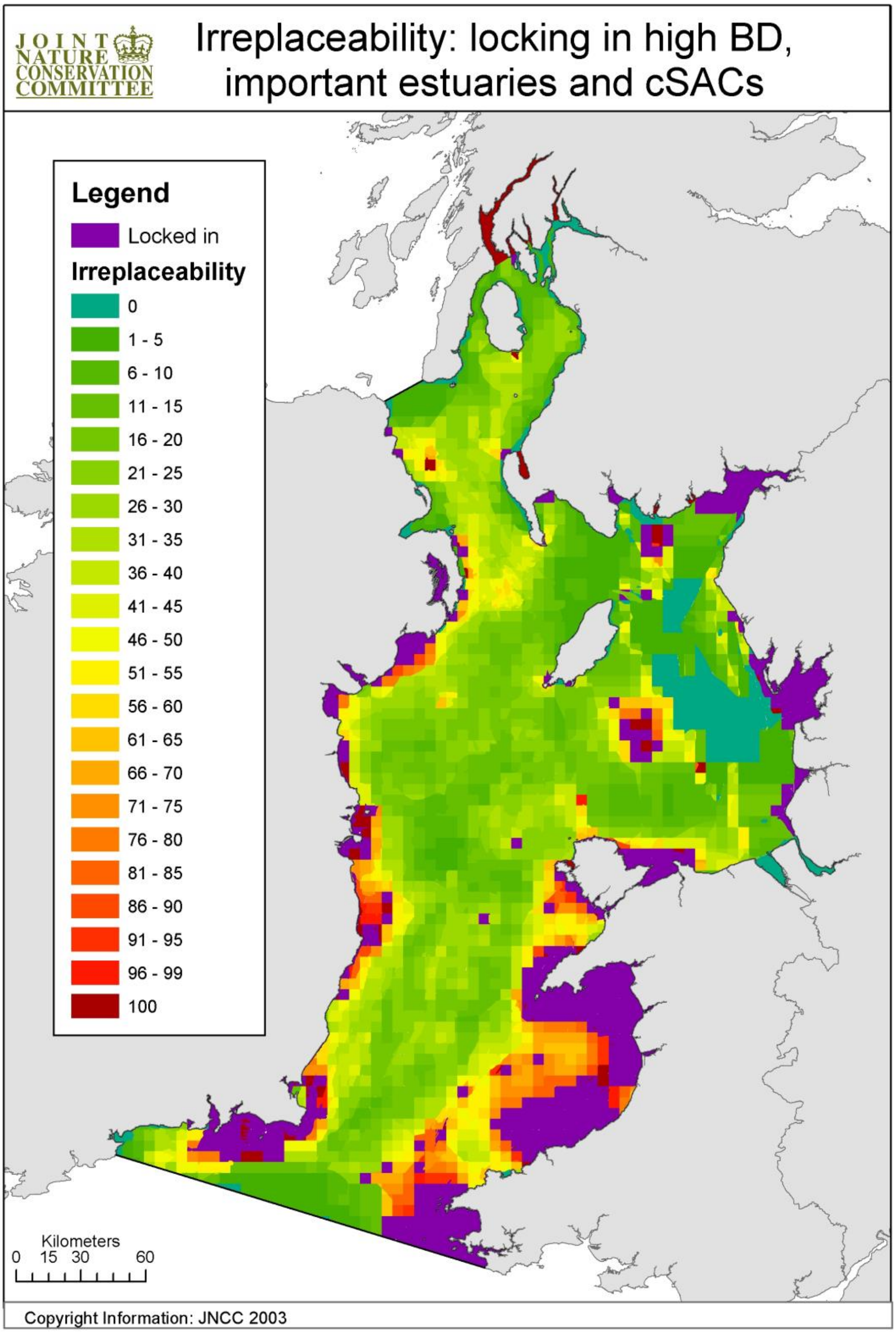

Figure 4.4.5a(i). Scenario 5a: the irreplaceability values of planning units for scenario 5a - targets with boundary length modifier of 2, and high biodiversity planning units, important estuaries and cSACs locked in

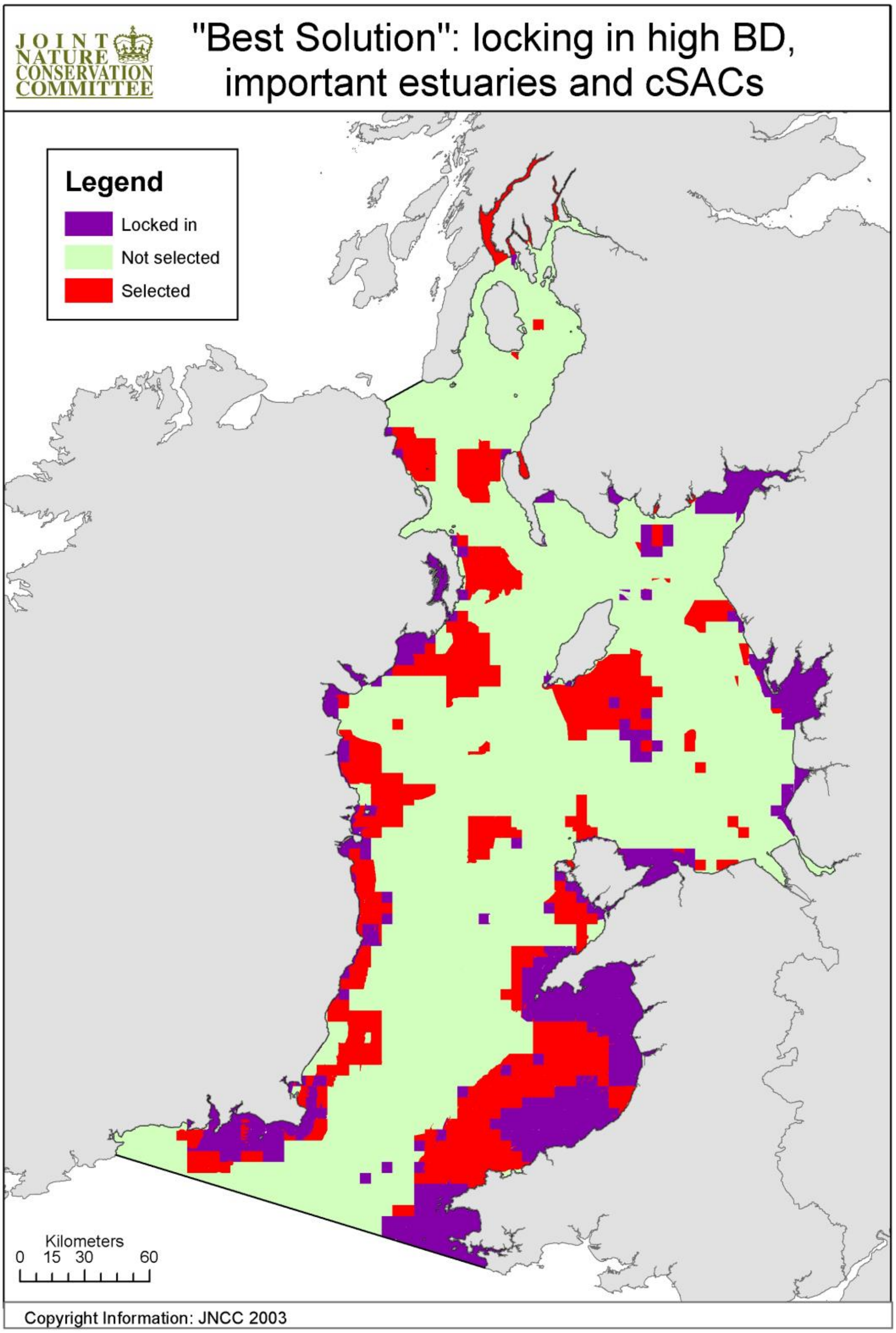

Figure 4.4.5a(ii). Scenario 5a: the "best solution" for scenario 5a - targets with boundary length modifier of 2, and high biodiversity planning units, important estuaries and cSACs locked in

