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Systematic conservation planning in the eastern English Channel: comparing the Marxan and Zonation decision-support tools

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Abstract :

The systematic conservation approach is now commonly used for the design of efficient marine protected area (MPA) networks, and identifying these priority areas often involves using specific conservation-planning software. Several such software programmes have been developed in recent years, each differing in the underlying algorithms used. Here, an investigation is made into whether the choice of software influences the location of priority areas by comparing outputs from Marxan and Zonation, two widely used conservation-planning, decision-support tools. Using biological and socio-economic data from the eastern English Channel, outputs are compared and it is shown that the two software packages identified similar sets of priority areas, although the relatively wide distribution of habitat types and species considered offered much flexibility. Moreover, the similarity increased with increasing spatial constraint, especially when using real-world cost data, suggesting that the choice of cost metric has a greater influence on conservation-planning analyses than the choice of software. However, Marxan generally produced more efficient results and Zonation produced results with greater connectivity, so the most appropriate software package will depend on the overall goals of the MPA planning process.

Keywords : eastern English Channel ; marine conservation planning ; Marxan ; spatial conservation prioritization ; Zonation

1. Introduction

The 1992 Convention on Biological Diversity set the ambitious target of establishing, by 2012, a global system of marine protected areas (MPAs) covering 10% of all marine ecological regions, comprising both multiple-use areas and strictly protected areas. MPAs are increasingly seen as important instruments for conserving biodiversity and maintaining fish stocks (Leathwick *et al.*, 2008), and there is some evidence of their potential benefits in the management of fisheries (Halpern and Warner, 2002; Gell and Roberts, 2003). In its strategy for the marine environment (EC, 2008), the European Commission (EC) is also promoting the idea of marine spatial planning (MSP) to provide a framework to improve decision-making and delivering an ecosystem-based approach to the management of marine activities. MSP is also expected to provide a more transparent process of conflict resolution in situations where there are many demands for the use of marine resources and sea space.

This context has led to renewed interest in developing methods for designing efficient MPA networks (Smith *et al.*, 2009). In particular, it is widely recognized that conservation planners must account for opportunity costs and potential biodiversity loss when designing MPA systems. This has led to the widespread adoption of the systematic conservation-planning approach (Margules and Pressey, 2000; Margules and Sarkar, 2007), which is a target-driven process that aims to identify networks of priority areas for ensuring the representation and long-term persistence of biodiversity (Margules *et al.*, 2002; Leslie *et al.*, 2003). Setting targets helps increase transparency and measure progress, but it also allows socio-economic data to be included in the planning process without influencing or endangering conservation goals. Thus, MPA networks can be designed so that they meet targets, whilst also minimizing impacts on stakeholders and increasing the likelihood of their successful implementation (Knight *et al.*, 2006).

Systematic conservation planning generally involves: (i) producing a list of important species and habitat types, known collectively as conservation features; (ii) setting targets for each of these conservation features; (iii) dividing the planning region into a series of planning units; (iv) calculating the amount of each feature found in each planning unit; (v) assigning a cost value to each planning unit; and (vi) using computer software to identify priority areas for conserving biodiversity, reducing fragmentation levels and minimizing planning unit costs (Moilanen *et al.*, 2009a). A number of conservation-planning software packages have been produced, several of which have been used to design MPA networks (e.g. Leslie *et al.*, 2003; Fernandes *et al.*, 2005; Klein *et al.*, 2008a; Leathwick *et al.*, 2008). However, this has created some uncertainty amongst practitioners about whether the location of the identified priority areas varies with the software used. Here, we investigate this issue by comparing results from Marxan and Zonation, two of the most widely used conservation-planning, decision-support tools (Moilanen *et al.*, 2009a).

Marxan uses a minimum-set approach to identify portfolios of planning units that achieve conservation targets at a near-minimal cost. It does this by first defining the cost of a portfolio as an objective function made up of (i) the combined cost of the planning units in the portfolio, which can be a measure of any aspect of the planning unit, such as its area, the risk of being affected by anthropogenic impacts, or the opportunity costs resulting from protection; (ii) a penalty for each unmet target; and (iii) a spatial constraint cost reflecting the portfolio's fragmentation level (Ball and Possingham, 2000; Possingham *et al.*, 2000). The spatial constraint is based on the boundary length of the portfolio, as fragmented portfolios have more of this exposed edge. Reducing this fragmentation involves adding more planning units to the portfolio, producing more viable, but less efficient, results (Ball and Possingham, 2000).

