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A review of methodologies that could be used to formulate ecologically meaningful targets for marine habitat coverage within the UK MPA network

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Summary

- Humans have many competing interests on the use of space (i.e. land, water, and air) and resources on Earth. The conservation of biodiversity is only one of these interests; others include activities with a well known economic return (e.g. agriculture, farming, estate building, fishing, and aquaculture). For this reason planning for the current and future use of space and resources needs overarching, broad goals to be stated, along with explicit, quantitative targets that are derived from these goals.

- While the formulation of broad goals is usually semantically vague, targets should be as quantitative as possible. Targets provide a clear purpose for conservation decisions, and allow the measurement of the success during various implementation phases of the plan. Targeted biodiversity features can include species, habitat types, communities, ecosystems, and more recently ecosystem services.

- Irrespective of the size and location of the planning area, data on the distribution of biodiversity are always incomplete and patchy. Formulation of explicit targets involves therefore the interpretation of goals through the filter of available data on the biodiversity of the region. While broad goals might have long-term relevance targets should have shorter life-spans.

- Under proposals in the Marine and Coastal Access Act 2009, the selection of Marine Conservation Zones (MCZs) will need to take account of both ecological and socio-economic data in the identification of proposed sites. The Marine and Coastal Access Act 2009, in effect, focuses on the broad goal of *persistence* of marine biodiversity through a *network* of Marine Protected Areas. In addition to numerical quantitative targets for biodiversity features, the goal of biodiversity persistence requires the appropriate *design* of the network of protected areas.

- The objective of this study is to assess which approaches can be used to formulate ecologically meaningful percentage ranges for the coverage of EUNIS level 3 marine habitat types and 'habitats of conservation importance' within an MPA network.

- This report reviews the relevant literature on formulating ecologically meaningful targets for habitat coverage within a protected area network. This included published peer-reviewed journal articles and unpublished grey literature, with research findings and conservation plans from around the world covering terrestrial and marine ecosystems. This review assesses the amount and quality of data required by each approach against the data available for the task, and a SWOT analysis is undertaken to evaluate the methodologies reviewed.

- The existing methodologies for target identification for habitat types can be broadly divided into five categories: (1) methods that identify fixed percentage targets to be applied across all habitats; (2) methods that identify variable targets for habitats based on the fit of a species-area curve; (3) heuristic methods applied to a variety of specific goals; (4) methods that aim at the protection of habitat types indirectly, by protecting the habitat of selected focal species; and (5) methods that trade off target size with some measure of expected impact of the protected area network on other human interests and activities.

- The category of heuristic methods can be further subdivided on the basis of the specific goal that they are applied to. Habitat types can in fact be used as surrogates of different structural and functional components of biodiversity, e.g. species and communities, ecological processes, ecosystem services.

- No single ideal method for target setting exists. The SWOT analysis identified relevant weaknesses and threats for all methods, with some methods appearing to be weaker than others.

- The methods that identify fixed targets that are constant across all habitats are not suitable, because they exclusively rely on generic literature and do not use any real data on the distribution of biodiversity in the planning area. The methodology that trades-off the size of target with some measure of cost is not suitable because it does not use biodiversity data and its application can lead to incorrect results. The methodologies based on Population Viability Analyses of focal species require large amounts of species-specific and habitat-specific data on population dynamics that are not available in the UK.

- The methodology to formulate targets based on the fitting of habitat-specific species-area curves is suitable for the formulation of targets in the case considered by this study, because it makes use of biodiversity data on the planning area. Yet it only aims at the representation of species in a network of protected areas (biodiversity patterns), not at the persistence of these species, which requires specific design criteria.

- Heuristic methods can accommodate a variety of specific goals (conservation of biodiversity patterns, processes, ecosystem services). They can also accommodate biodiversity data of variable quality and quantity. In this respect, they are the most flexible methods applicable to the formulation of biodiversity targets.

- Heuristic principles can be used to formulate targets on ecological processes, because no quantitative methods to formulate targets for these components of biodiversity exist yet. This review recommends that ecosystem services should only be used to target marine habitats if data is readily available.

- The apparent pattern of available biodiversity datasets suggests that the amount and quality of data decrease from the coast outwards. Therefore, this review recommends that the planning area be divided in two parts: the sub-area between the coast and the limit of the territorial waters, and the sub-area between the limit of the territorial water and the limit of the continental shelf. The target for marine habitat coverage should be formulated separately for the two sub-areas because they differ in the amount and quality of data.

- The targets for marine habitat coverage should be composite for two reasons: (1) EUNIS level 3 habitat types are mapped as polygons while 'habitats of conservation importance' are mapped as sampled points, therefore the methodologies that can be applied to the two datasets are different; and (2) no single methodology exists to formulate targets that are valid at the same time for habitat types as surrogates of structural (patterns) and functional (processes) components of biodiversity.

- The composite target for the EUNIS habitat types should be formulated as follows: (1) as a surrogate of biodiversity patterns, baseline percentage targets can be formulated by using the species data in the Marine Recorder database to estimate habitat-specific z values to fit species-area curves; and (2) if the level of threat to each biotope can be estimated at least qualitatively, then the percentage targets can be increased based on a heuristic rule that links the percentage increase to the level of threat.

- The composite target for habitats of conservation importance' should be formulated as follows: (1) as these habitats are represented as points, species-area curves cannot be used. Therefore, to use them as a surrogate of biodiversity patterns (species representation), heuristic methods need to be developed; and (2) if levels of threat to each habitat can be estimated at least qualitatively, the percentage targets can be increased based on a heuristic rule that links the percentage increase to the level of threat.

- The best way to proceed in order to estimate the minimum size of protected sites is to identify the target ecological processes to be conserved by the network. Each of these processes will take place at a spatial scale that can be identified at least approximately and should guide the decisions on the minimum size. Given the constraint of the overall proportion of each biotope and habitat type to be conserved, the minimum size of protected sites will also determine also the approximate number of replicates for each habitat type in the MPA network.

Contents

1 Introduction

Humans have many competing interests on the use of space (i.e. land, water, and air) and resources on Earth. The conservation of biodiversity is only one of these interests; others include activities with a well known economic return (e.g. agriculture, farming, estate building, fishing, and aquaculture). For this reason planning for the current and future use of space and resources needs overarching, broad goals to be stated, and explicit, quantitative targets that are derived from these goals. Broad goals reflect the societal value and political or institutional intent (Tear *et al* 2005) and steer future decisions (Noss 1999). Goals should include, but not be limited to, the conservation of biodiversity. This has not been the case in the past and as a result, most protected areas worldwide have been placed in sites chosen due to their low economic value, including high mountains and deserts ("the land that nobody wanted") (Pressey 1994). The practice of limiting protection of biodiversity to areas of little economic value, also known as "ad-hoc" reservation, has consistently led to inefficient conservation action and unsatisfactory conservation results.

While the formulation of broad goals is usually semantically vague (e.g. "achieve the persistence of biodiversity"), targets should be as quantitative as possible. Biodiversity targets are interpretations of broad conservation goals set by experts and stakeholders, and indicate how much of each biodiversity feature is needed for it to be conserved (usually in the long term). Targeted biodiversity features can include species, habitat types, communities, ecosystems, and more recently ecosystem services. Setting numerical targets makes the planning approach more transparent and open to stakeholder involvement, and less likely to be affected by political interference (Cowling *et al* 2003). Targets provide a clear purpose for conservation decisions, lending them accountability and defensibility (Pressey *et al* 2003). Furthermore quantitative targets allow the measurement of the success during various implementation phases of the plan. At an early stage, when sites for the conservation of biodiversity are identified, targets are used to quantify the contribution of sites towards the achievement of targets. Over time targeted elements of biodiversity can be monitored and their trends estimated, allowing the comparison of the observed trends with the benchmark of targets. This highlights when and where conservation management needs to be modified and adapted.

Irrespective of the size and location of the planning area, data on the distribution of biodiversity are always incomplete and patchy. Formulation of explicit targets involves the interpretation of goals through the filter of available data on the biodiversity of the region. Due to the need to be quantitative, biodiversity targets are constrained by the availability of information (Margules and Pressey 2000). Even if focussing on a small subset of biodiversity features, often conservationists have to set targets based on a limited knowledge and limited availability of biodiversity data. The major limitation of setting conservation objectives is uncertainty about the data used to define the requirements of features. Biodiversity surrogates are always a partial solution to the problem, as land types are only an approximate surrogate for ecosystem and individual taxonomic groups are only approximate surrogates for other groups in conservation planning (Brooks 2004, Cowling 2004, Pressey 2004). Yet data and undocumented knowledge on biodiversity are always open to review and their amount and quality is expected to increase over time. Therefore, while broad goals might have long-term relevance for regional planning, targets should have shorter life-spans. Targets are provisional estimates of the requirements for persistence of a region's biodiversity made within the constraints of limited information, and as such it has been suggested that they be reassessed every five years (Pressey *et al* 2003).

The incomplete information used to set quantitative targets for biodiversity conservation may be perceived as a major limitation. Yet this is not necessarily the case. A recent study (Stewart *et al* 2007) compared a reserve network chosen in a single step, to a reserve network chosen in several steps, with targets being modified (enlarged) at each step. The second reserve network simulated a real process of sequential adjustment and addition of protected areas to a reserve network over time. The authors did not find any significant loss of efficiency in the second case: even if collecting more data led to increased reservation, the enlargement of targets did not diminish the value of the areas chosen in the first steps. This is an indication that reserve networks selected on the basis of incomplete information (all real-world reserve networks) do serve the purpose of biodiversity conservation. It is particularly important to note that their finding applied only when protected areas were chosen using the principles and methods of systematic conservation planning (Margules and Pressey 2000). When they repeated the analysis starting from a reserve network that had been chosen ad-hoc, Stewart and colleagues (2007) found that the gradual addition of protected areas to the reserve network was highly inefficient. This highlights the importance of using systematic conservation planning principles and tools when planning a network of protected areas.

The issue of developing targets for biodiversity conservation has promoted a lively debate in the policy-making and scientific communities over the last 15 years, and a vast range of different approaches with mixed inputs from the two communities have been developed. Svancara *et al* (2005) made a literature review of prominent references addressing the issue of conservation targets and divided the approaches into four categories: (1) policy driven to evidence based: policy targets with little or no scientific grounding; (2) quantitative targets chosen a priori for comparative or definitive purposes; (3) results from conservation planning exercises or assessments; and (4) research results that identified thresholds (percentages of suitable habitat) at which habitat fragmentation or loss has deleterious effects on the feature(s) of interest.

The most widely known example of a large-scale, data-free, policy-driven, percentage-based conservation target is the 10% (or 12%) target set by the World Parks Congress (McNeely and Miller 1984, IUCN 1993). Percentage targets in general refer to the proportion of the Earth's surface that should be protected in order to achieve the goal of biodiversity conservation. Politically convenient (Solomon *et al* 2003) and so called "acceptable" conservation targets that aim to set aside 10–15% of total land (and water) areas for conservation purposes have been heavily criticised because they are ecologically irrelevant. These targets potentially undermine the goal of biodiversity protection (Soulé and Sanjayan 1998); are rarely sufficient to ensure the persistence of populations (Wood 2007); may fail to adequately sample regional or global ecotypes, biomes or vegetation types, and ensure that ecological processes are functioning adequately and persist over time (Pressey *et al* 1996). Furthermore aiming to a fixed, uniform percentage target for all ecosystems may lead towards the dangerous tendency to create a false sense of security that conservation issues are being dealt with adequately (Agardy *et al* 2003).

Although the limitations of fixed percentage targets are well known, in 2003 the World Parks Congress recommended that the minimum targets for the protection of marine biodiversity features should be 20-30% of each habitat (WPC 2003). Since then the 20% figure has become an unofficial standard for the minimum proportion of a habitat or ecosystem type that must be delineated as no-take Marine Protected Area (MPA) in order for the MPA network to be effective in protecting natural resources. The US Coral Reef Task Force has set a national target of 20% coverage for no-take MPAs in coral reefs under US jurisdiction, and the figure has been proposed as a potential target for all marine ecosystems in a number of countries including the USA, Australia, Bahamas, Canada, Galapagos Islands, Philippines, and South Africa, without open objective discussion on possible shortcomings of doing so in all situations (Agardy *et al* 2003). Similarly, fixed percentage targets have been recommended by the Science Advisory Panel of the Marine Reserves Working Group for developing a network of marine reserves in the California Channel Islands (Airame *et al*

2003) and have been used by Leslie *et al* (2003) for the identification of conservation priorities for different marine benthic habitats of the Florida Keys.

Many authors strongly advocate that policy-driven, data-free conservation targets be abandoned (Solomon *et al* 2003, Svancara *et al* 2005, Wiersma and Nudds 2006). With the development of a variety of conservation planning approaches, tools, and guidelines, there is no longer the need to rely on simple and flat policy-driven numbers. These should be replaced with targets informed by conservation planning processes that are based simultaneously on the biological needs of species, communities, and ecosystems. The consequences of these changes are huge - on average the size of evidence-based conservation targets is nearly three times larger than that of targets resulting from policy-driven approaches (Svancara *et al* 2005). Data-driven target quantification provides the evidence that a large share of the Earth needs protection if most of biodiversity is to persist. Yet the fact that this target may seem unachievable should not deter scientists and policy makers from setting it. On the contrary, the biodiversity target needs to be scientifically credible and robust, so that any shortfalls on the target as a result of the trade-off between biodiversity conservation and other interests can be quantified explicitly.