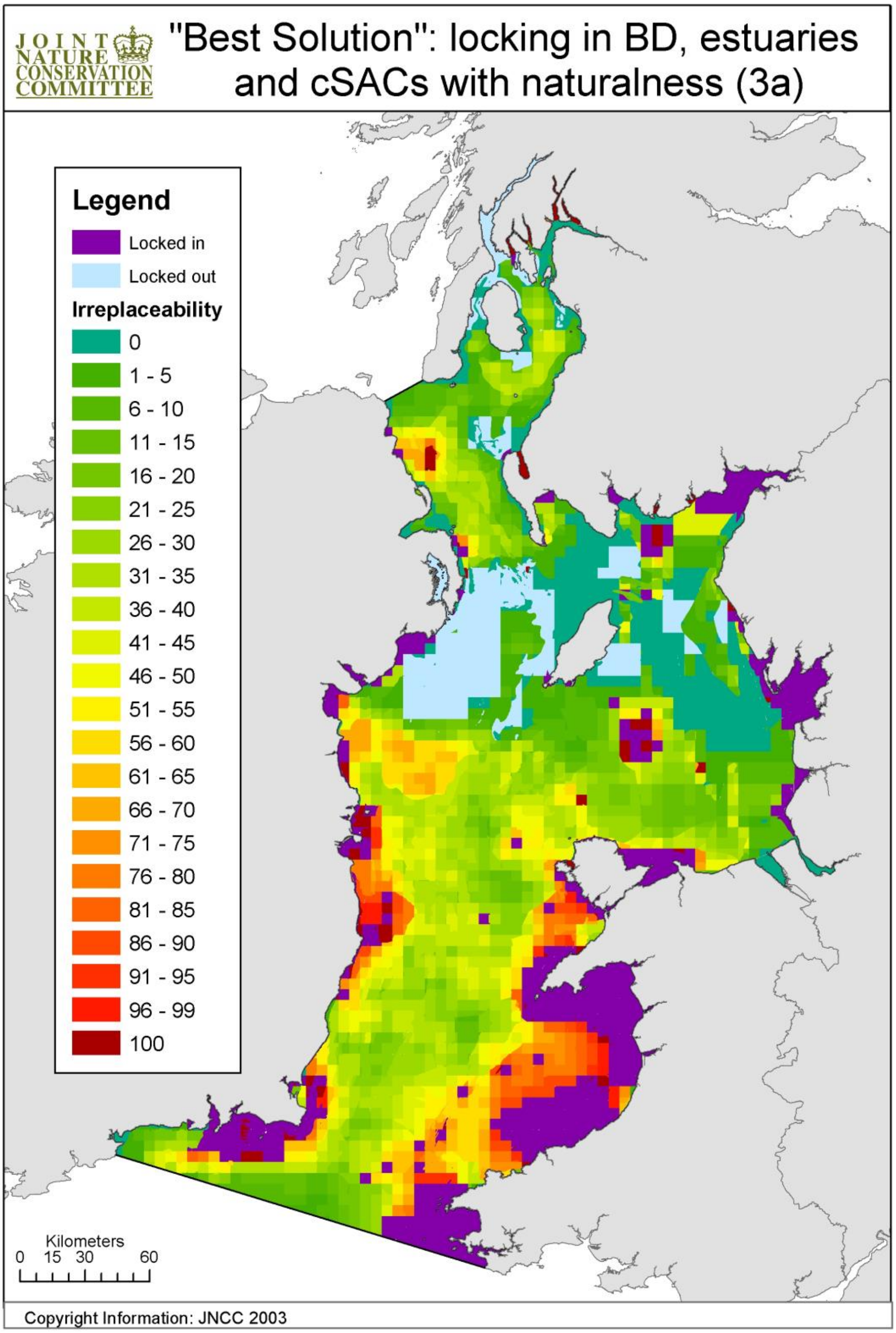

Figure 4.4.5b(i). Scenario 5b: the irreplaceability values of planning units for scenario 5b: targets with boundary length modifier of 5 and high biodiversity planning units, important estuaries and cSACs locked in, with naturalness (two most unnatural categories locked out – as for scenario 3a)

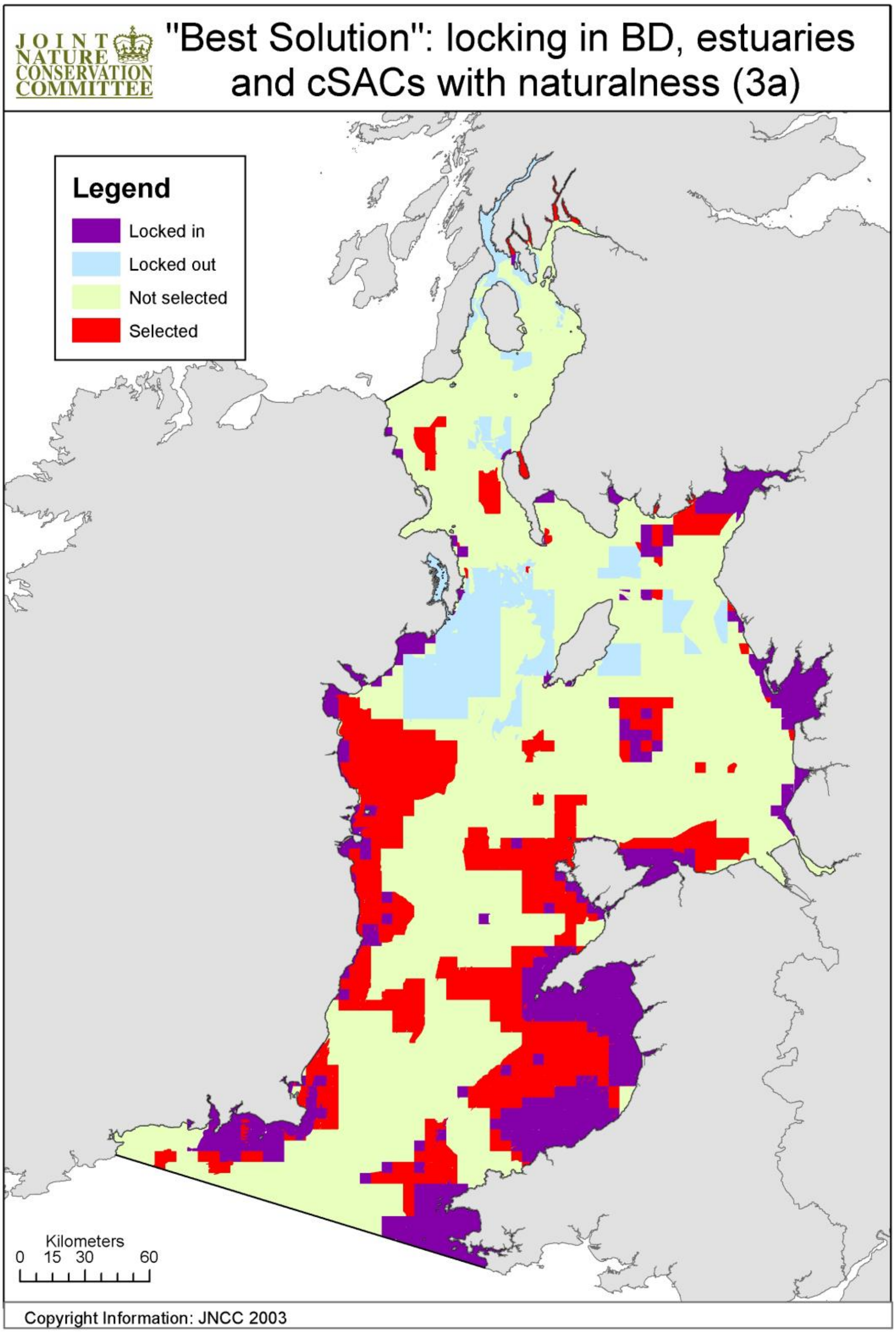

Figure 4.4.5b(ii). Scenario 5b: the "best solution" for scenario 5b - targets with boundary length modifier of 5, and high biodiversity planning units, important estuaries and cSACs locked in, with naturalness (two most unnatural categories locked out – as for scenario 3a)