In contrast, Zonation uses a maximum-cover approach that aims to maximize the conservation benefits for a fixed cost specified by the user by first calculating the marginal loss for each of the cells in the planning region (Moilanen *et al.*, 2005; Moilanen *et al.*, 2009b). It then removes cells one at a time based on maximizing the overall conservation value of the remaining area to produce a conservation-value map based on the hierarchical ranking of the landscape. This conservation-value map then forms the basis of further analyses, and Zonation has a range of options for incorporating connectivity and viability into the prioritization process (Arponen *et al.*, 2006; Cabeza and Moilanen, 2006; Moilanen *et al.*, 2009b).

This means the approaches that underpin Marxan and Zonation are fundamentally different, with Marxan seeking to minimize costs, while meeting specified targets, and Zonation seeking to maximize biodiversity benefits given a specified cost. However, the Zonation outputs can be modified to identify priority areas for meeting specified targets, and this is why marine conservation planners have used both software packages to identify MPA networks based on a target-setting approach (e.g. Klein *et al.*, 2008b; Leathwick *et al.*, 2008). Given these differences, one might expect Marxan and Zonation to identify different sets of priority areas, which could create confusion and doubt about the value of both software packages. Alternatively, one might assume that results should be similar because areas that are needed to meet targets will always be selected, and this was found in earlier work that compared outputs between Marxan and C-Plan, another reserve-system-design tool (Carwardine *et al.*, 2007). In addition, one might expect similar results when using real-world cost data in the analyses, such as information on opportunity costs or threats. This is because these data have a specific spatial pattern within the planning region, and so the same low-cost areas containing important biodiversity tend to be selected (Richardson *et al.*, 2006; Nhancale and Smith, 2011). Therefore, in this paper, we use data from the eastern English Channel to investigate whether priority-area and conservation-value maps produced by Marxan and Zonation differ and whether this is sensitive to the conservation target and the type of cost metric used in the analysis.

2. Material and methods

2.1. Study area

The English Channel is a shallow epi-continental sea located in the temperate Northeast Atlantic, covering approximately 77 000 km² and separating the south coast of the United Kingdom from the north coast of France (Dauvin, 2008). The English Channel has two distinct parts, the western and eastern, both of which have markedly different oceanographic characteristics and which can be regarded as different ecosystems (Vaz *et al.*, 2007; Coggan and Diesing, 2010). The eastern English Channel (Figure 1) is a biogeographical transition zone between the warm temperate Atlantic oceanic system and the boreal North Sea, and encompasses a wider range of ecological conditions than other European seas (Dauvin, 2008; Carpentier *et al.*, 2009). The area is shallow (<50 m) and is strongly influenced by the River Seine. The eastern English Channel is not only important from an ecological point of view, but is of considerable economic value for fisheries, maritime traffic, marine aggregate extraction, and other sectors (Martin *et al.*, 2009).

2.2. Mapping the physical data

Five environmental parameters were selected to describe the range of ecosystems found in the eastern English Channel: depth, temperature, sediment type, salinity, and bed-shear stress. Depth combined bathymetry and mean sea level. Bathymetric data were derived from SHOM (Service Hydrographique et Océanographique de la Marine) hydrographic charts, whilst mean sea level (at mid-tide) was estimated using a hydrodynamic model. Temperature and salinity data were measured *in situ* during IFREMER's Channel Ground Fish Survey (CGFS, 1997–2006) and were used to estimate anomalies (observed surface temperature or salinity minus the mean for the area surveyed) and bottom–surface differences. Seabed shear-stress estimates were obtained from a 2D hydrodynamic model originally developed for the Irish Sea, but extended to cover the northwest European shelf (Carpentier *et al.*, 2009). Seabed sediment types were extracted from a sediment map of the English Channel (Larsonneur *et al.*, 1982), in which the original 29 sediment classes were aggregated into the following five broader classes: (i) fine sand, (ii) coarse sand, (iii) fine heterogeneous sandy gravel, (iv) coarse heterogeneous sandy gravel, and (v) pebbles. We used this sediment type map because previous studies in the eastern English Channel showed that benthic invertebrate communities (San-Vicente Añorve, 1995) and fish, cephalopods, and macroinvertebrate species assemblages (Vaz *et al.*, 2007) were related to substrate type.