1.1 Context and scope of this work

The Joint Nature Conservation Committee (JNCC) is working with the UK Government to support the development of an ecologically coherent network of Marine Protected Areas within UK waters. Under the Marine and Coastal Access Act 2009, the selection of Marine Conservation Zones (MCZs) will need to take account of both ecological and socio-economic data in the identification of proposed sites.

The Marine and Coastal Access Act 2009 is the legislation that will provide for the designation of Marine Conservation Zones (i.e. Marine Protected Areas, MPA) in UK waters. Clause 119 of the Act (“Creation of network of conservation sites”) states that:

> “ *[...] (2) The objective is that the MCZs designated by the appropriate authority, taken together with any other MCZs designated under section 113 and any European marine sites that have been established in the UK marine area, form a network which satisfies the conditions in subsection (3).*
>
> *(3) The conditions are - (a) that the network contributes to the conservation or improvement of the marine environment in the UK marine area; (b) that the features which are protected by the sites comprised in the network represent the range of features present in the UK marine area; (c) that the designation of sites comprised in the network reflects the fact that the conservation of a feature may require the designation of more than one site.*”

The Marine and Coastal Access Act 2009 in effect focuses on the broad goal of *persistence* of marine biodiversity, because conservation and improvement of the marine biodiversity (“the network contributes to the conservation or improvement of the marine environment”) requires that the components of biodiversity persist over time. Both the Act and the UK Government's vision strongly support the idea that this should be achieved through a *network* of Marine Protected Areas. In addition to numerical quantitative targets for biodiversity features, the goal of biodiversity persistence requires the appropriate *design* of the network of protected areas (Cowling 1999, Cowling *et al* 1999, Cowling *et al* 2003). Design refers to the spatial components of a network of protected areas, including: the number of separate occurrences of biodiversity features to be included in the MPA network (replication); the minimum size of each protected site (viability); the minimum and maximum separation distance between MPAs (connectivity); and the location of new MPAs with respect to the existing ones. The design of MPAs is covered in separate reports (Roberts *et al* in prep.) and will not be taken into account in this report, with two exceptions: the minimum size of patches for biodiversity features, and the minimum number of replicates per biodiversity feature in the network.

Conservation targets can be divided into two categories based on the scale to which these are applied. Coarse-filter approaches set targets for features such as vegetation, ecosystems, habitat types, or land classes; while fine-filter approaches use species or populations (Desmet and Cowling, 2004). Representing all native ecosystem types and communities within protected areas constitutes the coarse filter; but some rare and vulnerable species and natural communities would be inadequately protected by coarse filters. Therefore, a second fine filter is necessary to ensure effective conservation (Tear *et al* 2005). JNCC are working towards the identification of both broad-scale features and features of conservation importance. As such, this report focuses on quantitative targets for these features. The features considered here will be the EUNIS level 3 marine habitat types (Appendix I) and the provisional list of habitats considered to be habitats of conservation importance (Appendix II) as defined by JNCC. Although many of the general considerations made in this report apply to conservation targets for all kinds of biodiversity features, the recommendations will be specific to the two sets of features mentioned above.

A systematic conservation plan requires that the planning area is subdivided into planning units (sometimes called sites), and that each planning unit can potentially be selected for inclusion in the network of protected areas (apart from some planning units that for various reasons cannot be devoted to conservation and therefore may be excluded *a priori* from the selection process). A final map of planning units for the systematic identification of new Marine Conservation Zones has not yet been agreed upon, but currently a map is in use with square planning units of $4km^2$ inside UK territorial waters and of $10km^2$ between the limit of territorial waters and the external boundary of the planning area (A. Aish and B. Stoker pers. comm.). In this report I will assume that whatever the final size and shape of planning units will be, they will be of the same order of magnitude of those currently in use.

The latest developments of systematic conservation planning (work undertaken by the laboratory of Prof. H. Possingham at the University of Queensland) include tools for the systematic identification of zones with different contributions to the achievement of conservation targets (zoning). The process of developing the MPA network at present is not explicitly dealing with zoning, and the software for systematic zoning (MarZone) has not yet been officially released. Therefore, this report does not deal with the identification of separate quantitative targets for habitat types in different types of zones.

1.2 Objectives

1. To review the approaches that can be used to formulate ecologically meaningful percentage ranges for EUNIS level 3 marine habitat types within an MPA network (Appendix I);
2. To review the approaches that can be used to formulate ecologically meaningful percentage ranges for 'features of conservation importance' coverage within an MPA network (Appendix II);
3. To assess which approach(es) (with regard to both Objectives 1 and 2) might be best applied in the UK marine environment in order to achieve the UK Government’s vision; and
4. To review the application of alternative approaches to ensuring adequate habitat coverage within the MPA network, for example those based on minimum habitat ‘patch sizes' and number of replicates per feature in the network.

2 Methodology

2.1 Literature review

This report reviewed the relevant literature on formulating ecologically meaningful targets for habitat coverage within a protected area network. This included published peer-reviewed journal articles and unpublished grey literature, with research findings and conservation plans from around the world covering terrestrial and marine ecosystems.

Much literature on conservation planning was already available to the author, along with half of the relevant literature on targets. The collection of additional peer-reviewed literature was undertaken through searching on the following parameters:

- keywords: “target AND conservation planning”; “objective AND conservation planning”; “representation AND conservation planning”; “persistence AND conservation planning”; "representation target"; "conservation target"; “conservation objective”; "marine conservation planning";
- key authors: R. Cowling, P. Desmet, H.P. Possingham, R.L. Pressey, M. Rouget, S. Sarkar, R.J. Smith.

The following search engines were used:

- Scopus;
- Web of Science;
- ConserveOnline;
- ScienceDirect; and
- Google Scholar.

Forward search of literature was also undertaken, enabling the identification of recent literature that cited selected fundamental papers. Technical reports and other grey literature were searched through Google and Google Scholar. In addition to searching literature through web engines, key references on target setting were obtained directly from colleagues around the world (L. Boitani, R. Cowling, A. Falcucci, E. Game, H. Grantham, A. Lombard, L. Maiorano, E. Nicholson, H.P. Possingham, R.L. Pressey, R.J. Smith, R. Stuart, K.A. Wilson).

After a preliminary review of the initial literature found, a decision tree was developed in order to focus the review on subjects relevant to the objectives of the present work (Figure 1).

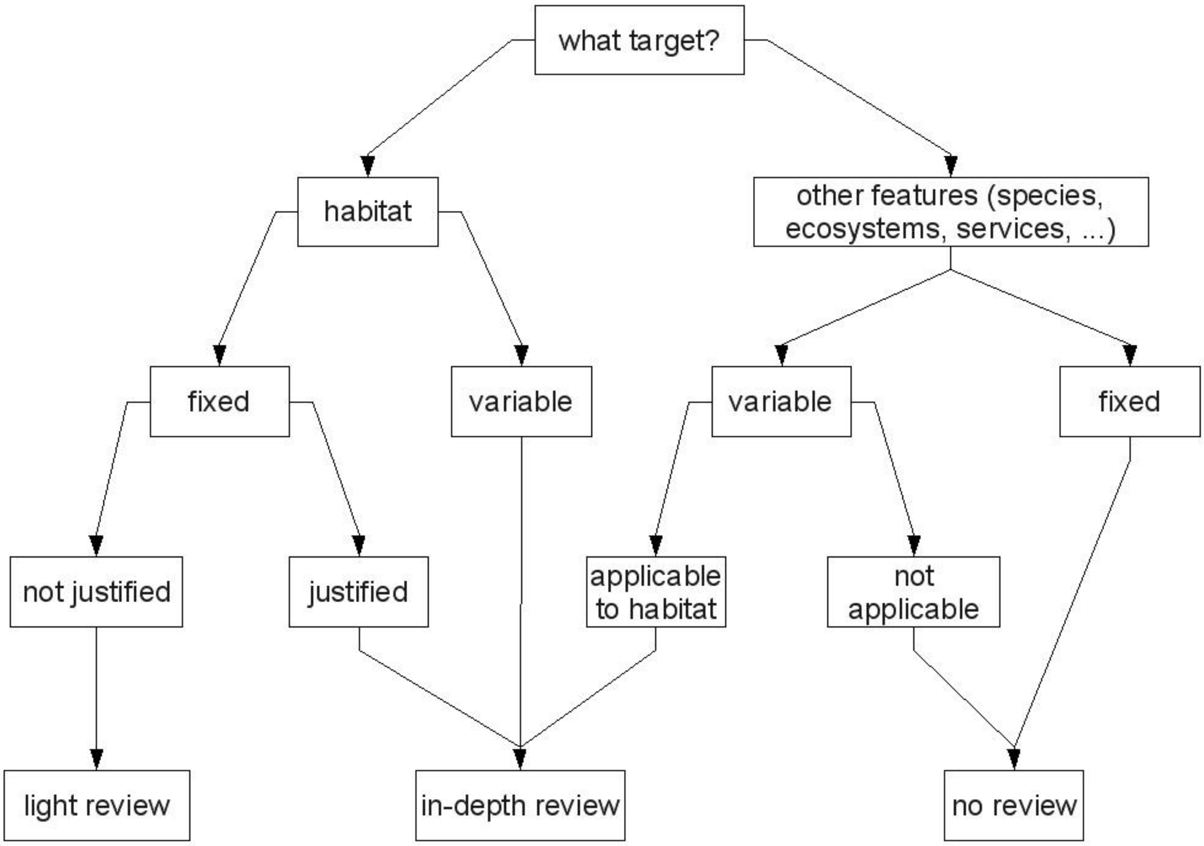


Figure 1. Decision tree for the screening of collected literature

The literature reviewed was divided into the following categories: papers and reports dealing with fixed targets with little or no scientific grounding, either for habitat types or for other biodiversity features; and papers and reports dealing with variable targets (based on research results that identify specific thresholds and use scientific methodologies such as population viability analysis or species-area relationships), either for habitat types or for other biodiversity features. The papers and reports dealing with variable targets were further subdivided into the following categories:

- heuristic principles to represent species (fixed target);
- species-area relationship applied to habitat types to represent species;
- heuristic principles applied to habitat types to protect species and ecological processes;
- heuristic principles applied to habitat types to protect ecosystem services;
- target-area (target-cost) trade-off; and
- targets based on Population Viability Analysis for selected (focal) species.

Each paper and technical report reviewed was briefly commented, and a subset selected for short case studies on the application of each methodology and its outcome. An electronic database of the reviewed literature was developed both in BibTex and EndNote format. Tabular data on the literature reviewed were stored in a spreadsheet, summarising the relevant existing approaches to target setting (Appendix 3). The spreadsheet contains the following fields:

- citation;
- biological realm (terrestrial, freshwater, marine);
- study area;
- targeted biodiversity feature(s);
- target type (fixed or variable);
- target justification (if present);applicability of methodology to habitats;
- brief description of methodology; and
- selected for case study (yes/no).

2.2 Assessment of applicable approaches and recommendation

2.2.1 Synthesis and data requirements of each approach

A synthesis of each of the types of approach to target setting was made, taking into account the following aspects and with particular attention to the details regarding the types and amount of data required:

- goal (representation, persistence);
- scope of applicability;
- data requirements;
- scientific soundness;
- objectivity and repeatability;
- frequency of use; and
- defensibility.

The types and amount of available data that are directly related or can be related to the EUNIS level 3 marine habitat types (Appendix I), and to the 'habitats of conservation importance' (Appendix II) as defined by JNCC. The assessment also took into account that more information and data may become available within a few months (A. Aish and B. Stoker pers. comm.), and therefore can potentially be used to set quantitative biodiversity targets for the expansion of the MPA network. All the data were kindly provided, or described *in litt.* if not yet available, by B. Stoker of JNCC.

2.2.2 Suitability of available data for each approach (SWOT analysis)

In order to assess the feasibility of the application of each methodology to the identification of biodiversity targets for the development of the MPA network, a cross-table between data requirements of each approach and data availability on marine habitat types and habitat types was created. Those methodologies for which enough data were available to quantify biodiversity targets were retained for the subsequent SWOT analyses.

A SWOT analysis is a method for strategic planning that aims to highlight the Strengths, Weaknesses, Opportunities and Threats of a project (Table 1). Although originally developed to assess an objective, a SWOT analysis can be applied to analyse and compare methodologies, as is the case in this study. Strengths and Weaknesses are factors internal to the methodology (for example, the level of scientific rigour and repeatability), while Opportunities and Threats are factors external to the methodology (for example, data quality and quantity).