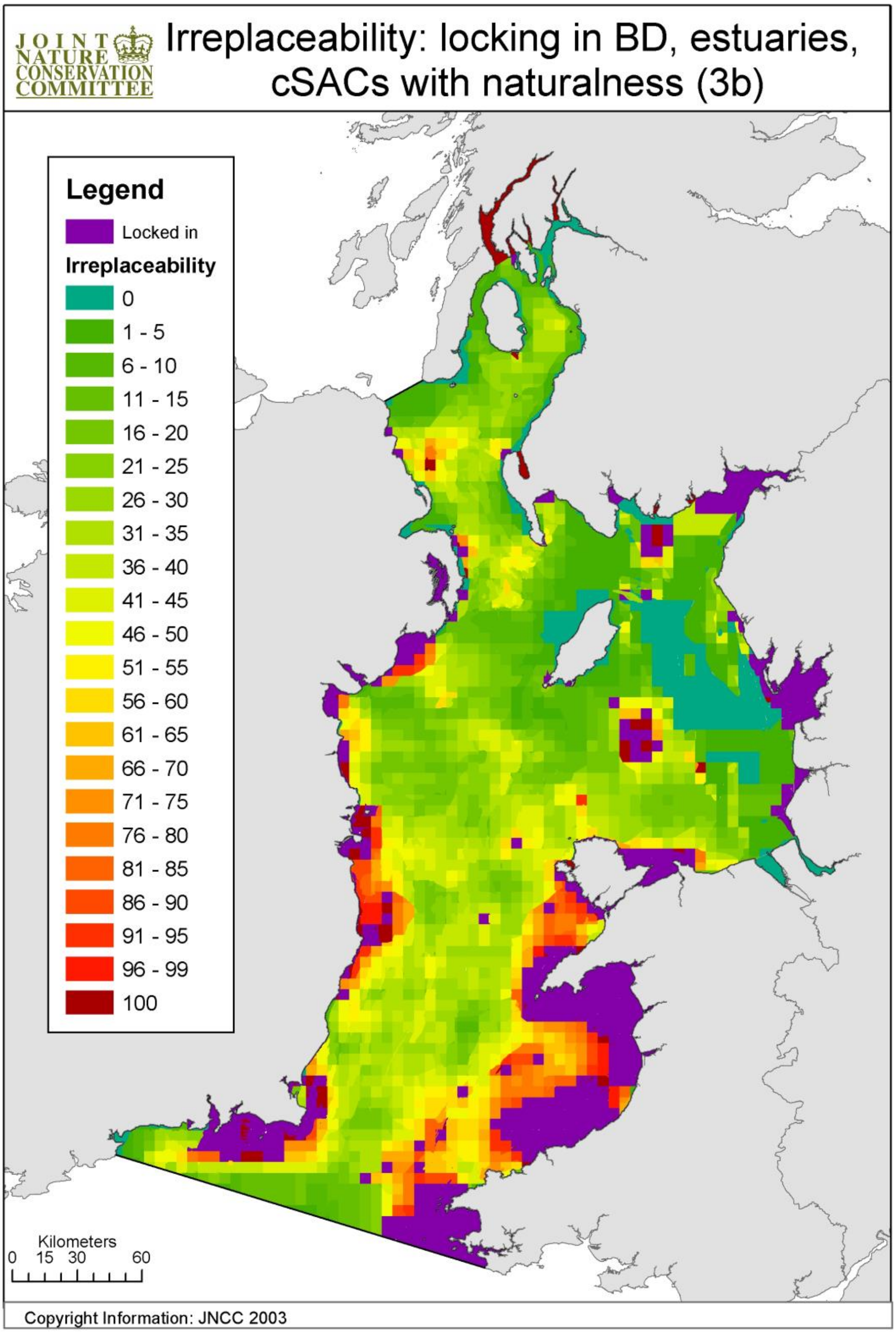

Figure 4.4.5c(i). Scenario 5c: the irreplaceability values of planning units for scenario 5c - targets with boundary length modifier of 5, and high biodiversity planning units, important estuaries and cSACs locked in, with naturalness (no categories locked out – as for scenario 3b)

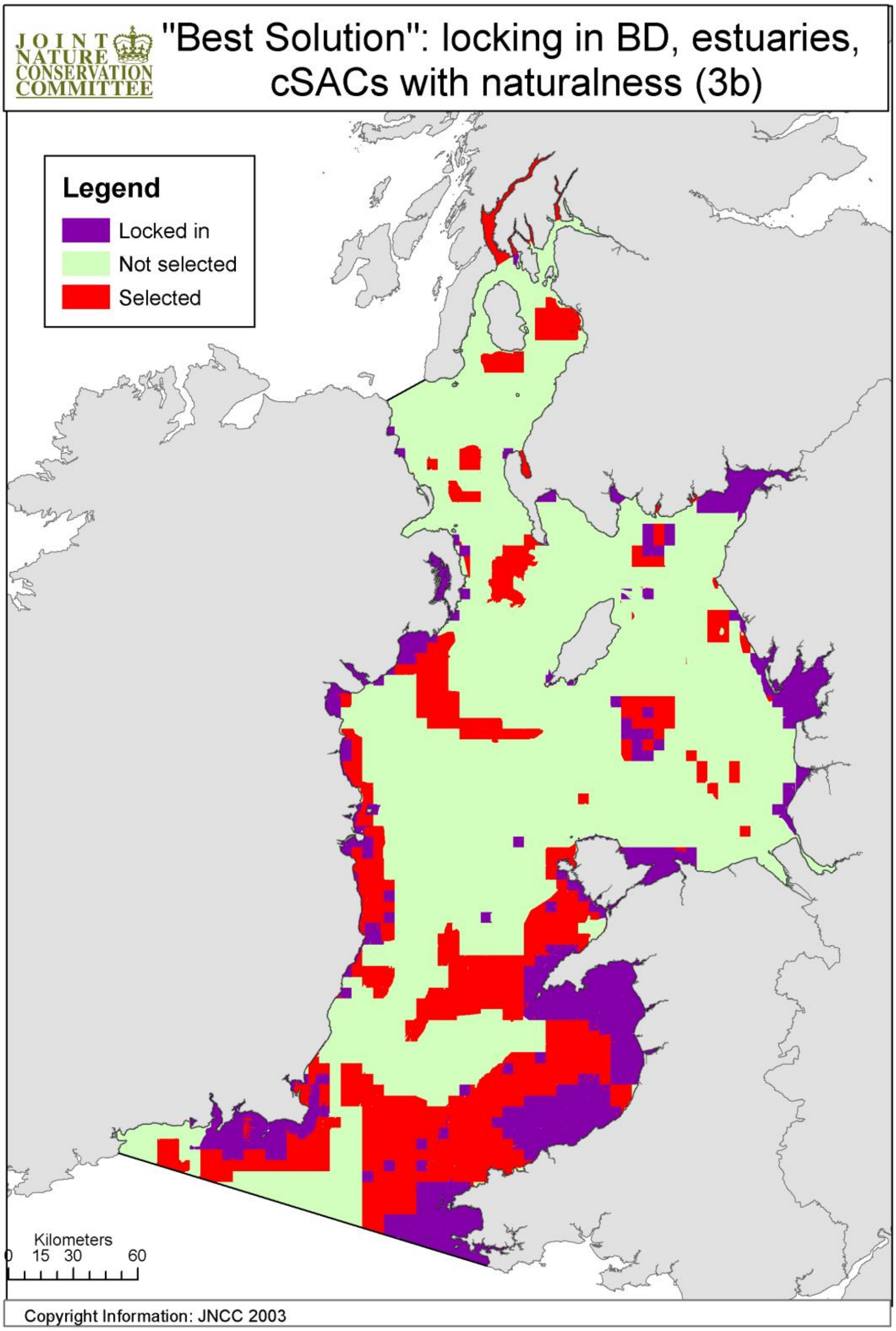

Figure 4.4.5c(ii). Scenario 5c: the "best solution" for scenario 5c - targets with boundary length modifier of 5, and high biodiversity planning units, important estuaries and cSACs locked in, with naturalness (no categories locked out – as for scenario 3b)