We classified the depth and seabed shear-stress maps into five types based on quantile values. Temperature and salinity exhibited less variation, so we used the same approach to divide these into three types. This classification system produced maps that contained an equal area of each type, so that each broad range of the physical environment would be represented in the final portfolios. However, it should be stressed that this is a preliminary approach and that there is a need for a better classification that takes into account the temporal dynamics and biodiversity value of these different types of physical phenomena.

2.3. Mapping the biological data

We used two types of biological distribution data in the analyses: a habitat map based on benthic invertebrate communities to represent broader biodiversity, and eight species-distribution maps to represent "fine-scale" biodiversity patterns (Noss, 1990). We selected these eight additional species because they are economically and ecologically important and ensured the representation of species with offshore and inshore spatial distributions (Table 1). This study aimed at comparing outputs from the different software packages, so it was not deemed necessary to include a large number of species in this exercise.

2.4. Designing the conservation planning system

We produced the planning unit theme by creating a series of 5629 16-km^2 grid squares using the repeating-shapes extension in ArcView 3.2 and then calculated the area of each conservation feature found in each planning unit. Because some of the planning units overlapped the coastline, less of their area fell within the planning region. For these overlapping planning units, we calculated their area within the planning region by clipping them with the coastline boundary and used these area values as the basis of the planning unit costs. Thus, planning units that only contained a small amount of the English Channel tended to contain less of each conservation feature, but also had a lower cost.

We carried out nine Marxan and nine Zonation analyses by using three different planning-unit cost metrics and three different sets of targets. Cost metric 1 was "area cost", which was based on the surface area of each planning unit, so that all the planning units had the same cost value apart from those located at the edges of the planning region. Cost metric 2 was "accessibility cost", which was also based on the surface area, but values were reduced by 50% in planning units considered more likely to be suitable for inclusion in a MPA network based on current human activity patterns. Thus, lower values were given to planning units falling within the 3-nautical-mile zone, where trawling is restricted, and within shipping lanes and ferry routes, where fishing pressure is reduced (Figure 1). Cost metric 3 was "fishing cost", which was based on the fishing profitability of the planning unit, using official data from the French Maritime Fisheries and Aquaculture Office (undertaken by the IFREMER-Halieutic information system) that was then modified to weight the costs by the distance to the nearest French port. French vessels dominate fisheries in the eastern English Channel (Martin *et al.*, 2009). The number of vessels vary, but, for example in 2005, 641 French boats and 49 English boats over 10 m were recorded (Carpentier *et al.*, 2009), so this cost variable was only based on data from the French Maritime Fisheries and Aquaculture Office and French ports.

In each analysis, we used the same percentage target for all the habitat types and species, but in the different analyses, we used targets of 10, 30, and 50%. The 10% target has been commonly applied in the literature, but has also been criticized for not being ecologically relevant (Pressey *et al.*, 2003), and the 30% target is currently recommended by the IUCN (IUCN, 2003) and has also been used in previous studies (Klein *et al.*, 2008b). The maximum target of 50% has a stronger ecological basis, but is rarely used in conservation planning because it is assumed to be too politically contentious (Soule and Sanjayan, 1998). However, it should be noted that the English and French MPA agencies have developed or are developing their own targets (e.g. JNCC and Natural England, 2010).

2.5. Marxan and Zonation analyses

As described above, Marxan and Zonation use different approaches for identifying priority areas and measuring conservation value, so we needed to select methods and outputs that were most comparable. In terms of methodology, this involved choosing the following options in Zonation: (i) the target-based cell removal rule to produce the priority-area map, so that Zonation sequentially removes the lowest-value planning unit from its conservation-value map, as long as that planning unit is not needed to meet the targets for the different features (Moilanen, 2005), and (ii) the boundary-length-penalty (BLP) option, which most closely resembles the BLM factor in Marxan (Moilanen, 2007; Moilanen and Wintle, 2007).