Table 1. Elements of a SWOT analysis

	Helpful	**Harmful**
External factors	Strengths	Weaknesses
Internal factors	Opportunities	Threats

Based on the assessment, this study provides the following outputs:

- a recommendation of the methodology which might be best applied to the UK marine environment. The recommendation is tailored to the data available on the target habitats, and to the 3-4 months time frame suggested by JNCC for the application of the methodology to set the quantitative targets;
- operational guidelines for the application of the selected methodologies to the existing data on UK marine habitat types; and
- a synthesis of the selected approach to be circulated among selected stakeholders in order to assess the transparency and comprehensibility of the approaches.

2.3 Quality control procedures

In order to avoid pitfalls that may lower the quality of the work at various stages and may lead to an incorrect recommendation, the actions detailed in Table 2 were undertaken.

Table 2. Procedures applied for quality control during the review and assessment process.

Pitfall	**Action**
Review of literature that is out of topic	Review keywords periodically during literature search and keep focused on these keywords; rapid assessment of literature for relevance to the topic before in-depth assessment.
Incomplete review of the available literature	Periodical cross-check of agreement between literature found using different methods (keywords, key authors, key cited references)
Drift during the process of evaluating of reviewed literature	At an intermediate and final stage of the literature review, re-evaluation of a sample of papers assessed at the early stages
Wrong estimation of the data and time needed to apply each methodology	Work out with the highest possible detail the actions that need to be taken to apply the methodology, in order to identify which data are necessary and estimate the time needed to gather them.
Incorrect report language	Get feedback on draft report.

3 Results

3.1 Summary of literature review

Overall 71 items (papers and technical reports) were retained for review after the initial screening outlined in the methods (Figure 1). Of these, 15 papers are literature reviews or broad discussions on topics related to conservation targets or to marine conservation planning; and 17 are "conceptual" papers that deal with a number of issues relevant to the subject of this study. Of the remaining studies:

- 23 apply a fixed percentage target across all habitats to be protected;
- Four used the species-area relationship to formulate variable percentage targets for habitat types, aimed at the representation of a given proportion of species (Desmet and Cowling 2004, Ferrar and Lotter 2007, Rouget *et al* 2004, Smith and Leader-Williams 2006);
- Two papers (Lombard *et al* 2007, Pressey *et al* 2003) applied heuristic principles to formulate variable percentage targets for habitats with the aim to represent biodiversity patterns and protect ecological processes;
- One paper (Chan *et al* 2006) applied heuristic principles to formulate variable percentage targets for habitats with the aim to conserve a given proportion of selected ecosystem services;
- One paper (Justus *et al* 2007) fitted a regression between size of the biodiversity target and area (as a surrogate of cost) of the reserve network needed to achieve that target, with the aim to trade-off between the two; and
- Two papers (Burgman *et al* 2001, Carroll *et al* 2003) used a Population Viability Analysis on selected species to quantify variable targets for their conservation (with this latter methodology, the target on habitat types is secondarily derived from the target on species).

The full list of papers reviewed, with a synthetic comment on the aim and methods of each paper, is provided in Appendix 3.

3.2 Detailed description of reviewed methodologies used to quantify targets

For each reviewed methodology one or two case studies were selected as a worked example of its application to a real conservation planning issue (Table 3).

Table 3. Selected case studies

Methodology	Reference	Target features	Study area
Heuristic principles to represent species (fixed target)	Neely *et al* 2001	species, communities, and ecological systems	Southern Rocky Mountains
species-area relationship on habitat to represent species	Desmet and Cowling 2004	land classes	Succulent Karoo, South Africa
	Rouget *et al* 2004	vegetation types, wetlands, estuaries and species	South Africa
Heuristic principles on habitats to protect biodiversity patterns and processes	Pressey *et al* 2003	land classes; locality records for plant species, species of reptiles, amphibians and freshwater fish; estimated distributions and densities of large and medium-sized mammals; and six types of spatial surrogates for ecological and evolutionary processes	Cape Floristic Region, South Africa
	Lombard *et al* 2007	species, benthic habitats and ecosystem processes	Prince Edward Islands
Heuristic principles on habitats to protect ecosystem service	Chan *et al* 2006	biodiversity and ecosystem services	Central Coast ecoregion of California
Target-area trade-off	Justus *et al* 2008	different surrogates (species, vegetation types, environmental parameters)	6 different regions
Target based on PVA for selected species	Carroll *et al* 2003	species	Rocky Mountains

3.2.1 Heuristic principles to represent species (fixed targets)

i Data required

A well-established relationship exists between habitat area and the number of species that an area can support (species-area relationship) (MacArthur & Wilson 1967). Loss of habitat tends, over time, to result in the loss of species within an approximate range (Neely *et al* 2001). On this basis, the approximate amount of species that is expected to be retained in a given proportion of the original habitat can be inferred (Figure 2).

The method is entirely based on data existing in the literature, which are used to parameterise the species-area curve which is calculated from the following equation:

$$S = cA^z$$

Where S is the number of species, A is the area, c a constant, and z the parameter to be estimated. Average values of z from the literature are commonly around 0.3. If S and A are replaced with proportion of species and proportion of area (S' and A') there is no need to estimate the constant c.

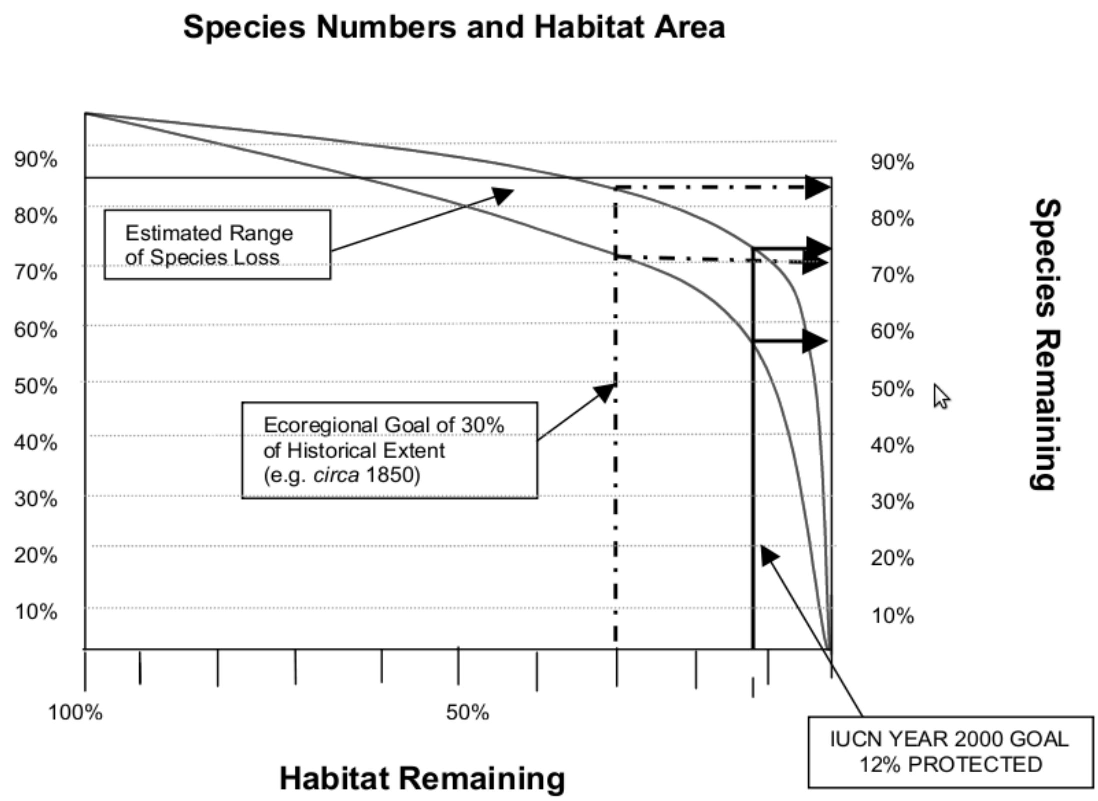


Figure 2. Proportion of species retained as a function of the proportion of original habitat that is conserved (from Neely *et al* 2001).

ii Case study

Neely *et al* (2001) implemented an assessment of the Southern Rocky Mountains (SRM) eco-region in the USA. The features to be conserved included both coarse-scale features (39 terrestrial ecological systems and 107 aquatic ecological systems) and fine-scale features (79 rare plant communities, 177 plants, and 206 animals). Ecological systems, both aquatic and terrestrial, were used to represent a broader level of biological diversity across the eco-region. The team selected the fine filter features based on their imperilment, vulnerability, endemism, declining status, and the inability of coarse-scale measures to conserve them.

Conservation targets were expressed in different forms, depending on the typical spatial pattern of the feature occurrences. For matrix-forming, large-patch, and linear ecological systems, they expressed conservation targets as 30% of estimated historic extent (ca. 1850), while targets for small-patch types were expressed as numbers of occurrence. The authors chose 1850 as that period that marks the approximate beginning of the most extensive and rapid human/technology-driven changes to SRM ecosystems, and is recent enough to reflect vegetation patterns under modern climatic conditions and therefore provides a useful and important reference point. In addition to setting a goal for area extent, the team used two approaches to represent proportionally all large-patch, linear, and matrix-forming systems across all major physical gradients. First, all systems were represented in each of the eco-regional sections or ecological drainage units of their natural distribution. Second, the team programmed the site selection software to apply percent targets to vegetation/ecological land unit combinations and aquatic system/macro-habitat combinations.

For setting species targets, the team had too little information on population quality so they established the initial conservation targets for species using the species' conservation status and its distribution relative to the eco-region.

The primary outcome of this assessment was an eco-regional portfolio of protected areas, based on the best available and current information, representing the targeted species, natural communities, and ecological systems of the SRM. The portfolio consisted of 188 sites representing roughly 50% of the eco-region.

3.2.2 Heuristic principles applied to habitats to protect biodiversity patterns and processes

i Data required

In order to capture biodiversity patterns and processes in a MPA network design, a clear understanding of their spatial and temporal variability within the study area is required. Patterns emerge and processes operate at a variety of scales, which should be recognized in MPA network design. Qualitative and quantitative design criteria may be used to indicate preferences of planners when choices are available. In the lack of quantitative data, heuristic principles can be applied. These include rules of thumb, transformation of ordinal scales into quantitative thresholds (e.g. three levels of threat into increasing percentage targets for habitat types), and even educated guesses. These require planners to interpret qualitative knowledge of specific processes.

ii Case study 1

The 2003 Cape Action Plan for the Environment has been called, "one of the most detailed and explicit conservation plans to date for any part of the developing world" (Balmford 2003). This systematic conservation planning exercise covered the Cape Floristic Region of South Africa, a global biodiversity hotspot (Cowling *et al* 2003). A special issue of Biological Conservation (112: 1–297) illustrates this conservation assessment with 15 papers working their way through a modified version of Margules and Pressey's (2000) framework for systematic conservation planning (Balmford 2003).

Pressey and colleagues (2003) in a paper of this special issue deal with the formulation of explicit, quantitative targets. They proposed several heuristic principles for setting targets for 102 habitat types, 364 plants of the Proteaceae family, 345 vertebrates in the Cape Floristic Region of South Africa, estimated distributions and densities of 41 species of large and medium-sized mammals; and six types of spatial surrogates for ecological and evolutionary processes (Table 4). This last task involves first identifying those processes in need of special attention, then developing spatial surrogates for them, and finally setting targets for the capture of those features. The formulation of the target for species is not described in detail here because it is not relevant for the objective of this study.

Table 4. Summary of targets set for biodiversity features in the Cape Floristic Region reproduced from Cowling *et al* (2003), see Pressey *et al* (2003) for details.

Feature	No. entities	Baseline target	Retention target	Total target (baseline+retention)
Land classes				
Broad habitat units (BHUs)	102	10–25%	0–30%	10–55%
Species				
Proteaceae taxa	364 spp.			
	176,082 popns	5–10 popns	0–5 popns	5–15 popns
Non-mammal vertebrates	345 spp.			
	8472 popns	1 popn.	0–1 popns	1–2 popns
Large and medium-sized mammals	41 spp.	0–2000 individuals (200 for 31 spp.)	n.a.	0–2000 individuals
Processes				
Edaphic interfaces	8	0–120km interface		
Upland–lowland interfaces	146	0–508km interface		
Sand movement corridors	6	386–7959 ha		
Inter-basin riverine corridors	6	106–1520km of corridor		
Upland–lowland gradients	55	1–218km		
Macroclimatic gradients	3	263–617km		

iii Targets for broad habitat units

Pressey *et al* (2003) formulated targets for Broad Habitat Units (BHU) taking into consideration: differences in requirements for protection and the estimated “original” extent, preceding intensive land use, native vegetation in each BHU. Requirements for protection can be inferred from: factors such as physical or biological heterogeneity (more heterogeneous types need more extensive protection); natural rarity; and vulnerability to threats such as vegetation clearing. The advantages of using the estimated “original” extent of BHUs are that this produces larger targets, in terms of percentages of extant vegetation, for those BHUs that have been more heavily transformed by intensive land use; and that it decouples target percentages from further loss of vegetation which could be substantial in some BHUs.