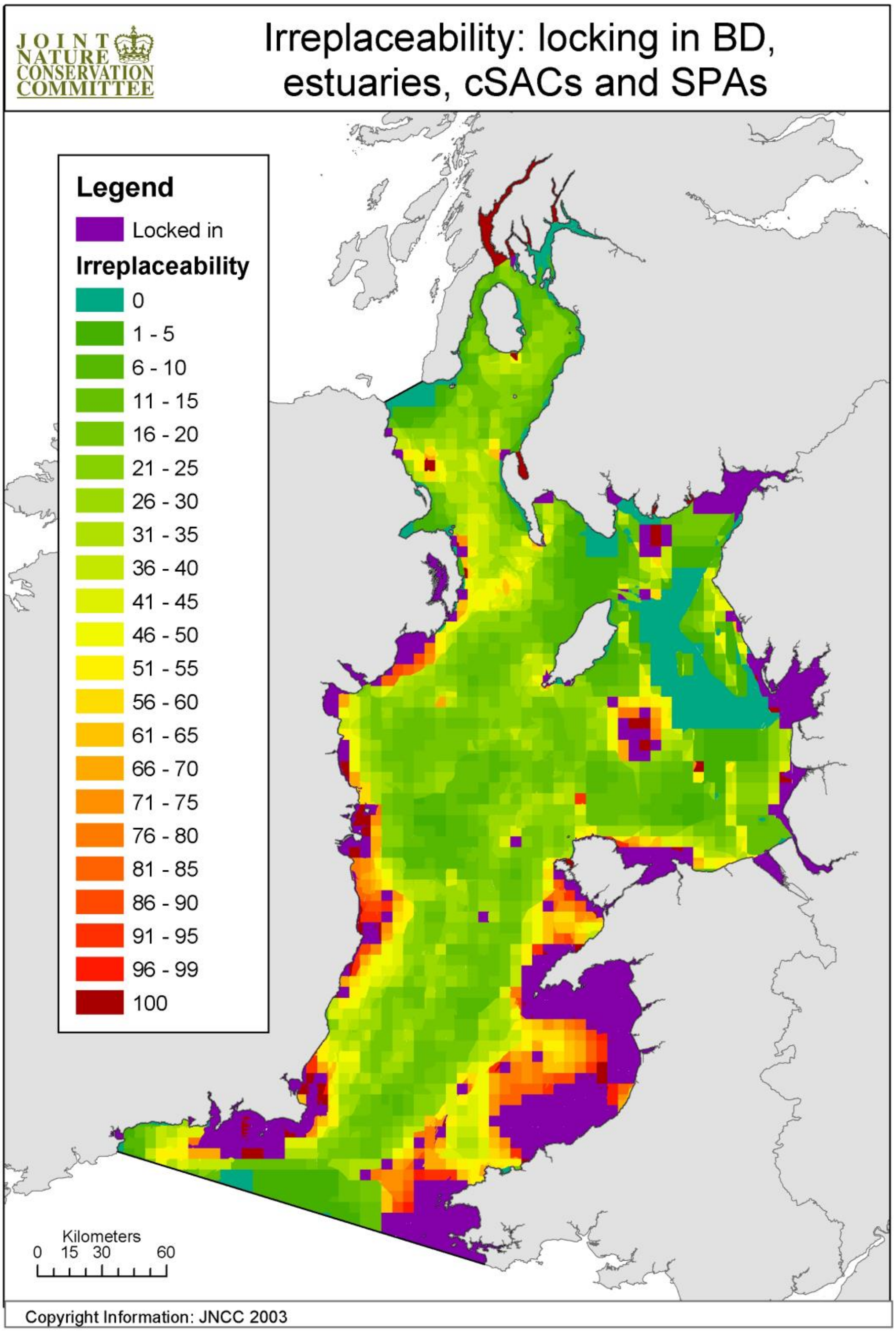

Figure 4.4.6a(ii). Scenario 6a: the irreplaceability of planning units for scenario 6a - targets with boundary length modifier of 2, and high biodiversity planning units, important estuaries, cSACs and SPAs locked in, as well as targets of 20% of Annex I habitat.

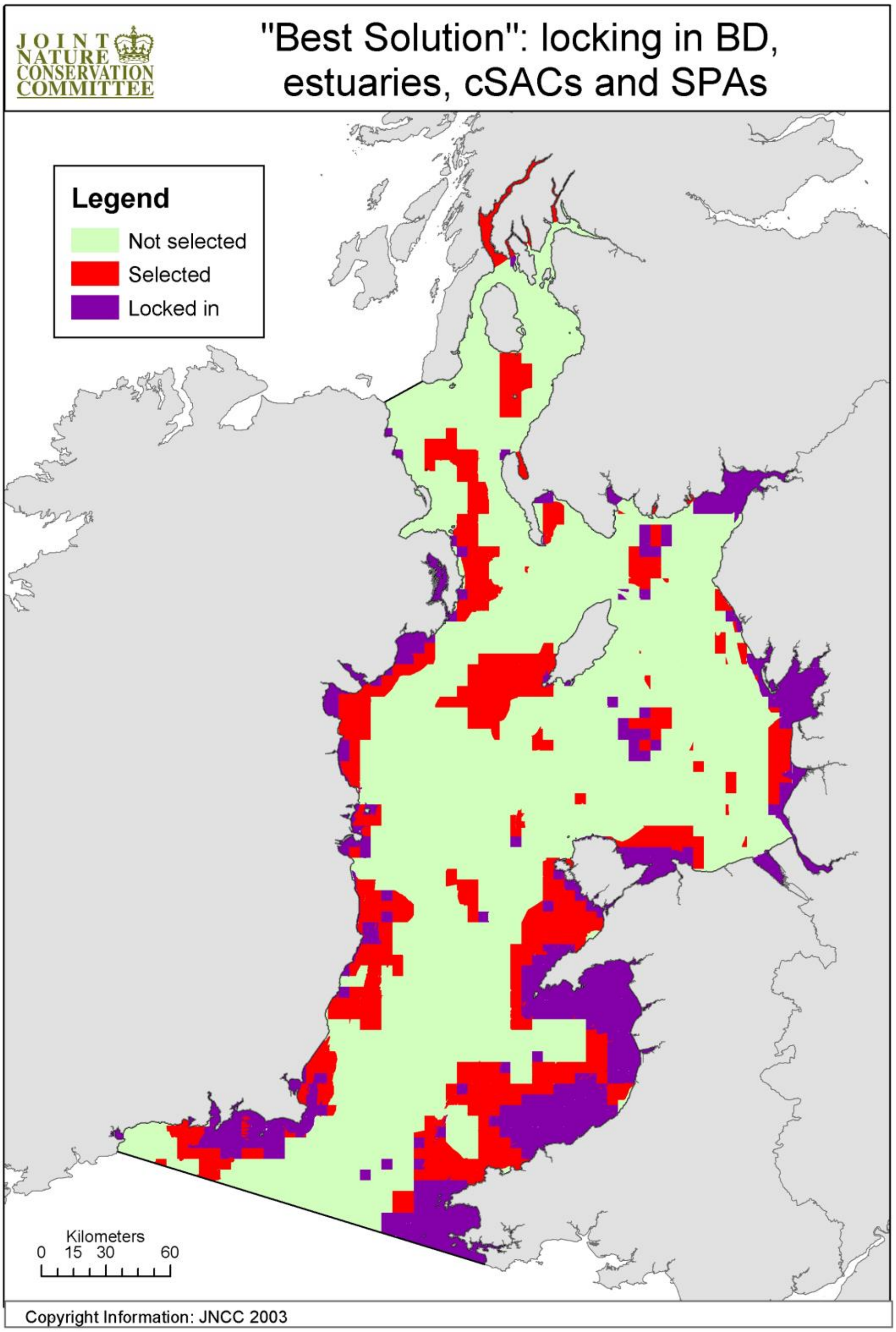

Figure 4.4.6a(ii). Scenario 6a: the 'best solution' for scenario 6a - targets with boundary length modifier of 2, and high biodiversity planning units, important estuaries, cSACs and SPAs locked in, as well as targets of 20% of Annex I habitat.