Identifying suitable outputs was relatively straightforward, although it is important to understand the differences in the software packages. A Marxan analysis involves running the software a number of times and producing a near-optimal, but often different, portfolio at the end of each run. It then identifies the best portfolio as the one with the lowest cost, and produces a selection-frequency output by counting the number of times each planning unit appeared in the different portfolios (Ball *et al.*, 2009). In this analysis, we used the best output as Marxan's priority-area map and the selection-frequency output as Marxan's conservation-value map. Thus, Marxan's priority-area map can change between different analyses, and the extent of its near-optimality tends to increase with the number of runs used. Similarly Marxan's conservation-value map can vary between analyses, although these differences tend to be much smaller because each output is based on a number of runs.

In contrast, Zonation produces the same conservation-value map for a given set of inputs, based on the same hierarchical-ranking output, and also produces the same priority-area map for meeting the specified targets. Despite these differences, conservation practitioners use the outputs in similar ways: both priority-area maps show areas that are needed to meet the specified targets, and both conservation-value maps show the relative importance of each planning unit for meeting the conservation objectives.

We undertook nine analyses using Marxan and Zonation to run assessments based on the three different planning-unit cost metrics (Table 2) and the three different targets: 10, 30, and 50%. The Marxan analyses involved running the software 100 times, with each run consisting of one million iterations. After conducting a sensitivity analysis, we used a BLM value of 5 in all three subsequent Marxan analyses, as this best balanced efficiency and portfolio-fragmentation levels (Possingham *et al.*, 2000; Carpentier *et al.*, 2009), and used a target-penalty factor of 100 000 for each conservation feature to ensure that Marxan identified portfolios that met all the targets. The Zonation analyses used the target-based removal rule to identify portfolios that best met the targets, and we selected the BLP value to ensure the lowest boundary length/area value.

We used the Marxan and Zonation conservation-value maps to measure the impact of using different planning-unit cost metrics. We did this by first using a quantile classification in ArcGIS to convert both outputs into maps divided into 10 classes of equal area based on their measure of conservation value. Thus, each planning unit was given a ranking value from between 1 and 10 for both software outputs, and we then used Spearman Rank tests to determine the similarity of the outputs, although we did not record the significance values for these tests because the data were influenced by spatial autocorrelation (Balmford *et al.*, 2001; Nhancale and Smith, 2011). We also investigated the priority-area maps produced by the two different software packages and tested for differences in total area, number of patches, and median patch size using a Wilcoxon Signed Rank test. Finally, we tested whether the priority areas selected by Zonation had higher Marxan conservation-value scores using Mann–Whitney tests.

3. Results

The conservation-value maps produced by Marxan and Zonation were both strongly influenced by cost metric, with similar areas being identified as important (Figure 2). However, important areas were widely scattered when using the area metric, more likely to occur around the coast and the shipping lanes in the Dover Strait when using the accessibility metric, and more likely to occur on the English side of the planning region when using the fishing metric. Using higher targets tended to increase the number of planning units with high conservation-value scores (Figure 2). Zonation outputs generally consisted of more rectangular patches of planning units, whereas the important areas in the Marxan outputs had less regular boundaries (Figure 3; Table 5). The conservation values of the planning units calculated by Marxan and Zonation were correlated and varied with cost metric (Table 3). The results also broadly showed that correlations were higher with increasing conservation targets and when using the fishing-cost metric.

In general, the planning units that were identified as part of the Zonation priority-area maps had higher Marxan selection-frequency scores than those planning units that were not selected by Zonation, with the exception of the 10% targets and accessibility cost-metric analysis (Table 4). Marxan generally produced smaller priority-area systems than Zonation (N = 9, Z = –2.429, p = 0.015), but there was no pattern with median patch size or number of patches. There was a linear relationship between priority-area extent and targets, so that priority-area extent ranged between 11 821 km^2 for the 10% target- and area-cost metric Marxan analysis and 67 583 km^2 for the 50% target- and accessibility-cost metric Zonation analysis (Figure 4), but there was no obvious trend with number of patches and median patch size (Table 5).