BHU targets each had three components: a baseline target that was larger for BHUs with higher biological heterogeneity; a retention target that was larger for BHUs with higher levels of threat to their remaining native vegetation; and upward adjustment of targets for some BHUs to reduce the risk of target achievement mainly at their interfaces with other BHUs. The magnitude of species turnover within BHUs was inferred by drawing on analyses of botanical data sets covering gradients at broader scales. The inferred patterns of species turnover within BHUs were used to set a baseline target (B) for each BHU with the formula:

$$B = b \times A/100$$

Where *A* is the total area of the BHU (ignoring loss of native vegetation), and *b* was proportional to estimated species turnover and equal to 10 for lowland and mountain BHU in the eastern subregion, 15 for lowland BHU in the western subregion, and 25 for mountain BHU in the western subregion.

Retention targets were formulated to address different levels of threat to the extant vegetation of BHUs. The authors based retention targets on a threat category for each BHU to reflect its exposure to further transformation from each of three sources: agriculture, alien plants and urbanisation. They used rule-based methods to give each BHU a high, medium or low category for each of the three threats. The retention targets were allocated with the formula:

$$R = t \times A/100$$

Where *A* is the total area of the BHU (ignoring loss of native vegetation), and *t* was the threat weighting (30 for high threat, 15 for moderate, 0 for low). While the threat weightings can be justified qualitatively, the actual percentages have no theoretical or empirical support (Pressey *et al* 2003). Final targets varied from 10 to 55% of the total areas of BHUs, with a median value of 26%.

iv Targets for ecological processes

Pressey and colleagues (2003) identified six surrogates of ecological processes, four of which are described here in some detail.

- Edaphic interfaces are specific juxtapositions of soil types. The authors focused on eight edaphic interfaces and then recorded the extent to which the native vegetation in each interface had been transformed by urbanisation, agriculture and high density alien plants. The extant targets for interfaces range from 0 to 120km.
- Upland–lowland interfaces are associated with ecological diversification of plant lineages and possibly animal lineages. The role of interfaces in the conservation plan is to keep options open for lowland-upland biotic exchange in the face of ongoing transformation in the lowlands. The authors used 500m buffers along each side of the boundaries between upland and lowland BHUs to delineate interfaces of 1km width. To reflect differences in species assemblages throughout the region, they identified 146 types of interface, each defined by a unique pair of upland and lowland BHUs. The extent targets for unique interfaces were their remaining untransformed lengths, ranging from 0 to 508km.
- Upland–lowland gradients are complementary to upland-lowland interfaces although their expected contributions to ecological processes are similar. This analysis

identified gradients varying in length from 1km to 218km, most of which consisted entirely of extant native vegetation.

- Macroclimatic gradients were identified to link biogeographic zones across large parts of the region. These gradients will facilitate adjustments of species distributions to climate change and have a role in maintaining evolutionary processes for both plants and animals. Protection and restoration of macroclimatic gradients will also allow dispersal of many species between protected areas. As for upland–lowland gradients, the authors identified 1km-wide paths. The lengths of macroclimatic gradients were 263km, 565km and 617km. They traversed between 7 and 14 BHUs and between two and four biogeographic zones.

v Case study 2

Lombard *et al* (2007) employed systematic conservation planning methods (Margules and Pressey 2000) to delineate a Marine Protected Area around Price Edward Islands, off the coast of South Africa. The main objectives of their analysis were: representation of biodiversity patterns (species and ecosystems); conservation of ecological processes (e.g. foraging grounds, nutrient cycles); avoid conflict with the fishing industry where possible; and to have sensible marine management boundaries.

The biodiversity patterns and processes targeted by Lombard *et al* (2007) are summarised in Table 5. The study did not report the explicit rules adopted for the formulation of quantitative targets. The authors divided processes into those that are fine scale and spatially fixed, and those that are broad scale and spatially flexible (variable). Fixed processes included:

- coastal processes: captured with a 1km coastal buffer around the islands to define a coastal inshore zone;
- island shelf processes: derived from bathymetry (500m isobath around the islands);
- productive island areas: derived from bathymetry (1800m isobath around the islands);
- inshore foraging areas: captured with 40km buffer from island coastlines.

The authors defined and mapped three flexible processes:

1. seabird foraging areas: produced using Kernel density distribution maps;
2. elephant seal foraging areas: produced using Kernel density distribution maps; and
3. average position of the Sub-Antarctic Front (SAF) and the Antarctic Polar Front (APF).

Table 5. Targets for the systematic conservation planning of a Marine Protected Area for the Prince Edward Islands (reproduced from Lombard *et al* 2007).

Biodiversity patterns and processes		**Target**
Biodiversity patterns (species)	Fish	All two minute cells with four to 13 species
Biodiversity patterns (habitats)	Broad scale habitats	MPA to represent each of the four broad-scale habitats
	Major water masses	MPA to represent each of the three major water masses
	Benthic habitats	20% of the area of each of 20 habitats, and all of the Land habitat
	Seamounts	All of the 11 seamounts and rises
Fixed processes	Coastal processes	Entire area of 1km coastal buffer
	Island shelf processes	Entire area of inshore island shelf
	Productive island areas	Entire area of productive island areas
	Inshore foraging areas	Entire area of 40km buffer
Flexible processes	Sea bird and elephant seal foraging areas	MPA to incorporate major movement axes as shown by the combined bird and seal habitat utilization data
	Average position of the fronts	MPA to incorporate average positions of the SAF, SSAF and APF

3.2.3 Heuristic principles applied to habitats to protect ecosystem services

Ecosystem services are the benefits that people obtain from ecosystems. The Millennium Ecosystem Assessment (2005) distinguishes four categories of ecosystem services: provisioning (e.g. fisheries, fresh water, wood fuel, charcoal, biological products), regulating (e.g. carbon sequestration, water flow regulation), supporting (e.g. soil formation, pollination, pest control for food production), and cultural (e.g. serenity, inspiration). A recent review by Egoh *et al* (2007) points out that despite calls for developing methods to include ecosystem services into conservation assessments and planning processes, only a small number of peer-reviewed conservation assessments have actually done so.

i Data required

Including ecosystem services into conservation assessments requires a proper understanding of the ecology of the service, its conservation or management requirements and the benefits to humans both in space and time. Although the techniques for conservation planning are well advanced, definitions, data and tools for mapping ecosystem services, as well as methods to quantify them are under development and the scales over which services are produced are being investigated (Roberts *et al* 2003).

ii Case study

Chan and colleagues (2006) used a spatially explicit conservation planning framework to explore the trade-offs and opportunities for aligning conservation goals for biodiversity (terrestrial ecological systems and terrestrial and aquatic species) with six ecosystem services (carbon storage, flood control, forage production, outdoor recreation, crop pollination, and water provision) in the Central Coast eco-region of California. They mapped terrestrial biodiversity and the six ecosystem services listed above using both coarse-filter and fine-filter datasets and developed networks of protected areas for each service. Targets were set as percentages or quantities of total service produced within the eco-region and served as initial hypotheses for testing the necessary levels of replication and abundance to ensure feature persistence. The targets for each feature were as follows.

1. Biodiversity: all viable occurrences for species that were “critically imperilled” or “imperilled”.
2. Carbon storage: they set a feature based solely on what is available to store in the ecoregion, namely 50% of the carbon in above- and below-ground vegetation.
3. Flood control: they used U.S. Census data and calculated the total number of housing units in those census blocks with their centroid within the floodplain. The targets for the flood control network were based on these housing-unit numbers for each stratification unit divided into quantiles.
4. Crop pollination: 75% of feature value across the ecoregion (threshold adopted subjectively).
5. Forage production: 75% of forage production value (threshold adopted subjectively).
6. Recreation: they assumed an average demand of 12 recreation days per person per year (one per month). The amount of land necessary depends in part on the appropriateness of the contributing areas for recreation. They derived a baseline estimate of 0.0023 hectares from the actual usage of an ideal case from the Golden Gate National Recreation Area.
7. Water provision: they used county-level statistics for year 2000. They included all freshwater use (ground and surface) for residential, agricultural, and industrial purposes. The authors summed water usage by stratification units by taking the proportion of a county’s developed and agricultural land in the stratification unit and multiplying the county usage total by this proportion. Given the considerable amount of water delivered to the Central Coast eco-region from the Sierra Nevada Mountains by pipes, aqueducts, and more natural flow, the authors set targets of 40% of total use for each stratification unit.

The authors found some weak positive and negative associations between the priority areas for biodiversity conservation and the flows of the six ecosystem services across the eco-region. A network of protected areas that targeted five services (biodiversity, carbon, flood control, recreation, and water provision) met all targets far better than did the network targeted to the biodiversity features, both overall and especially for biodiversity protection. The authors conclude that the inclusion of ecosystem services in conservation planning can act a positive role also for the protection of biodiversity.

3.2.4 Species-area relationship applied to habitat to represent species

The species-area relationship represents one of the earliest quantitative models in biogeography. The relationship between the number of species (species richness) and land area has the general form of a power function:

$$S' = A'^{z}$$

where the parameter z describes the rate at which species are encountered in an area. Using the equation above it is possible to predict the number of species observed if a given percentage of a habitat type is sampled, provided that the z-value for the vegetation type is known. Here S' denotes the proportion of species expected to be found and A' denotes the proportionate area of the habitat type. This equation can be reordered to formulate conservation targets for habitat types, to determine the proportion of area required to represent a given percentage of species:

$$\text{Log } A' = \text{Log } S'/z$$

i Data required

The method for setting targets involves estimating the area of a land class that is required to represent a given proportion of the species occurring in the land class (Desmet and Cowling 2004). From the log transformation of the power model, the slope of the curve (hence, the *z*-value) can be determined using the formula for calculating the slope of a straight line:

$$z = (y_2 – y_1)/(x_2 – x_1)$$

Here *z* is the slope of the straight line, y_2 = log (total number of species in a land class); y_1 = log (average number of species per survey sample); x_2 = log (total area of land class); and, x_1 = log (average area of samples). When using inventory data, three of these variables are known and can be used to estimate the total number of species that occur in the vegetation type (Desmet and Cowling 2004).

ii Case study

Desmet and Cowling (2004) used the species-area relationship for setting targets for vegetation types in the Succulent Karoo biome (South Africa). Phytosociological survey data were used to calculate the z-values for land classes (Succulent Karoo biome vegetation types) by estimating the true number of species per vegetation type using the software EstimateS.

The problem faced by the authors in the Succulent Karoo was that there are inadequate survey data for some of the land classes. For the Succulent Karoo study, 42 out of 132 vegetation types had 30 or more survey sites, with only nine having more than 100 surveys. Therefore, firstly z-values for vegetation types with sufficient survey sites were calculated, and then the observed z-values were extrapolated to other vegetation types without sufficient survey data. This was achieved by relating known z-values to landscape physical properties (e.g. topography) that acted as surrogates for geographic species turnover and habitat diversity. They found that targets of 14–30% of 42 vegetation types in the Succulent Karoo were required to represent 70–80% of plant species.

Desmet and Cowling (2004) discuss a number of important limitations associated with the method and the interpretation of these targets. Most importantly, these targets are aimed only at species representation, and ecological processes are not considered. Conservation targets that consider both species and processes would in effect have significantly higher values. Other applications of this method indicate that as targets are refined with better data they tend to increase rather than decrease (Rouget *et al* 2004). The most important limitation of using z-values to set conservation targets is that it says nothing about where species are located in the landscape. Only if species are distributed randomly in a land class, then reserving any given percentage of habitat type should capture roughly the predicted percentage of species targeted (Desmet and Cowling 2004).

The South African National Biodiversity Institute (SANBI) has used this methodology to set targets for each vegetation type listed in the national vegetation classification system for the South Africa's first National Spatial Biodiversity Assessment (NSBA). Available phytosociological survey data have been used to estimate the z-value for the species-area relationship. Within this assessment in South Africa, the planning team in consultation with the reference group decided that the goal for statutory reserves should be to represent at least 75% of species that occur in a vegetation type within at least one or more statutory reserves. This goal translates into conservation targets ranging between 16% and 36% of the original extent of vegetation types (Rouget *et al* 2004).

3.2.5 Target-area trade-off

Many methods for setting targets require large amount of detailed datasets and these data should be used whenever available. The target-area relationship does not require such data. According to the authors it provides a rationale for setting targets that can complement, and be refined by, other target-setting methods (Justus *et al* 2008).

i Data required

The application of this method only requires the information on the area of planning units, which should always be available.

ii Case study

Justus *et al* (2008) based their analysis on a target-area function (*f*), which assigns amounts of land to protected area networks at different target levels. The function *f* can be used to provide a justification for target selection. If *t* is the target of representation, then *f(t)* is the area of the network that is needed.