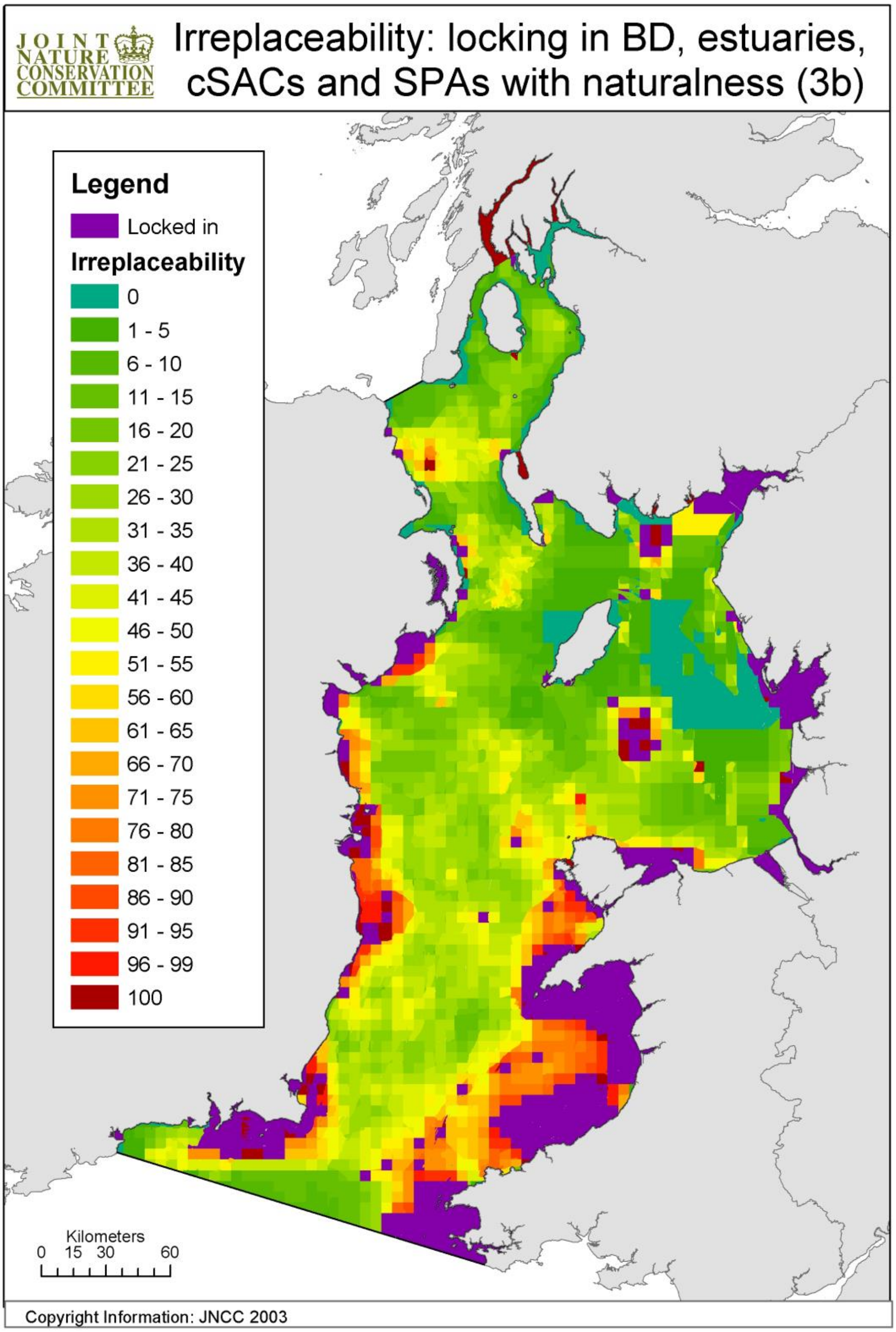

Figure 4.4.6b(i). Scenario 6b: the irreplaceability values of planning units for scenario 6b - targets with boundary length modifier of 5 and high biodiversity planning units, important estuaries, cSACs and SPAs locked in, as well as targets of 20% of Annex I habitat, with naturalness (no categories locked out – as for scenario 3a)