4. Discussion

Systematic conservation planning is a widely used approach for designing MPA networks, and most planning assessments rely on computer software to identify priority areas for conservation. These software packages are based on the same principles, but generally use different approaches for measuring conservation value and selecting portfolios of planning units. This has created some confusion amongst conservation practitioners about which software to use and whether this affects the results. Our analysis investigated this issue using the Marxan and Zonation software packages and data from the eastern English Channel. In this section, we discuss whether it is possible to compare the two software packages, given their underlying differences, and go on to discuss how these results are influenced by the application of different cost metrics and targets in the analysis. Finally, we provide suggestions on how practitioners should collect and use data to minimize the influence of these software packages on their results to help produce more relevant results.

4.1. Comparing software packages

Marxan uses the minimum-set approach to identify priority areas for meeting specific targets, whereas Zonation uses the maximum-coverage approach to identify priority areas given a fixed budget. Despite this, the software outputs can be compared because Zonation can adapt its ranked hierarchy output to identify the best areas for meeting targets, which it does by sequentially removing the least important planning units until further removal impacts target attainment. However, this ranked hierarchy output is based on the maximum-cover approach, so it will always be impossible to make exact comparisons between the two packages. Moreover, this comparison is further complicated by the different spatial constraints used by the software packages and the difficulty in determining equivalent BLM and BLP values. We used a standard approach for determining both sets of values, based on balancing the relative planning unit and boundary-length costs, but it is likely that their influence on the results differed.

It should also be noted that the conservation features and targets that we used in the analysis were designed to emphasize any differences in the results from the two software packages. This is because most of the conservation features were widely distributed, and the targets were never more than 50% of these distributions. Thus, there was a large amount of flexibility in the planning region, with no planning units always being needed to meet certain targets, and many planning units having similar conservation value. In such scenarios, it is likely that the spatial constraints would have a relatively large influence on which planning units were selected; therefore, differences in the way that the spatial constraints are used may have produced these effects. This is in contrast to previous work comparing results from Marxan and C-Plan, another conservation planning package, which used higher relative targets and included no spatial constraints and found that conservation-value outputs were very similar (Carwardine *et al.*, 2007).

Despite these differences, it should be noted that the two software packages still produced similar results. Whilst the priority areas identified were not identical, which was expected given the flexibility in the system, there was definite overlap, and the Zonation priority areas had significantly higher Marxan selection-frequency scores in almost all the scenarios that investigated the influence of cost metrics and targets (Table 4). Moreover, the strength of this similarity increased when using real-world cost data, such as the accessibility- and fishing-cost metric. This was because using these cost metrics reduced flexibility so that planning units with similar biodiversity value differed in terms of cost, making low-cost units more important (Smith *et al.*, 2008) and more likely to be selected by both software packages (Table 3). Priority-area extent increased with increasing targets, but this relationship was more linear with Marxan than with Zonation. This may be because Zonation tended to select larger and more connected patches, although some of the Zonation outputs also included a number of small fragments, which masked any difference in patch size and number when comparing Marxan and Zonation. Thus, we found that Marxan tended to produce more efficient priority-area networks and Zonation produced networks that had higher levels of connectivity.

4.2. Implications for designing MPA networks

Our analysis identified three broad aspects that can help inform marine conservation planners when deciding what types of data should be included in their conservation assessments and what type of software they should use. First, we found that, although making direct comparisons between Marxan and Zonation was not straightforward, the results were not highly affected by which software package was used and that the differences were reduced when using real-world cost data. Thus, conservation planners should select the software they consider most appropriate, based on the aims of the project and the additional functionality of the different packages. Second, we found that the conservation-value scores of most of the planning units used in our analysis were generally low, which was probably the main reason for the differences in the results from Marxan and Zonation. This arose because most of our conservation values were widely distributed and the targets were relatively low, which meant that there were many similar planning units and, hence, a great deal of flexibility in which ones were selected. This can be overcome by including some conservation features with more limited distributions into the conservation assessment, rather than relying on broad-scale and modelled habitat- and species-distribution data.

The third main finding echoes that from previous studies, which shows that the type of planning unit cost-metric plays a large role in determining the location of the priority areas (Klein *et al.*, 2008a; Ban and Klein, 2009). We found that using real-world data not only produced more robust results, as described above, but it also significantly shifted the location of the areas selected by Marxan and Zonation. Thus, using the accessibility cost meant that most priorities were found around the coast and in major shipping lanes, whereas using the fishing cost meant that most priorities were found on the English side of the planning region. This highlights the importance of choosing an appropriate cost metric when developing a conservation-planning system to inform decision makers in the region. However, this is likely to be challenging given that not only do multiple nations share access to the same resources, but the English Channel is commercially important for fishing, transport, aggregate extraction, and energy production sectors (Martin *et al.*, 2009).