The authors computed *f* for 12 datasets at 7 spatial resolutions and 19 target levels. They studied how the total area of protected area networks depends on percentage targets ranging from 5% to 95%. Each of the 12 datasets consisted of a set of areas for potential inclusion in the network. They analysed 12 data sets of different surrogate distributions from different regions: the Korean Demilitarized Zone, the Mexican Transvolcanic belt, Québec, Queensland, and West Virginia. Surrogate datasets were distributions of different types of environmental parameters, such as aspect, elevation, mean temperature, minimum temperature, maximum temperature, slope, and soil type. Other datasets used were modelled species distributions. The target area function was calculated from the results of area prioritization at different target levels.

The results demonstrated a linear relationship between area of the network and level of target for a wide variety of surrogates and regions for all spatial resolutions analysed. The slope of this relationship indicated how total area increased with target level. The problem with a linear relationship is that it does not help the quantification of a target. If the relationship were non-linear, it could be theoretically possible that a small increase in the cost of a conservation plan produces a relatively large increase in the amount of biodiversity protected, or that a small decrease of the amount of biodiversity protected allows a relatively large money saving.

Many other factors that may influence the choice of target level were not been considered in this study (e.g. availability of areas for conservation action, possible spatial configurations, and various socio-political factors, costs) (Justus *et al* 2008).

3.2.6 Target based on Population Viability Analysis for selected species

The rationale of this methodology is that integrating tools used in single-species Population Viability Analysis (PVA) with reserve selection tools can add biological realism to regional reserve designs, making them more effective at conserving wide-ranging species in developing landscapes (Cabeza and Moilanen 2001). While the use of this method can be advisable for the conservation of one or a few well-known species, its application to a set of species with the intent to protect landscapes or habitat types is not straightforward. This would require the identification of a small set of species whose ecological requirements include those of many others, so that their conservation implies the conservation of many species (umbrella or focal species) (Lambeck 1997). Yet the concept of focal species, and their ability to act as an umbrella for others, have been heavily criticised (e.g. Lindenmayer *et al* 2002). Furthermore there is no clear methodology to identify focal species, therefore the definition of a list of focal species would likely be a long and debated process with no clear final answer.

i Data required

Compared to other alternatives for making conservation decisions, PVA provides a rigorous methodology that can use different types of data. These models can be applied to only the best studied species because of their stringent data requirements. Even in these cases, results may be sensitive to variation in poorly known parameters. The huge amount of high quality data that it requires is the reason why, so far, PVA found little application especially for multispecies site-selection exercise (Cabeza and Moilanen 2001).

ii Case study

Carroll *et al* (2003) developed a regional conservation plan for eight mammalian carnivores in the Rocky Mountain region using both a reserve selection algorithm (SITES) and a spatially explicit population model (SEPM) to build flexible and biologically realistic conservation strategies. Spatially explicit population viability models (PVAs), such as PATCH, can be used to show dynamic relationships between landscape species and changes in habitats due to threats, seasonality or climate change.

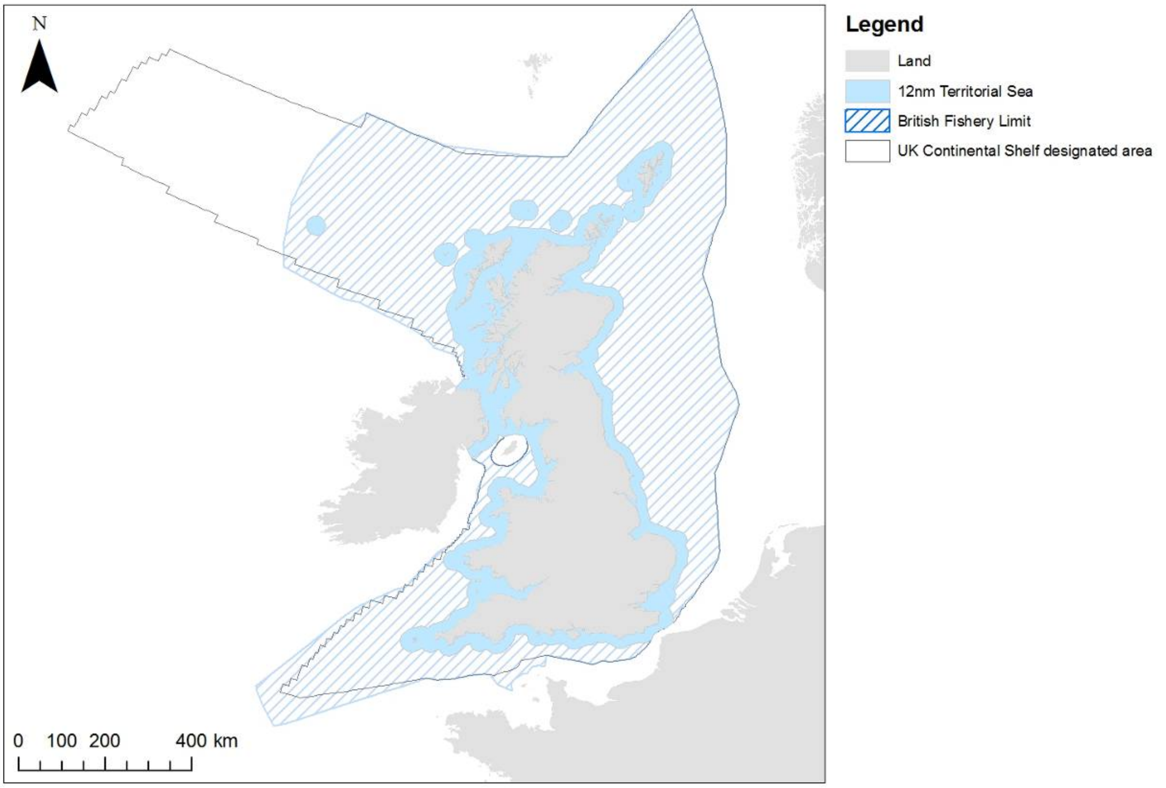
The authors built predictive habitat models (static models) for eight species using a combination of data on various habitat components and information on species-habitat associations. Initially, SITES used the static habitat suitability models for the eight species. Goals for the species were expressed as a percentage of the total habitat value in the region, measured by the output of the static model. Secondly, they used the results from the dynamic model (SEPM) to refine the reserve selection process. SEPMs combine information on habitat characteristics with demographic data to evaluate area and connectivity factors that influence the probability that a patch of suitable habitat will remain occupied by a species over time. The authors added two targets derived from the PATCH: one targeted habitat with a high source value and high threat, the other targeted highest value source habitat.

The authors found that SITES solutions using the PATCH-based targets are slightly more efficient than those based on static models (e.g. a network based on PATCH targets requires 26.7% of the region to achieve the same level of potential grizzly bear population size shown by a static model-based network covering 30.8% of the region). This is equivalent to a reduction in size of the necessary reserve network by about 30,000km^2.

This method, although needing more data than all other methods to formulate targets, can add valuable information on habitat thresholds and the effect of corridors that is unavailable with simple reserve design rules (Carroll *et al* 2001).

3.3 Available data to set targets for marine habitat coverage in UK

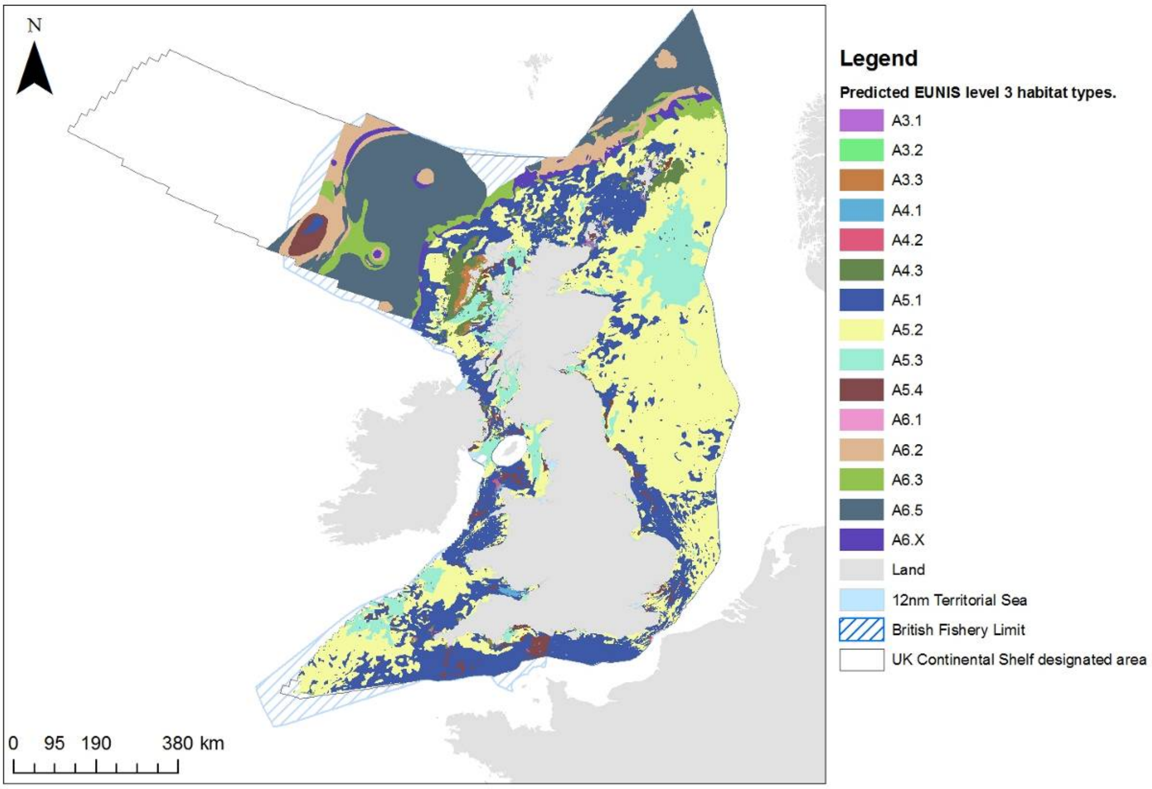
The planning area for the expansion of the MPA network in the UK encompasses the territorial waters and the surrounding UK continental shelf (Figure 3).



Map projected in Europe Albers Equal Area Conic (Modified Standard Parallels - Standard Parallel 1 = 50.2; Standard Parallel 2 = 58.5). The exact limits of the UK Continental Shelf are set out in orders made under section 1(7) of the Continental Shelf Act 1964 (© Crown Copyright). World Vector Shoreline © US Defense Mapping Agency. Map copyright JNCC 2010.

Figure 3. Map of the UK territorial waters and continental shelf

The map of EUNIS level 3 marine habitat types has been selected as a coarse-filter surrogate of habitat diversity (A. Aish and B. Stoker pers. comm.). This map contains 25 legend items (listed in full in Appendix I) and covers most of the UK continental shelf, with the exception of its north-western portion (Figure 4). This map contains a large number of polygons with small areas (most are smaller than 1km^2) and fewer larger polygons, with the largest being > 80,000km^2 (Figure 5). There is a tendency for small polygons to be closer to the coast, due a greater understanding of coastal processes (i.e. classification system more developed inshore than offshore) and due to the greater number of physical parameters near-shore (i.e. wave disturbance, light etc.). This justifies the choice of planning units of different sizes (i.e. smaller inside UK territorial water and larger outside) and could justify the choice of separate targets for two planning zones.



Map projected in Europe Albers Equal Area Conic (Modified Standard Parallels - Standard Parallel 1 = 50.2; Standard Parallel 2 = 58.5). The exact limits of the UK Continental Shelf are set out in orders made under section 1(7) of the Continental Shelf Act 1964 (© Crown Copyright). World Vector Shoreline © US Defense Mapping Agency. Map copyright JNCC 2010.

Figure 4. Map of predicted EUNIS level 3 habitat types

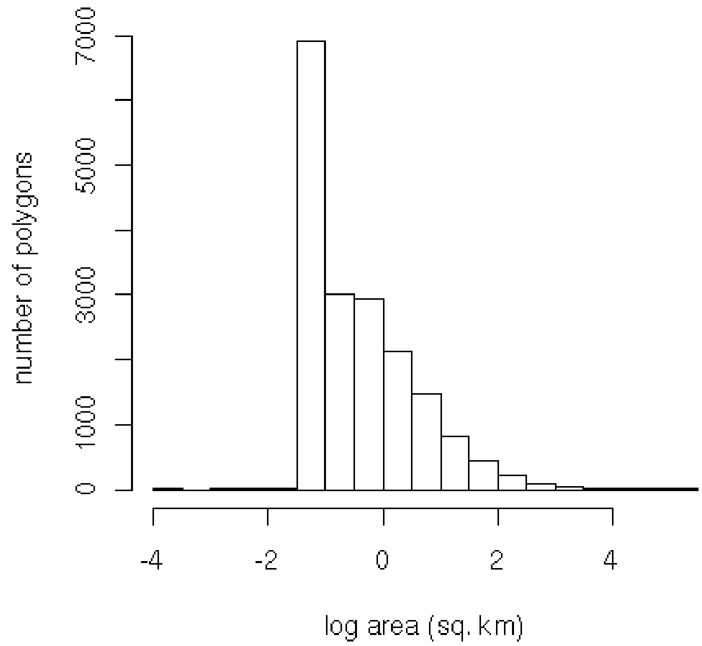


Figure 5. Frequency distribution of polygon size in the EUNIS level 3 habitat types map. Where a log value of 0 is equivalent to $1km^2$

The ‘habitats of conservation importance' have been selected as a fine-filter surrogate of habitat diversity (A. Aish and B. Stoker pers. com.). This list of habitats has been obtained by merging marine habitats listed by the UK Biodiversity Action Plan (BAP)[1] with marine habitats listed by the OSPAR Commission in the OSPAR List of Threatened and/or Declining habitats[2]. The list of ‘habitats of conservation importance' contains 28 habitats (listed in full in Appendix II). These habitats are not generally mapped as polygonal habitat boundaries but as sampled point locality data. As of 13 February 2009, more than 16,500 point data are available for BAP habitat types, but they are expected to increase in the near future (B. Stoker *in litt.*). So far, BAP point data are mostly concentrated inside the UK territorial waters and cover fairly uniformly the coastal areas, but are patchily distributed offshore with one cluster in the northeast and one in the south (Figure 6). This pattern of distribution of BAP data reinforces the idea that it would be advisable to identify two planning areas (inside and outside the territorial waters) and set separate targets for the two, possibly using different methodologies given that the amount and presumably the quality (resolution) of data available is different.