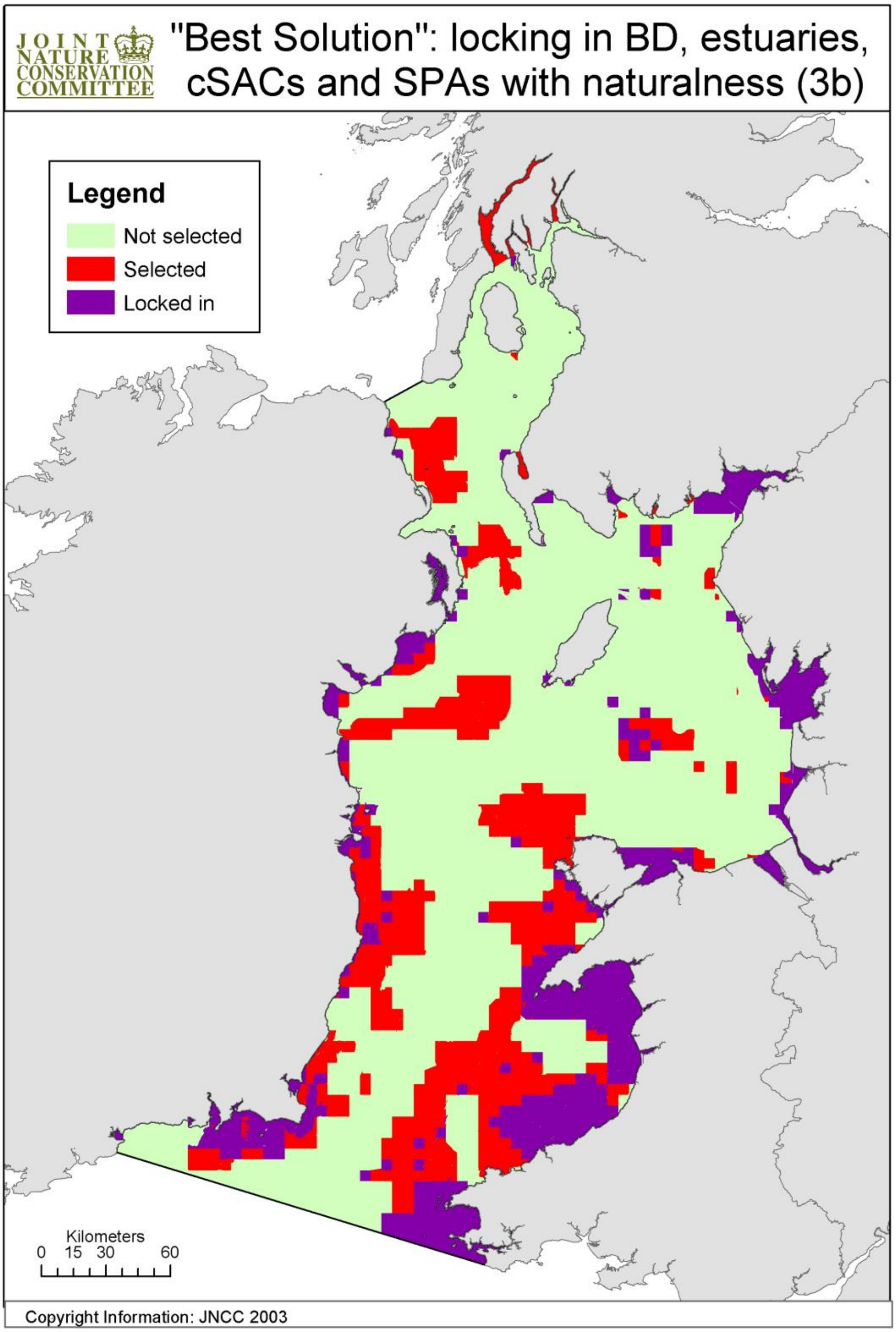

Figure 4.4.6b(ii). Scenario 6b: the ‘best solution’ for scenario 6b - targets with boundary length modifier of 5, and high biodiversity planning units, important estuaries, cSACs and SPAs locked in, as well as targets of 20% of Annex I habitat, with naturalness (no categories locked out – as for scenario 3a)

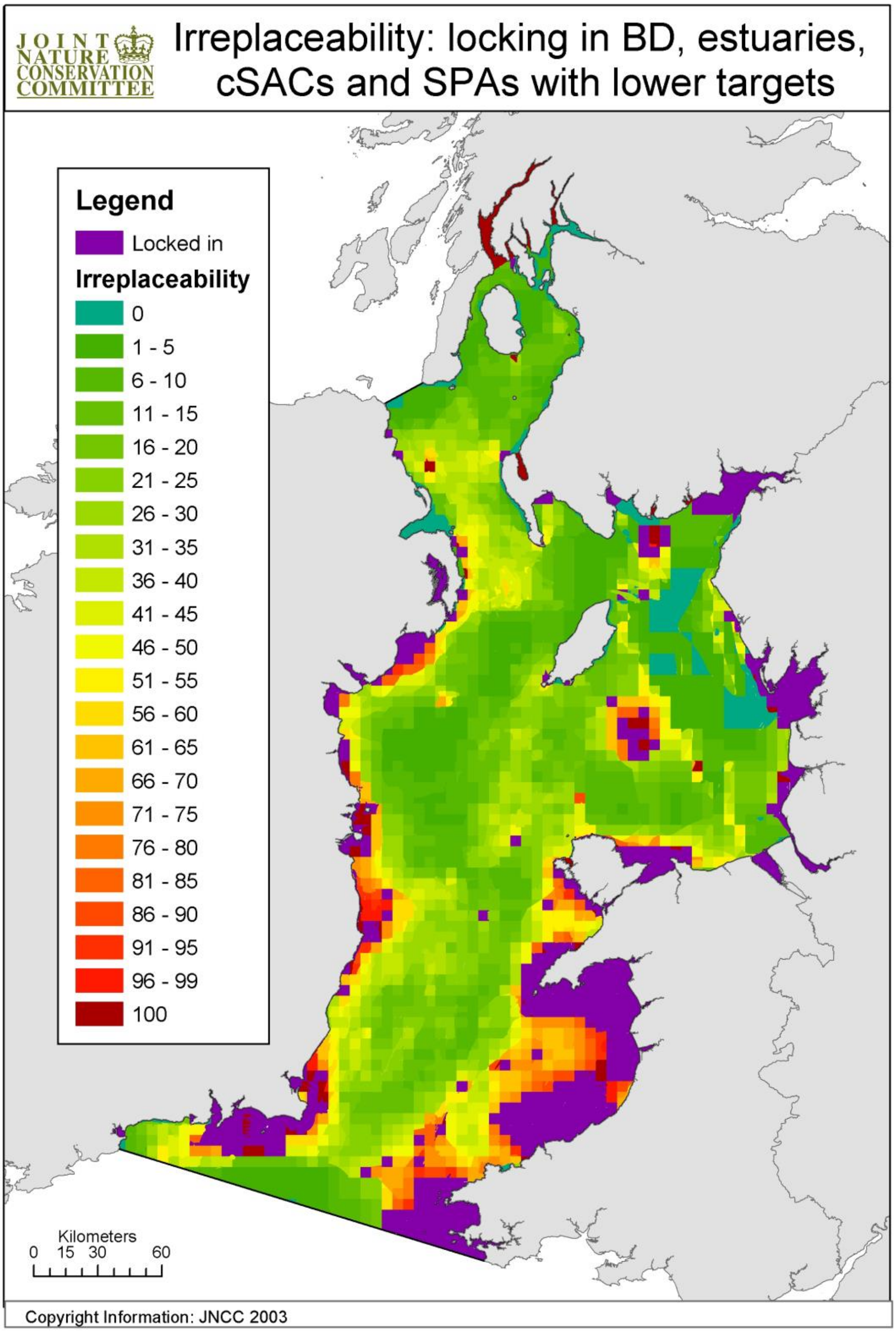

Figure 4.4.6c(i). Scenario 6c: the irreplaceability of planning units for scenario 6c - targets (lower targets for marine landscapes as in table 3.5) with boundary length modifier of 5, and high biodiversity planning units, important estuaries, cSACs and SPAs locked in, as well as targets of 20% of Annex I habitat, with naturalness (no categories locked out – as for scenario 3b)