Our fishing-cost metric also highlights the problems of using direct financial value in conservation assessments, as this can overly impact marginalized groups (Adams *et al.*, 2010). In this case, the English fishing fleet consists of fewer and smaller boats, so establishing MPAs in English waters would have a smaller impact on the financial value of the catch. However, establishing more MPAs in English waters would have large impacts on the local economies and societies, and any plans advocating such changes would be politically untenable. Thus, our results confirm evidence from a number of studies which show that the value and success of conservation assessments generally depends much more on understanding and reflecting the social conditions found in a planning region (Smith *et al.*, 2009) rather than on the type of selection algorithm or conservation-planning software used. If MPAs are designed to address both conservation and management issues, they will have to be implemented based on a larger set of criteria than those used in the present study. In addition to better descriptors of the socio-economic context, future analyses should account for the population dynamics of exploited species, as well as the essential habitats for the completion of their life cycles, such as the location of spawning and nursery grounds. Moreover, it may be necessary to dynamically link conservation-planning outputs to bioeconomic models (Mahévas and Pelletier, 2004) to be able to evaluate the medium- to long-term effect of the proposed MPA network on both the exploited population and fishery viability.

MPAs are now expected to be possible management tools in the context of ecosystem-based management of fisheries (Pauly *et al.*, 2002). Although some findings relating to coral reefs led to recommendations that 20–30% of each marine habitat should be closed to exploitation (Hughes *et al.*, 2003; Roberts *et al.*, 2003), there are many types of MPAs, with management arrangements ranging from multiple-use to strict protection within “no-take zones”. In complex systems such as the English Channel or the North sea, MPA networks will have to be designed with different levels of conservation management (Watts *et al.*, 2009) to enable a full MSP exercise. Finally, and more importantly, developing a coherent MPA network for areas shared amongst many countries will need to move away from current national approaches, which are limited to the Exclusive Economic Zone, and to work on a scale that is relevant to the eco-region. This requires international collaboration and shared access to both biological and socio-economic data, which was the approach adopted in this study.

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Tables

Table 1. Species used as representative features.

Common name	**Latin name**	**Development stage**
Herring	*Clupeus harengus*	<1 year old and >1 year old
Cod	*Gadus morhua*	All ages
Tope	*Galeorhinus galeus*	All ages
Veined squid	*Loligo forbesis*	All ages
Plaice	*Pleuronectes platessa*	<1 year old and >1 year old
Spider crab	*Maja brachydactyla*	All ages
Lesser-spotted dogfish	*Scyliorhinus canicula*	All ages
Spurdog, spiny dogfish	*Squalus acanthius*	All ages

Table 2. Parameters used in the three sets of analyses.

Metric	**Marxan BLM value**	**Zonation BLP value**	**Cost layer**
Area	5.0	0.5	Area of planning unit
Accessibility	5.0	10.0	Area of planning unit, but reduced by 50% for inshore areas and shipping lanes
Fishing	5.0	0.0	French fishermen profitability

Table 3. Spearman rank correlations of the conservation-value scores produced by Marxan and Zonation based on the three different targets and cost metrics.

Metric	10%	30%	50%
Area	0.270	0.284	0.554
Accessibility	0.249	0.394	0.133
Fishing	0.720	0.830	0.788

Table 4. Results from Mann–Whitney tests for the Marxan selection-frequency scores of planning units falling inside and outside the priority areas identified by Zonation.

Cost metric	10%	30%	50%
Area	15.29*	12.97*	34.83*
Accessibility	0.18	20.14*	25.45*
Fishing	35.79*	52.79*	50.29*

*$p < 0.001$

Table 5. Spatial characteristics of the portfolios identified by both Marxan and Zonation based on the three different cost metrics and targets.