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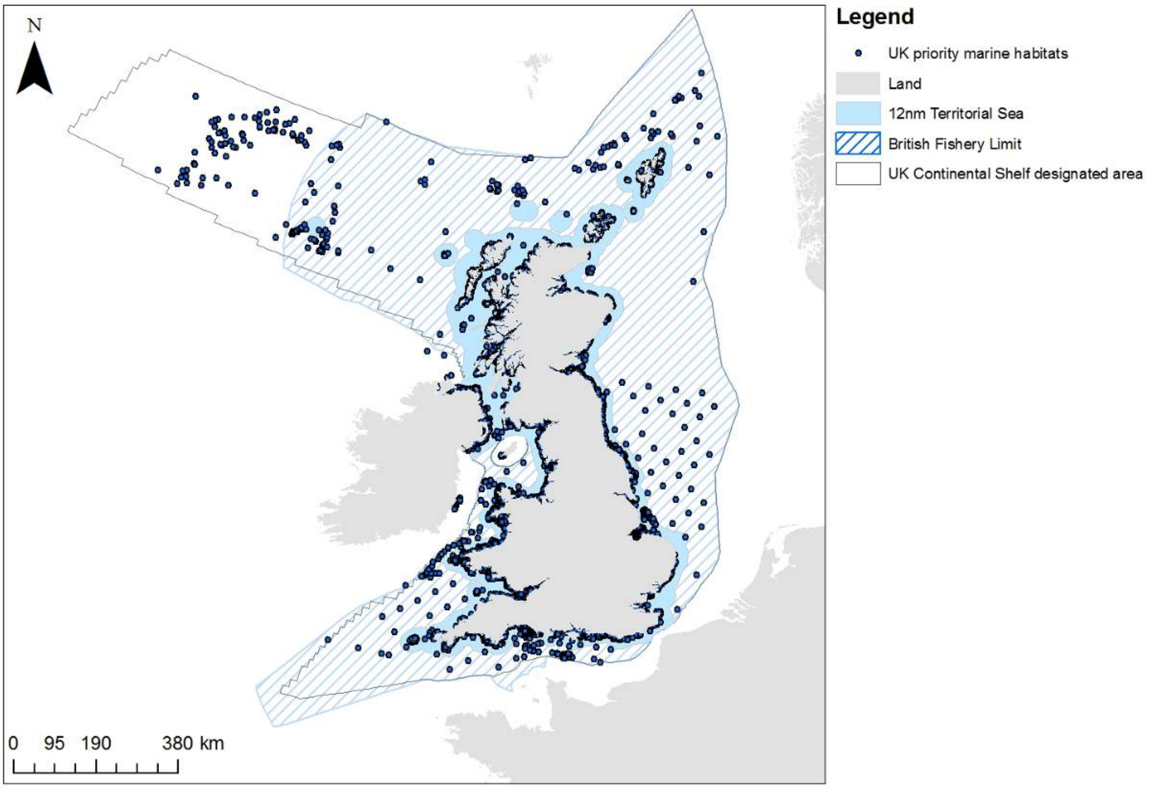
[1] www.ukbap.org.uk/PriorityHabitats.aspx
[2] http://data.nbn.org.uk/hosted/ospar/ospar.html



Map projected in Europe Albers Equal Area Conic (Modified Standard Parallels - Standard Parallel 1 = 50.2; Standard Parallel 2 = 58.5). The exact limits of the UK Continental Shelf are set out in orders made under section 1(7) of the Continental Shelf Act 1964 (© Crown Copyright). World Vector Shoreline © US Defense Mapping Agency. Map copyright JNCC 2010.

Figure 6. Map of sampled habitats listed by the UK Biodiversity Action Plan

For the ‘habitats of conservation importance' derived from the OSPAR list there exist a variable number of point locality data. These are shown on the UK National Biodiversity Network Gateway (http://data.nbn.org.uk/) (Figure 7). Given that these data are not readily downloadable and were not available at the time of writing this report, it is not clear how abundant and evenly distributed they are, therefore it cannot be inferred whether they can be representative of the overall distribution of these habitat types. Their potential use for the quantification of biodiversity targets for the expansion of the MPA network remains to be assessed.

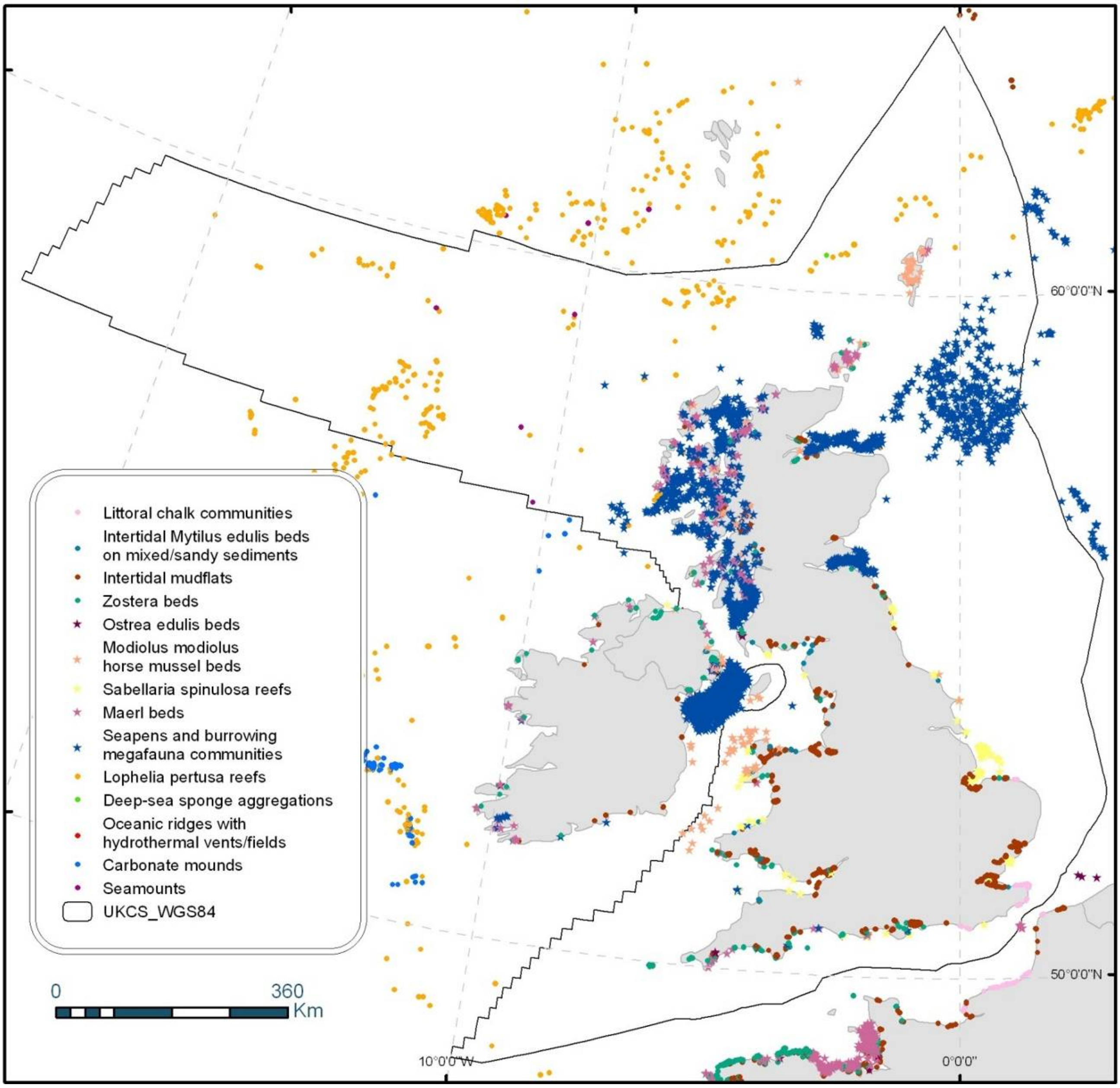
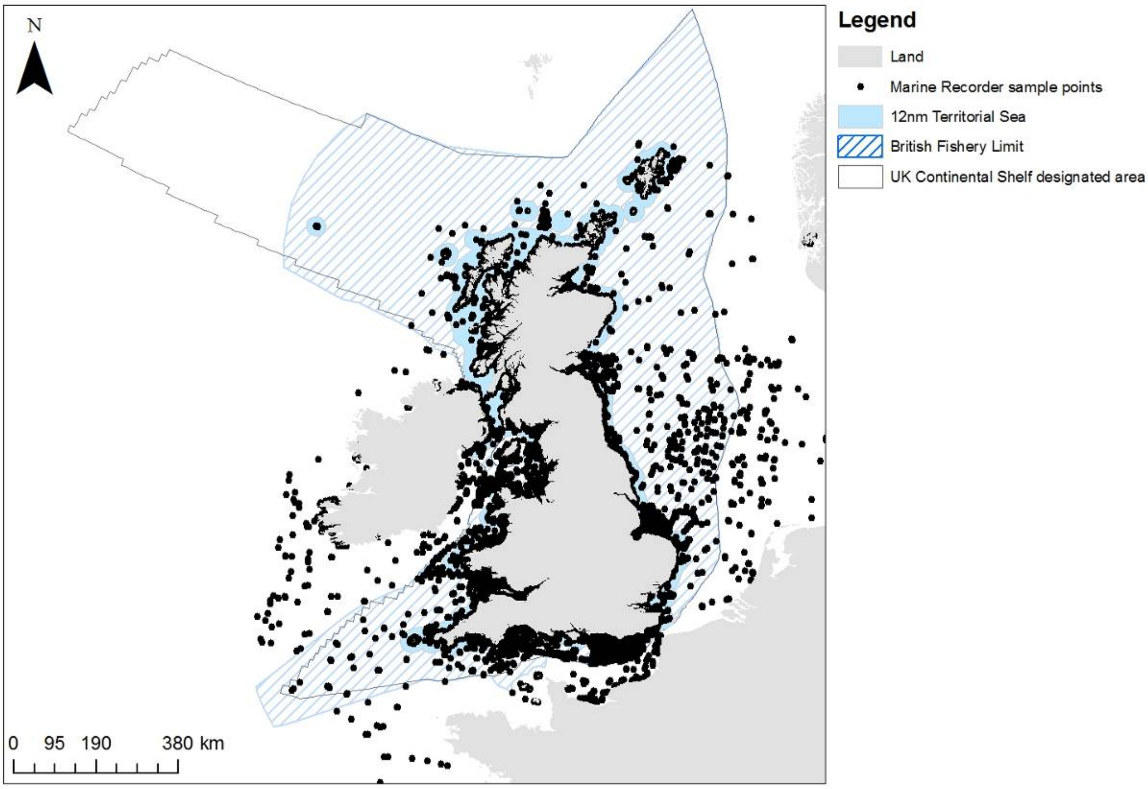


Figure 7. Map of OSPAR habitat types



Map projected in Europe Albers Equal Area Conic (Modified Standard Parallels - Standard Parallel 1 = 50.2; Standard Parallel 2 = 58.5). The exact limits of the UK Continental Shelf are set out in orders made under section 1(7) of the Continental Shelf Act 1964 (© Crown Copyright). World Vector Shoreline © US Defense Mapping Agency. Map copyright JNCC 2010.

Figure 8. Map of sampled locations stored in the Marine Recorder database

In addition to the data on the distribution of the coarse- and fine-filter surrogates for habitat types, other datasets are available and should be used to aid the formulation of quantitative targets for marine habitat types. These include data on the spatial distribution of species and on characteristics of the environment that could be used as surrogates of ecological processes.