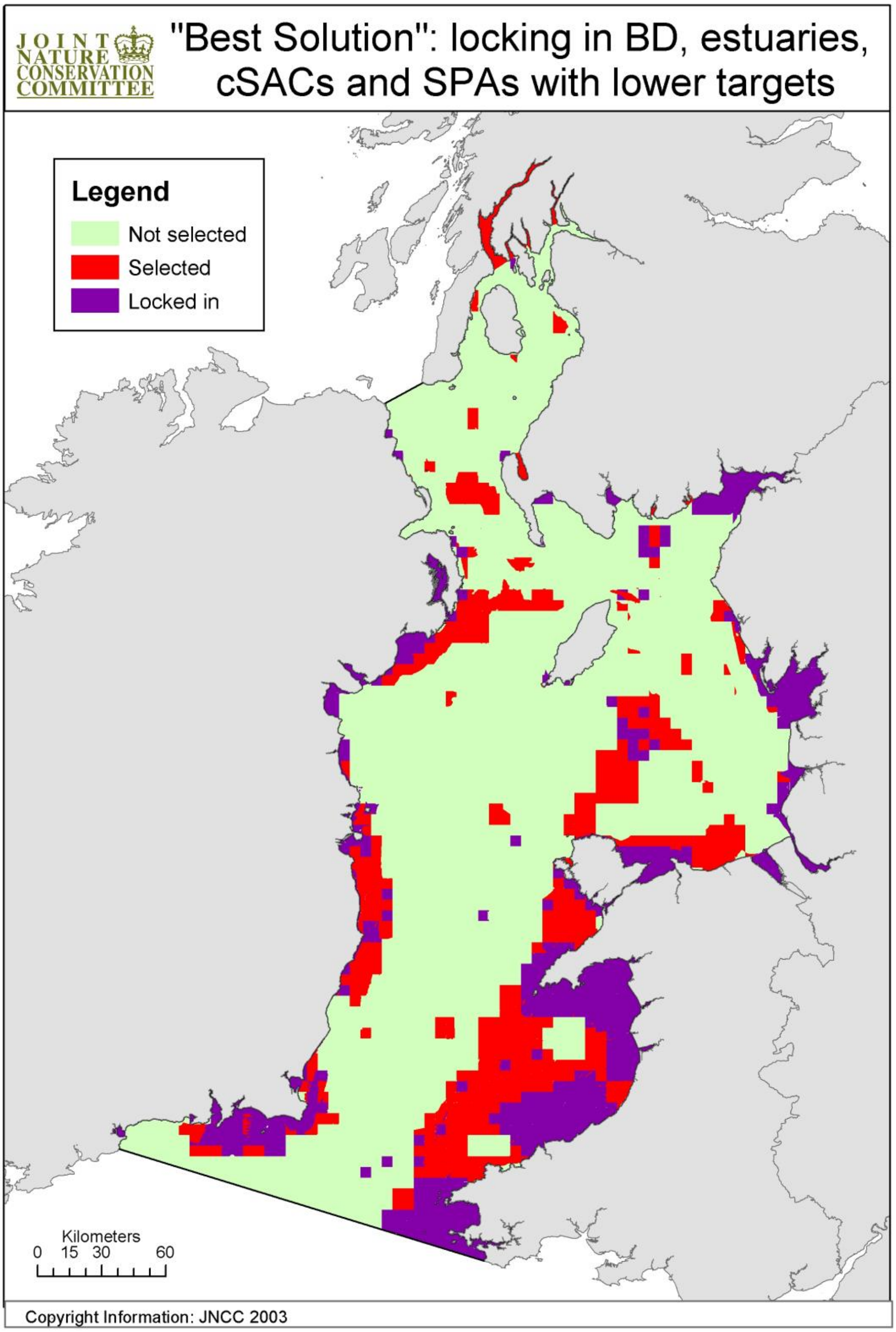

Figure 4.4.6c(ii). Scenario 6c: the 'best solution' for final scenario 6c - targets (lower targets for marine landscapes as in table 3.5) with boundary length modifier of 5, and high biodiversity planning units, important estuaries, cSACs and SPAs locked in, as well as targets of 20% of Annex I habitat, with naturalness (no categories locked out – as for scenario 3b)

7 References

Allen, P. L. & Rees, E. I. S. (1999). *ISSIA (Irish Sea Seabed Image Archive). A Directory of Seabed Camera Studies in the Irish Sea.* University of Wales, Bangor, for DETR.

Ardron, , J. A.; Lash, J. and Haggarty, D. (2002) *Modelling a Network of Marine Protected Areas for the Central Coast of British Columbia. Version 3.1.* Living Oceans Society, Sointula, BC, Canada.

Ball, I.R. and Possingham, H. P. (1999) MARXAN - A Reserve System Selection Tool. www.ecology.uq.edu.au/marxan.htm

Ball, I.R. and Possingham, H. P. (2000) *Marxan (v1.8.2). Marine Reserve Design using Spatially Explicit Annealing. A Manual Prepared for The Great Barrier Reef Marine Park Authority.* Available to download at www.ecology.uq.edu.au/marxan.htm

Ballantine, W.Y. (1999). *Marine reserves in New Zealand. The development of the concept and principles.* Paper for workshop of MPAs: KORDI, Korea, November 1999.

Brazier, D. P.; Holt, R. H. F.; Murray, E. and Nichols, D. M. (1999). *Marine Nature Conservation Review Sector 10. Cardigan Bay and North Wales: area summaries*. Peterborough, Joint Nature Conservation Committee. (Coasts and Seas of the United Kingdom. MNCR series.)

Clarke, K. R. and Warwick, R. M. (2001) *Change in Marine Communities: An Approach to Statistical Analysis and Interpretation. 2nd edition*. PRIMER-E: Plymouth

Connor, D. W. & Hill, T. O. (1998) *Marine Nature Conservation Review natural heritage assessment protocol. Version 98.01*. Unpublished, Joint Nature Conservation Committee, Peterborough.

Connor, D.W., Breen, J., Champion, A., Gilliland, P.M., Huggett, D., Johnston, C., Laffoley, D. d'A., Lieberknecht, L., Lumb, C., Ramsay, K., and Shardlow, M. (2002) *Rationale and criteria for the identification of nationally important marine nature conservation features and areas in the UK. Version 02.11.* Peterborough, Joint Nature Conservation Committee (on behalf of the statutory nature conservation agencies and Wildlife and Countryside Link) for the Defra Working Group on the Review of Marine Nature Conservation.

Connor, D. W.; Allen, J. H.; Golding, N.; Lieberknecht, L. M.; Northen, K. O. and Reker, J. B. (2003) *The national marine habitat classification for Britain and Ireland. Version 03.02*. Joint Nature Conservation Committee, Peterborough. ISBN 1 86107 546 4 (available online at www.jncc.gov.uk/MarineHabitatClassification)

Covey, R. (1998). *Marine Nature Conservation Review Sector 11. Liverpool Bay and the Solway Firth: area summaries.* Peterborough, Joint Nature Conservation Committee. (Coasts and Seas of the United Kingdom. MNCR series.)

Davidson, N.C., Laffoley, D.d'A., Doody, J.P., Way, L.S. & Gordon, J. (1991) *Nature Conservation and Estuaries in Great Britain.* Nature Conservancy Council.

Dipper, F. A. and Beaver, R. (1999) *Marine Nature Conservation Review Sector 12. Sealochs in the Clyde Sea: area summaries.* Peterborough, Joint Nature Conservation Committee. (Coasts and Seas of the United Kingdom. MNCR series.)

Ferrier, S., Pressey, R.L. & Barrett T.W. (2000). A new predictor of the irreplaceability of areas for achieving a conservation goal, its application to real-world planning, and a research agenda for further refinements. *Biological Conservation* **93** 303-325.

Gilliland, P.G. (2001). *Understanding and managing human activities*. In: *EN, SNH, CCW, EHS (DOENI), JNCC and SAMS 2000. UK marine SACs project. Partnerships in Action.* Proceedings of a Conference held in Edinburgh 15-16 November 2000. English Nature, Peteborough.

Golding, N., Vincent, M.A. and Connor, D.W. (2004) *Irish Sea Pilot - Report on the development of a Marine Landscape classification for the Irish Sea.* JNCC. Available at www.jncc.gov.uk/irishseapilot.

Joint Nature Conservation Committee (1999). *The Birds Directive: Selection guidelines for Special Protection Areas.* JNCC, Peterborough. 6pp.

Laffoley, D. d'A., Connor, D.W., Tasker, M.L. & Bines, T. 2000. *Nationally important seascapes, habitats and species. A recommended approach to their identification, conservation and protection*.. Prepared for the DTR Working Group on the Review of Marine Nature Conservation by English Nature and the Joint Nature Conservation Committee. Peterborough: English Nature Research Reports, No. 392. 17 pp.

Lieberknecht, L. M.; Vincent, M. and Connor, D. W. (2003) *Criteria for the selection of nationally important marine areas. Irish Sea Pilot – interim report for consultation.* www.jncc.gov.uk/Marine/irishsea_pilot/pdfs/consultation_Sept2003/Marine_areas.pdf

Lieberknecht, L. M., Vincent, M.A. and Connor, D. W. (2004) *The Irish Sea Pilot - Report on the identification of nationally important marine features in the Irish Sea*. JNCC. Available at www.jncc.gov.uk/irishseapilot.

Lumb, C., Webster, M., Golding, N., Atkins, S. and Vincent, M.A. (2004) *Irish Sea Pilot – Project boundary, collation and mapping of data.* JNCC. & online at www.jncc.gov.uk/irishseapilot.

McLeod, C.R., Yeo, M., Brown, A.E., Burn, A.J. and Way, S.F. (Eds) (2002). *The Habitats Directive: selection of Special Areas of Conservation in the UK.* 2nd Edition. JNCC, Peterborough.