Target	Cost metric	Number of patches		Median patch area (km²)		Total area of portfolio (km²)	
		Marxan	Zonation	Marxan	Zonation	Marxan	Zonation
10%	Area	8	6	1315.8	3200.0	11821.4	20047.9
10%	Accessibility	11	6	384.0	3200.0	13380.6	20047.9
10%	Fishing	8	34	509.4	40.0	16334.7	19167.9
30%	Area	8	8	857.3	432.0	27855.0	25514.3
30%	Accessibility	12	3	1038.5	6015.4	26493.6	28695.8
30%	Fishing	19	27	4141.5	32.0	28810.9	31613.9
50%	Area	9	6	15.4	40.0	45333.4	54863.9
50%	Accessibility	6	4	336.0	40.0	47879.8	67583.8
50%	Fishing	9	15	384.0	16.0	21007.8	55823.9

Figures

Figure 1. Parameters used to define the planning-unit costs.

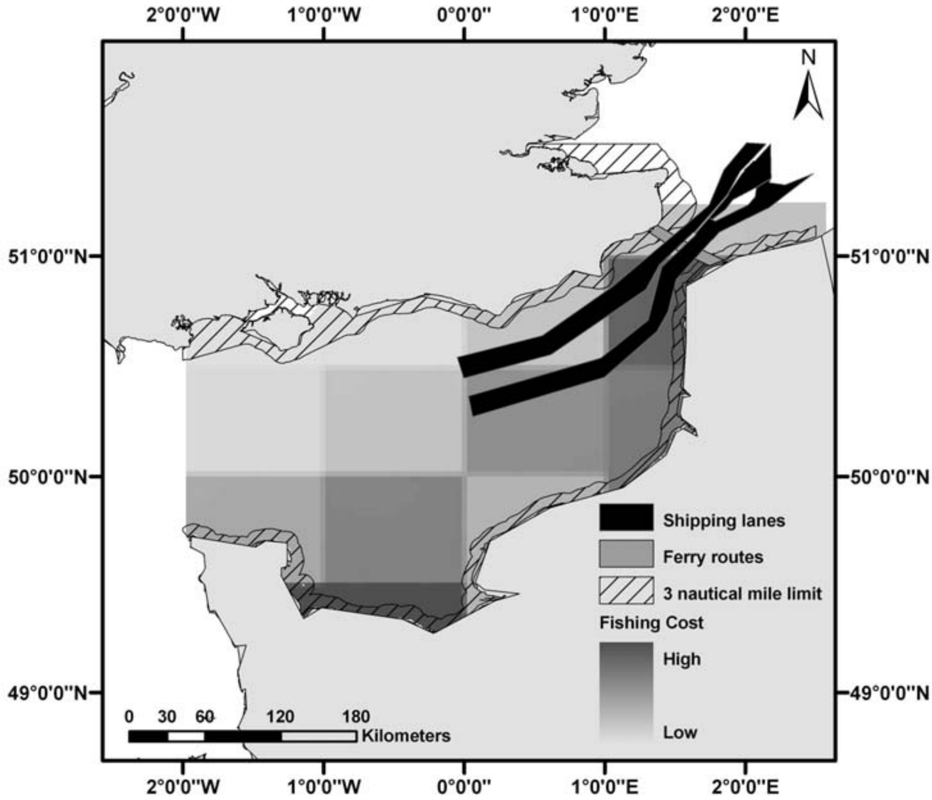

Figure 2. Conservation-value maps for Marxan (a–i) and Zonation (j–l) based on the three different targets and cost metrics. The conservation value for Marxan is based on selection frequency and for Zonation is based on the hierarchical solution output. There are only three maps for Zonation because the hierarchical solution output is a nested output and does not change when using different targets.