The UK Marine Recorder database contains data on 4,879 species collected in more than 900,000 sampling sites, for a total of more than 1,300,000 records. Most of these sampling sites are scattered along the coast inside the UK territorial waters, and further sampling sites are located in the Channel outside territorial waters. The rest of the continental shelf is mostly non-sampled (Figure 8). For a large number of species the database contains a fairly high number of records (more than 100 records for 1,309 species) (Figure 9). Given the large amount of sampling localities, the Marine Recorder data could be used to fit species-area curves at least for EUNIS level 3 habitat polygons inside UK territorial waters. Given that the majority of sampling localities are close to the coast the results may not be extrapolated to EUNIS level 3 habitat types outside the territorial waters, unless robust assumptions can be made that the distance to the coast does not influence the community structure and species richness (which may not be the case due to the likely flow of nutrients from the land).

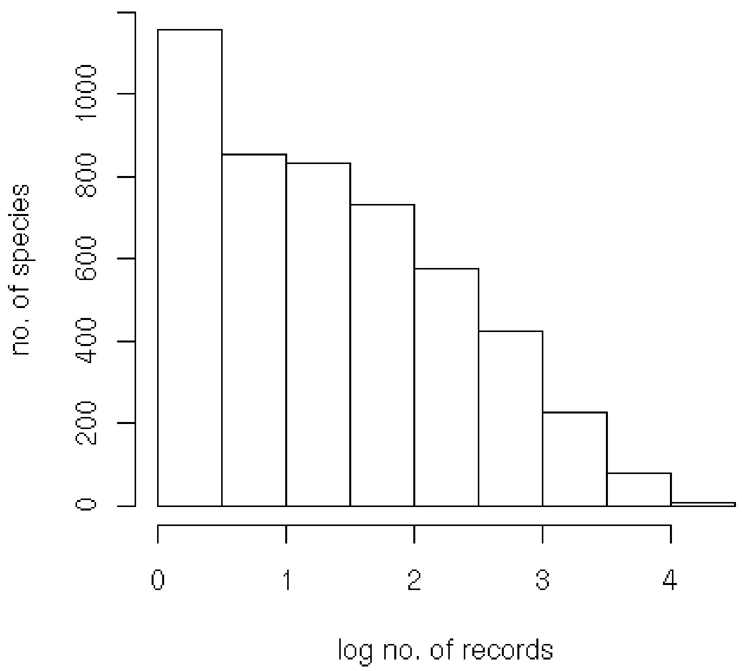


Figure 9. Number of records per species in the Marine Recorder database

Data on other environmental variables that have a spatial component and could be used as surrogates of processes include bathymetry data, chlorophyll a concentration and currents. Although the planning region is limited to the continental shelf, making its bathymetric range relatively restricted, bathymetric data could be used to identify canyons (that are usually rich and abundant in fish species) and seamounts. Areas of high chlorophyll a concentration should as well identify zones of high productivity. Depth and chlorophyll a maps are freely available at coarse resolution (hundreds of meters to thousands of meters) from various sources (e.g. http://earthobservatory.nasa.gov/GlobalMaps), and higher resolution maps may be available for the study region.

Further data that could be useful for assembling the targets are: original extent of habitat types and intensity of threat to habitat types, which could be used to increase the percentage target for habitats whose distribution has extensively contracted in the past or that are currently under high threat; and economic cost of sites, which could be used to trade-off the size of targets with the cost of the conservation plan. The data on the original extent of EUNIS habitat types and of 'habitats of conservation importance' are not available (A. Aish and B. Stoker pers. comm.). Limited, qualitative data on threats are available for a subset of the UK BAP habitats (Table 6). As of 13 February 2009 no map of the economic cost of sites has been agreed upon. One of the reasons is that cost depends on which activities are considered and it is very difficult to develop a comprehensive map of costs. On the other hand, even if target setting can be done without a map of costs, this map would be extremely important at a later stage of the conservation plan, when sites to be added to the network of MPAs will be chosen. Such map allows minimisation of the cost of the conservation plan while achieving the biodiversity targets, and changing the map of costs changes the spatial options of the plan.

Table 6. Estimated level of threat to some BAP habitats (from the UK Biodiversity Action Plan, http://www.ukbap-reporting.org.uk/status/uk_table.asp)

Habitat name	Trend	Accuracy	Data source / comments
Coastal saltmarsh	Declining (continuing/accelerating)	Best guess	No comprehensive UK-wide assessment of trends is available. Based on the country assessments, it is likely that a declining trend continues. In E this is almost certainly accelerating. The rate of decline is unlikely to be offset by any sustained increases elsewhere in the UK.
Littoral and sublittoral chalk	Fluctuating - probably declining	Best guess	
Lophelia pertusa reefs	Trend unknown		
Mud habitats in deep water	Trend unknown		
Mudflats	Trend unknown		There is no quantitative data on which to base any assessment of trends in extent and distribution.
Sabellaria alveolata reefs	Increasing	Best guess	
Sabellaria spinulosa reefs	Trend unknown		This habitat is naturally fluctuating, therefore assessment of trends is difficult.
Saline lagoons	Stable	Partial survey	There are some anthropogenic impacts from flood defence structures and unsuitable coastal / water management, particularly in England. Natural losses are generally offset by natural evolution and formation of new lagoons, particularly in East Anglia. Wales habitat extent has decreased but this is due to updated surveys and better classification of saline lagoons present. Scotland has better interpretation of this habitat resource too. No additional information supplied by NI.
Seagrass beds	Trend unknown		
Serpulid reefs	Stable	Sample or full survey	Site condition monitoring for the Loch Creran SAC which contains the greatest extent of this habitat was carried out in 2005 and published in 2006. It shows that the overall distribution and colony density has not changed significantly in the period 1994/1995-2005. Small serpulid aggregations were found in Loch Teacuis, Morvern during the site condition monitoring of the Sunart SAC in 2006 and mapped in more detail later that year. These small aggregations are thought to be a stage in a step wise development towards true serpulid reefs (live serpulid worms growing on dead, skeletal material) and were found to cover 20.02ha in 2006.

Habitat name	Trend	Accuracy	Data source / comments
Sheltered muddy gravels	Declining (continuing/ accelerating)	Best guess	Large area of intertidal particularly centred on the S and E of the UK are decreasing in extent as a consequence of coastal squeeze. Hence it is likely that this habitat is also declining.
Sublittoral sands and gravels	Stable	Partial survey	
Tidal rapids	Trend unknown		

In order to assess which methodologies can potentially be applied for the formulation of quantitative targets for marine habitat types, the data that are currently available or can be made available in the near future were listed against the data needed by each methodology (Table 7). The only methodologies for which data are unavailable are those based on Population Viability Analyses and Spatially Explicit Population Models, and the target-cost relationship variant of the target-area relationship method. For these two methodologies SWOT analyses were not undertaken.

Table 7. Data needed to apply each methodology and available data on the UK marine habitat types and habitats

Methodology	Data needed	Data available
Heuristic principles to represent species (fixed target)	Literature data on average parameters for the species-area curve	Yes (from literature)
Species-area Relationship for habitat types to represent species	Species point locality data inside habitat types	Yes for EUNIS level 3 habitat types inside UK territorial waters Partly for EUNIS level 3 habitat types outside territorial waters No for 'features of conservation importance'
Heuristics for habitat types to preserve biodiversity patterns	Species turnover per habitat type (qualitative can suffice)	Yes for EUNIS level 3 habitat types inside UK territorial waters. Can be used for inference? Maybe expert opinion for 'features of conservation importance'
	Current maps of habitat types	Yes for EUNIS level 3 habitat types (except northwest area of UK waters) Point data for the 'features of conservation importance'. Probably not enough outside UK territorial waters.
	Level of threat to habitat types	No for EUNIS level 3 habitat types Partly for UK 'habitats of particular conservation importance' (some BAP habitats) More may be available by summer 2009
	Original extent of habitat types	No
	Bathymetry (could be used to stratify EUNIS map)	Yes

Methodology	Data needed	Data available
Heuristics for habitat types to preserve ecological processes	List of target ecological processes	Can be obtained from marine ecology experts
	Scale of listed processes	Can be obtained from marine ecology experts
	Association of the process with habitat types	Can be obtained from marine ecology experts
	Design considerations: connectivity or adjacency between habitat types required to maintain a given process	Can be obtained from marine ecology experts
	Association with spatial elements other than habitat types (e.g. canyons)	Can be obtained from marine ecology experts
Heuristics for habitat types to preserve ecosystem services	List of target ecosystem services	Can be obtained from stakeholders and marine ecology experts
	Association of the ecosystem service with habitat types	Can be obtained from marine ecology experts
	Design considerations: connectivity or adjacency between habitat types required to maintain a given process	Can be obtained from marine ecology experts
	Association with spatial elements other than habitat types (e.g. canyons)	Can be obtained from marine ecology experts
Target-area (target-cost) trade-off	Area of planning units	Yes
	Map of economic cost of planning units	Not currently available, but may become available in the future
Target based on PVA on selected (focal) species	List of focal species that can be used as an umbrella for the protection of other species and habitats	Not easy to find agreement (highly subjective)
	Spatially explicit, habitat-specific population dynamic data	No

3.4 SWOT analysis

3.4.1 Heuristic principles to represent species (fixed target)

i Strengths

- The fixed percentage target is easy to communicate;
- Has been extensively used in the past and is well known among policy makers and conservation NGOs as well as the scientific community; and
- It is very fast as it does not involve any calculations.

ii Weaknesses

- It is a scientific fact that different habitat types do contain different numbers of species due to different rates of species turnover and because some habitats are more complex and allow more species to coexist. Therefore, there is no scientific justification for the method and most scientists now strongly advocate against using this approach; and
- Aimed only at species representation, not persistence.

iii Opportunities

- Does not require data collection;
- It is very easy to monitor progress towards target achievement as it just requires to compute percentage of area protected; and
- Being data insensitive it is unaffected by low quality data. In this respect it should be used when information on biodiversity is (almost completely) lacking.

iv Threats

- The quantity monitored (percentage of area protected) is not directly related to biodiversity outcomes; and
- The use of a data insensitive method can give a false sense of success when the target is achieved, when in reality nothing is known or expected on the effect of target achievement on biodiversity conservation.

3.4.2 Species-area relationship applied to habitat types to represent species

i Strengths

- The method is scientifically sound as it is based on the well established ecological theory of island biogeography (MacArthur and Wilson 1967); and
- If enough data are available, quantitative threshold can be linked to expected numbers of species conserved.

ii Weaknesses

- As most quantitative methods it relies on assumptions: e.g. if the maps of habitat types do not correspond to "natural" ecological communities the species-area curves may not progress smoothly towards an asymptote.

iii Opportunities

- Scientific rigour makes it easily defensible;
- Easy to communicate because the concept that increasing the area protected increases the number of species covered is intuitive; and
- The expected number of species included in protected areas can be validated by field studies, allowing a fast response (adaptive management) in case of wrong prediction.

iv Threats

- Data intensive: if not enough data area available, the parameter estimation for the species-area curves can be incorrect;

- Sensitive to data quality: patchily available data can bias the results towards habitat types with more data; and
- The method is oriented towards species representation in protected areas, not their persistence; therefore targets formulated with this methodology may fall short of preserving species if not supplemented by further persistence-oriented targets.

3.4.3 Heuristic principles applied to habitat types to preserve biodiversity patterns and processes

i Strengths

- Heuristic principles in general can be adapted to a variety of specific goals;
- Can take into account multiple criteria (e.g. Pressey *et al* 2003 took into account species richness, threat to habitat types and spatial location of reserved sites);
- Rules of thumb based on scientific theory;
- Applicable in absence of large amounts of data when other methods are not feasible.

ii Weaknesses

- The application of the methodology is semi-quantitative or sometimes qualitative, which introduces subjectivity in the results; and
- Very much data sensitive: changing the target habitat types or other (qualitative) data used to define the targets, can change the results substantially (much more than happens with quantitative methods, e.g. species-area curves, where changes in the baseline data lead to gradual changes in quantitative targets).

iii Opportunities

- Methodological standards are beginning to emerge for the definition of quantitative targets (e.g. Pressey *et al* 2003, Lombard *et al* 2007); and
- Qualitative data can be collected from experts.

iv Threats

- The subjectivity of the methodology makes it more difficult to communicate; and
- The subjectivity of the methodology makes it less defensible than other, more quantitative methods.

3.4.4 Heuristic principles applied to habitat types to preserve ecosystem services

i Strengths

- Heuristic methods in general can be adapted to a variety of specific goals;
- Ecosystem services are of direct interest to humans; and
- The conservation of ecosystem services generally entails the conservation of complex ecological patterns and processes.

ii Weaknesses

- The choice of target ecosystem services strongly influences the outcome in terms of amounts and types of habitats to be protected; and

- The development of methods for the quantification of ecosystem services is still in infancy, therefore quantification heavily relies on rough assumptions and subjective decisions (Egoh *et al* 2007).

iii Opportunities

- A number of studies are ongoing on ecosystem services and more can be expected in the future, therefore the availability of data and methods for setting targets will increase rapidly;
- Currently, rough data usable to quantify ecosystem services can be obtained from experts (e.g. Chan *et al* 2006); and
- Because ecosystem services are economically valuable, targeting them allows to trade-off explicitly the costs associated with a network of protected areas with the economic value of the services produced.

iv Threats

- The current lack of data on the association between habitat types and ecosystem services leads to many subjective decisions in the application of the methodology, which in turn increases the risk of reaching wrong conclusions; and
- The current lack of accepted methodologies to quantify ecosystem services makes the application less defensible.