Moore, J.; Smith, J.; Northen, K. O. & Little, M. (1998). *Marine Nature Conservation Review Sector 9. Inlets in the Bristol Channel and approaches: area summaries.* Peterborough, Joint Nature Conservation Committee. (Coasts and Seas of the United Kingdom. MNCR series.)

Nature Conservancy Council (1989). *Guidelines for selection of biological SSSIs*. NCC, Peterbrough.

Pollitt, M.S., Hall, C., Holloway, S.J., Hearn, R.D., Marshall, P.E., Musgrove, A.J., Robinson, J.A. & Cranswick, P.A. (2003). *The Wetland Bird Survey 2000-02: Wildfowl and Wader Counts*. BTO/WWT/RSPB/JNCC, Slimbridge.

Reid, J B, Evans, P G H, Northridge, S P (2003) *Atlas of cetacean distribution in north-west European waters.* Joint Nature Conservation Committee, Peterborough.

Roberts, C. M.; Gell, F. R. and Hawkins, J. P. (2003) *Protecting nationally important marine areas in the Irish Sea Pilot Project Region. Irish Sea Pilot – Interim Report for Consultation.* www.jncc.gov.uk/Marine/irishsea_pilot/pdfs/consultation_Sept2003/Protecting_marine_areas.pdf

Rogers, S.; Allen, J.; Balson, P.; Boyle, R.; Burden, D.; Connor, D.; Elliott, M.; Webster, M.; Reker, J.; Mills, C.; O'Connor, B.; and Pearson, S. (2003). *Typology for the Transitional and Coastal Waters for UK and Ireland*. (Contractors: Aqua-fact International Services Ltd, BGS, CEFAS, IECS, JNCC). Funded by Scotland and Northern Ireland Forum for Environmental Research, Edinburgh and Environment Agency of England and Wales. SNIFFER Contract Ref: WFD07 (230/8030).

Stewart, R.; Noyce, T. and Possingham, H. P. (2003) Opportunity cost of ad hoc marine reserve design decisions: and example from South Australia. *Marine Ecology Progress Series* **253: 25-38**

Tyler-Walters, H., Lear, D.B. & Hiscock, K. (2003). *Irish Sea Pilot - Mapping sensitivity within marine landscapes.* Report to the Joint Nature Conservation Committee from the Marine Life Information Network (MarLIN), Plymouth.

United Nations (2002). *Report of the World Summit on Sustainable Development*. Johannesburg, South Africa, 26 August - 4 September 2002. United Nations, New York.

8 Appendices

8.1 Biotope complexes recorded in individual estuaries

Table 8.1. Distribution of biotope complex data across the Irish Sea estuaries in relation to a SIMPER profile for the data set as a whole. The second column show percentage contribution to similarity scores for biotope complexes, as determined in the SIMPER carried out on the entire data set. Numbers in all the other columns show the number of records within each estuary that are labelled with particular biotope complex codes. All codes are taken from Connor *et al.*, 2003.

Biotope complex	% Contribution. to similarity	Aeron	Carew	Cleddau	Clyde	Dwyfor	Ffraw	Fleet	Lune	Nefern	Pilanton	Bach	Cree	Dee	Duddon	Dyfi	Malltraeth	Mawddach	Mochras	Nyfer	Solway	Teifi	Dysynni	Mersey	Ystwyth	Esk, Mite, Ir	Kent	Leven	Ribble
LS.LMu.UEst	27.23	1	8	8		2			1			4			3	6	1	48	1	1	18	6	5	10	1	7			2
LS.LMu.MEst	17.16						1	1	1			6	3	1	5	6	1	40	3		34	1		3		6	1	1	3
LR.LLR.FVS	12.68	2				1		1	2			3	1	2		4		8		4	14	4			3	10	1		
LS.LSa.MuSa	11.57							1	1		1	44	1	4	10	1		60		1	84	1		1		3	6		6
LR.LLR.F	9.92							2	1	1	3		2	2	1			2		2	34	4				2		2	
LS.LSa.FiSa	5.58							1				9		2		5	1	29	1	2	5	4	1						2
LR.FLR.Lic	4.3							2				1		3	1	2		3		1	24	3			1		1	1	
LR.FLR.Eph	3.12								3				1	1	2						13					10	1	1	2
LS.LSa.MoSa	2.98											10			4	10	1	37		1	6	2		2		2			
LS.LMx.L	2.41								1					1			1	1		1	1				1	3			2

Biotope complex	% Contribution. to similarity	Aeron	Carew	Cleddau	Clyde	Dwyfor	Ffraw	Fleet	Lune	Nefern	Pilanton	Bach	Cree	Dee	Duddon	Dyfi	Malltraeth	Mawddach	Mochras	Nyfer	Solway	Teifi	Dysynni	Mersey	Ystwyth	Esk, Mite, Ir	Kent	Leven	Ribble
Mus																					4								
LR.HLR.MusB	1.57				1			2							1						12	4				1		1	
LR.FLR.Rkp	0.97							2							1					2	6	1						1	
LS.LMp.Sm	0.27																	1	1		26					1			1
SS.SMu.EstMu	0.1		1	2																									
LR.MLR.MusF	0.08							1							1						2								
LR.MLR.BF	0.02														1			1			13								
LS.LMx.GvMu	0.02												1					2			1								
LR.MLR.Sab	0.01																				3					1			
LR.FLR.CvOv	0.01													1							1								
LS.LSa	0.01								1												2								
LS.LSa.ST	0.01															1					8								
LR	0																				31								
LR.HLR.FT	0		2																										
LR.MLR	0																				1								
LS	0																				6								
LS.LCS.S	0																				3								

Biotope complex	% Contribution. to similarity	Aeron	Carew	Cleddau	Clyde	Dwyfor	Ffraw	Fleet	Lune	Nefern	Pilanton	Bach	Cree	Dee	Duddon	Dyfi	Malltraeth	Mawddach	Mochras	Nyfer	Solway	Teifi	Dysynni	Mersey	Ystwyth	Esk, Mite, Ir	Kent	Leven	Ribble
h																													
LS.LMU	0																				4								
LS.LMX	0																				21								
LS.LMp.LSgr	0																				3								
SS.SSa.IFiSa	0																				4								
SS.SSa.IMuSa	0																				2								
SS.SSa.EstSa	0																				30								
SS.SMu.ISaMu	0																				1								
SS.SMx.EstMx	0			3																									
IR.LIR.K	0		4																										
IR.MIR.KT	0		1																										

8.2 Summary of Marxan solutions

Table 8.2. Summary of the results from running each of the scenarios in Marxan. Abbreviations: targets = targets set for scenario 1; blm = boundary length modifier, BD = high biodiversity areas and areas with more than eight species from the Irish Sea provisional list locked in; est = estuaries identified as nationally important in section 3 locked in; nat 3a = naturalness incorporated as described for scenario 3a; nat 3b = naturalness incorporated as described for scenario 3b; cSACs = cSACs locked in; SPAs = SPAs locked in; lower targ = targets set as described for scenario 6c.

Scenario	Description	BLM	Number of Targets unmet	Area (ha) in best solution for each scenario
1	targets only	0	0	754195
2	targets with blm	5	0	1404392
3a	3a naturalness	5	13	923638
3b	3b naturalness	5	0	1519335
4a	4a BD est	5	0	1668230
4b	4b BD est (nat 3a)	5	13	1377635
4c	4c BD est (nat 3b)	5	0	1346679
5a	5a BD est cSACs (blm 2)	2	0	2020215
5a	5a BD est cSACs (blm 5)	5	0	2470079
5b	5b BD est cSACs (nat 3a)	5	13	1686328
5c	5c BD est cSACs (nat 3b)	5	0	1830599
6a	6a BD est cSACs SPAs (blm 2)	2	0	2030403
6a	6a BD est cSACs SPAs (blm 5)	5	0	3778253
6b	6b BD est cSACs SPAs (nat 3b)	5	0	2256192
6c	6c BD est cSACs SPAs (lower targ)	5	0	1890388