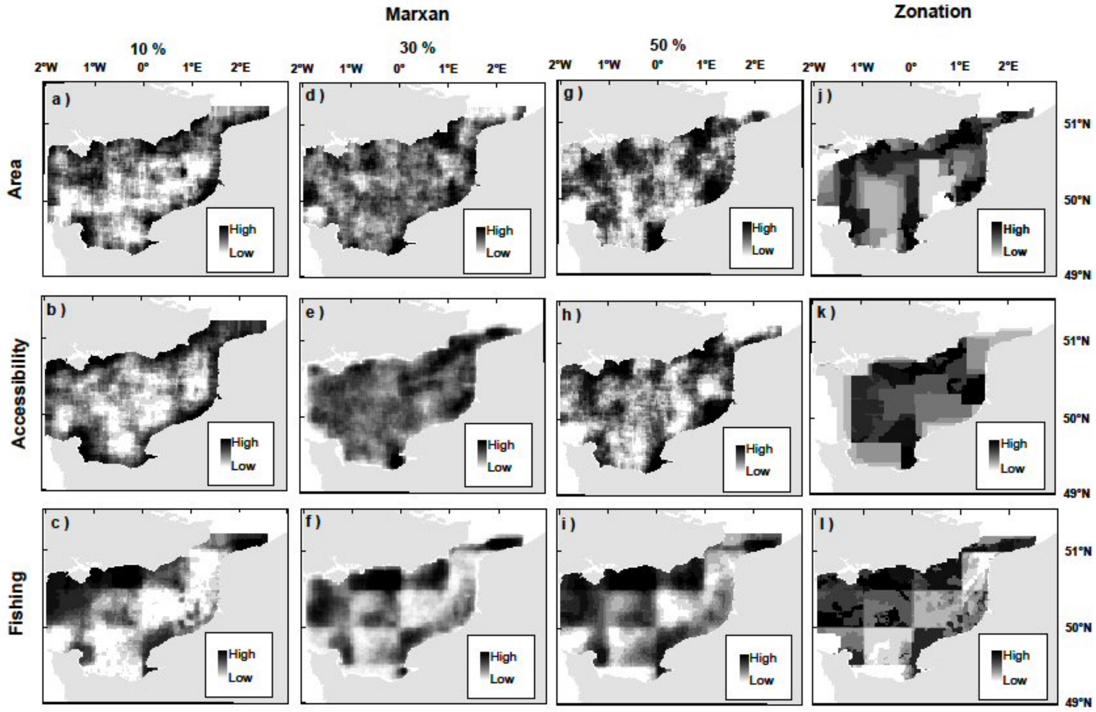

Figure 3. Priority-area maps identified using Marxan and Zonation based on the three different targets and cost metrics.

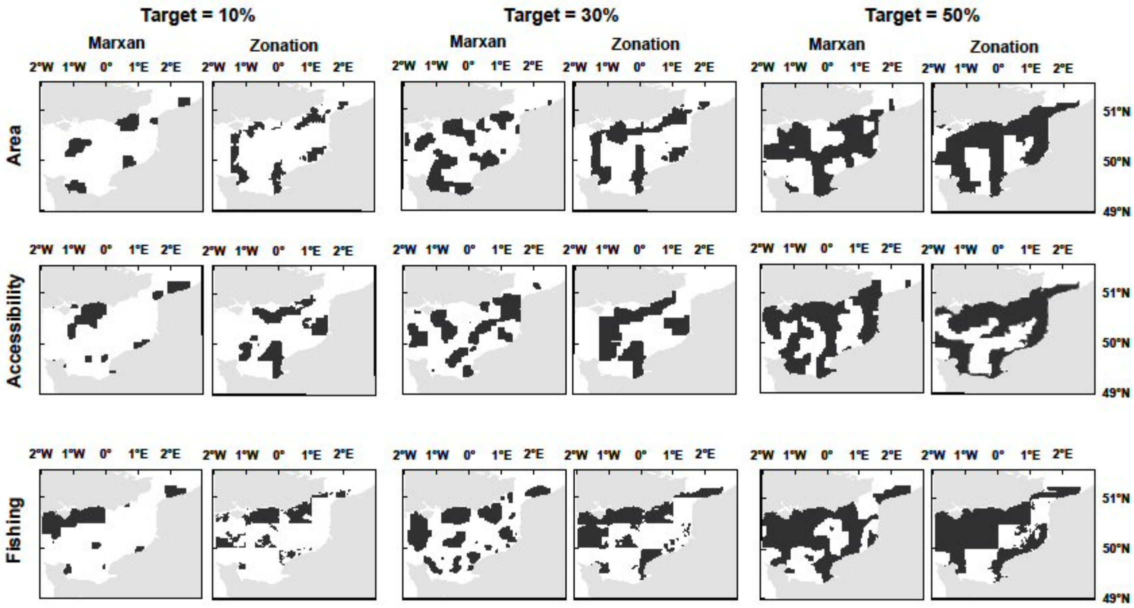

Figure 4. Area of priority areas identified by Marxan and Zonation based on the three different cost metrics and increasing targets.