3.4.5 Target-area trade-off

i Strengths

- Minimal data requirements (only area of planning units, which should be always known).

ii Weaknesses

- Dangerous if applied alone: the trade-off between the biodiversity target achieved and the amount of area reserved should be made after the biodiversity target has been set independently on the basis of the biodiversity goal (Cowling *et al* 2003, Pressy *et al* 2003); and
- When the relationship between target size and area reserved is linear (e.g. Justus *et al* 2008) the method is useless.

iii Opportunities

- The method could be applied to adjust targets, after it has been clearly defined with some other, biodiversity-based methodology: if the relationship between target size and area reserved is not linear, it is possible that a small increase of the area reserved can lead to a significant increase of the biodiversity protected, or that a small shortfall on the biodiversity target corresponds to a large reduction of the area reserved. If this is the case the trade-off can optimise the resources used in the conservation plan.

iv Threats

- Ideally the method should be applied as a target-cost trade-off. The use of area as a surrogate of cost is risky, because if cost is highly variable across sites (as is usually the case) the trade-off with area may lead to incorrect results.

4 Discussion and conclusion

The identification of a methodology that can be used to formulate ecologically meaningful targets for marine habitat coverage within the MPA network requires the knowledge of three pieces of information:

- broad goal of the conservation plan;
- existing methodologies; and
- amount and quality of available data.

The broad goal of the UK Government for the marine environment, to be achieved through the proposed development of the MPA network, is "clean, healthy, safe, productive and biologically diverse oceans and seas", and the aim is "to recover and protect the richness of our marine environment and wildlife through the development of a strong, ecologically coherent and well managed network of marine protected areas, that is well understood and supported by all sea users by 2012 (Defra 2009). Recovery and protection in the long term require that biodiversity is covered (represented) by the MPA network and that it persists over time. It can therefore be argued that, using terms with an established meaning in the conservation planning literature, the role of the MPA network is the representation and persistence of marine biodiversity.

The existing methodologies for target identification for habitat types can be broadly divided into five categories: methods that identify fixed percentage targets to be applied across all habitats (e.g. IUCN 1993, Neely *et al* 2001); methods that identify variable targets for habitats based on the fit of a species-area curve (e.g. Desmet & Cowling 2004); heuristic methods applied to a variety of specific goals (e.g. Chan *et al* 2006, Pressey *et al* 2003, Lombard *et al* 2007); methods that aim at the protection of habitat types indirectly, by protecting the habitat of selected focal species (e.g. Carrol *et al* 2003); and methods that trade off target size with some measure of expected impact of the protected area network on other human interests and activities (target-area relationship, target-cost relationship) (e.g. Justus *et al* 2008).

The broad category of heuristic methods can be further subdivided on the basis of the specific goal that they are applied to. Habitat types can in fact be used as surrogates of different structural and functional components of biodiversity, e.g. species and communities, ecological processes, ecosystem services. This report identified three sub-groups of heuristic methods: those aimed at the protection of biodiversity patterns, of ecological processes, and of ecosystem services. Although ecosystem services are directly dependent on patterns and processes of biodiversity, it is useful to identify a separate category here because the focus on ecosystem services can allow the translation of intangible biodiversity values into economic values that can then be traded-off with costs (cost of a network of protected areas, opportunity cost of conserving selected sites).

Unsurprisingly no single perfect method for target setting exists: the SWOT analysis identified relevant weaknesses and threats for all methods. Nonetheless, some methods appear to be weaker than others overall. Because the goal is the representation and persistence of biodiversity, the following criteria were identified as taking precedence in selecting an appropriate methodology:

1. the methodology should make use as much as possible of the available data on biodiversity;
2. structural and functional components of biodiversity should be taken into account;
3. the most advanced scientific knowledge on biodiversity conservation should be used; and
4. the methodology chosen should be defensible.

Based on these criteria, methods that identify fixed targets that are constant across all habitats are not suitable, because they exclusively rely on generic literature and do not use any real data on the distribution of biodiversity in the planning area. As well, the methodology that trades-off the size of target with some measure of cost (area or other surrogate) is not suitable for three reasons: (1) it does not use biodiversity data at all; (2) it gives priority to the economic cost of the conservation plan, while here the broad goal is persistence of biodiversity with no reference to cost; and (3) there are technical problems with the method, because it cannot identify any target size if the target-cost relationship is linear, and it can lead to wrong results if the surrogate of cost is not appropriate (e.g. when area is used as a surrogate).

The methodology to formulate targets based on the fitting of habitat-specific species-area curves is suitable for the formulation of targets in the case considered by this study, because it makes use of biodiversity data from the planning area. Yet being data intensive, it may require more data than are actually available for some habitat types or for some portions of the planning area. Furthermore, this methodology can be used to identify targets for species representation (inclusion of as many species as possible), but cannot ensure species persistence. While percentage targets are sufficient for the representation of species in a network of protected areas (biodiversity patterns), the persistence of these species require that ecological processes are conserved, and to be achieved this needs specific design criteria for the network (minimum size of protected sites, connectivity requirements) (Cowling 1999).

Heuristic methods can accommodate a variety of specific goals (conservation of biodiversity patterns, processes, ecosystem services). They can also accommodate biodiversity data of variable quality and quantity. In this respect, they are the most flexible methods applicable to the formulation of biodiversity targets. Furthermore, the application of heuristic principles is necessary to formulate targets on ecological processes because no quantitative methods to formulate targets for these components of biodiversity exist yet. These principles are used to define the minimum size that a protected site should have to be capable to protect a given process. Because heuristic methods use approximations and rely on a number of assumptions, they should be used when more rigorous methods are not available or cannot be applied due to the paucity of data. Very few applications of heuristic methods to the conservation of ecosystem services have been proposed so far (Egoh *et al* 2007). These applications rely on a number of assumptions because little data and methods exist. Although these applications look very promising, to avoid the risk of entering a long debate on targets this review recommends that ecosystem services should only be used to target marine habitats if data is readily available.

The methodologies based on focal species require large amounts of species-specific and habitat-specific data on population dynamics that are not available in this case (and seldom available in general). In addition, they rely on the assumption that a handful of focal species can be identified that act as an umbrella for other species and their habitat. This assumption has been heavily criticised in the past (e.g. Lindemayer *et al* 2002). For these reasons the methodologies based on focal species are not discussed in further detail here.

A number of biodiversity datasets are available for the planning area (UK continental shelf inside and outside the territorial waters). These include the distribution of EUNIS level 3 habitat types (polygonal map that covers most of the planning area) and the 'habitats of conservation importance' (point map with sampled habitats, derived partly from the UK Biodiversity Action Plan maps and partly from OSPAR threatened habitat maps). The above maps represent the biodiversity features for which quantitative targets should be formulated. Ancillary data sets that can be used to formulate the quantitative targets include point locality data on species distribution (Marine Recorder database). All point locality data sets show a marked tendency for points to concentrate inside UK territorial waters; and the polygons of the EUNIS habitat types map tend to be larger offshore than close to the coast. These patterns suggest that the amount and quality of biodiversity data decrease for increasing distances from the coast.

4.1 Recommendation of a methodology to set ecologically meaningful targets for marine habitat coverage within the UK MPA network

Based on the data reported in the results and on the considerations made above, the following recommendations are made:

- The planning area should be subdivided in two parts: the sub-area between the coast and the limit of the territorial waters, and the sub-area between the limit of the territorial water and the limit of the continental shelf (which is the external boundary of the planning area).

- The target for marine habitat coverage should be formulated separately for the two sub-areas because they differ in the amount and quality of data.

- Given the large size of the planning area, the opportunity to further subdivide EUNIS habitat types and habitats of conservation importance should be considered. For example, the maps of EUNIS habitat types and habitats of conservation importance could be intersected with a map of bathymetry to subdivide each habitat class into depth zones. This would reduce the internal variability of each of the habitat classes.

- The targets for marine habitat coverage should be composite for two reasons: (1) EUNIS level 3 habitat types are mapped as polygons while 'habitats of conservation importance' are mapped as sampled points, therefore the methodologies that can be applied to the two datasets are different; and (2) no single methodology exists to formulate targets that are valid at the same time for habitat types as surrogates of structural (patterns) and functional (processes) components of biodiversity.

- The composite target for the EUNIS habitat types should be formulated as follows: (1) as a surrogate of biodiversity patterns (species representation), baseline percentage targets can be formulated by using the species data in the Marine Recorder database to estimate habitat-specific z values to fit species-area curves; and (2) following Pressey *et al* (2003), if the level of threat to each biotope can be estimated at least qualitatively , then the percentage targets can be increased based on a heuristic rule that links the percentage increase to the level of threat.

- The composite target for 'habitats of conservation importance' should be formulated as follows: (1) because these habitats are represented as points, species-area curves cannot be used. Therefore, to use them as a surrogate of biodiversity patterns (species representation), heuristic methods need to be developed; and (2) If levels of threat to each habitat can be estimated at least qualitatively, the percentage targets can be increased based on a heuristic rule that links the percentage increase to the level of threat.

- The best way to proceed in order to estimate the minimum size and required connectivity of the network of MPAs is to identify the target ecological processes to be conserved by the network. Each of these processes will take place at a spatial scale that can be identified at least approximately. Some of these processes will need that more than one habitat type be adjacent to each other.

- Some of the target ecological processes will be linked to particular elements of the seascape (e.g. high productivity canyons, seamounts). These should be added to the target, and there may be no option but to include all of them in the MPA network.

- After the targets for marine habitat types have been formulated, the proportion of targets already achieved by the existing network of MPAs should be assessed through a gap analysis (Scott *et al* 1993), and to expand the MPA network to protect the part of the target not covered by the existing reserves the principles of systematic conservation planning (Margules & Pressey 2000) should be followed.

4.2 Operational guidelines for the application of the selected methodologies

4.2.1 Composite target for EUNIS habitat types

The species distribution data from the Marine Recorder database can be used to formulate baseline targets for EUNIS habitat types as surrogates of biodiversity patterns, at least inside the UK territorial waters where data are more abundant, by estimating the habitat-specific values of z necessary to fit biotope-specific species-area curves. These curves could then be used to estimate the percentage of species that are expected to be represented by any given percentage of habitat type protected.

For some of the habitat types inside the territorial waters it may not be possible to fit species-area curves due to the lack of data. This is a common situation that could be solved as in Desmet & Colwing (2004). The environmental heterogeneity of each biotope could be estimated based on depth variance and number of priority habitats in each biotope (and possibly other variables). A model that relates the environmental heterogeneity to z values could be fitted for the habitat types for which z values can be calculated. This model can then be used to extrapolate z values for the habitat types that lack species data.

For EUNIS habitat types outside UK territorial waters there are four options:

1. If data from the Marine Recorder are sufficient, use the same methodology described at the previous point; or
2. If it is reasonable to assume that their species composition and turnover are similar to that of the same habitat types inside territorial waters (i.e. closer to the coast and presumably in shallower waters) extrapolate the results obtained inside territorial waters; or
3. Estimate the z value based on heterogeneity as explained above; or
4. Develop heuristics based on expert opinion. For example, for the habitat types that are known to have the highest species richness and turnover, protect a percentage of the occurrences equivalent to the highest baseline percentage chosen for habitat types; for habitat types with medium species richness and turnover protect a percentage of the occurrences equal to the mean baseline percentages chosen for habitat types; for habitat types with low species richness and turnover protect a

percentage of the occurrences equal to the minimum baseline percentage chosen for habitat types. If the turnover rate is expected to diminish from the coast outwards, reduce all targets of a fixed percentage (defined by experts).

An additional percentage target, dependent on the habitat-specific level of threat, can be added to the baseline target defined above. Even in the absence of quantitative data on threats, these can be estimated at least qualitatively by experts, taking into account for example the level of exploitation of the areas or the species that are characteristic of each habitat type. For example Pressey *et al* (2003) assigned habitats to one of three levels on an ordinal scale of threat (high, moderate, low), and added to the baseline target an additional 30% for highly threatened habitat types and 15% for moderately threatened habitat types. The percentages chosen for this correction are completely subjective because no data exist to relate the additional percentage protected to a likelihood of persistence of that habitat type in the future. Whatever percentages are chosen, they should be of the same order of magnitude as the baseline percentage targets in order to avoid that one of the two becomes irrelevant.

4.2.2 Composite target for 'habitats of conservation importance'

The composite target for 'habitats of conservation importance' should be formulated on the basis of heuristic principles. Target formulation should take into consideration two facts: (1) these features are of special conservation interest and are particularly threatened, and (2) they are under-sampled (not all of their occurrences, and probably in many instances only a small proportion of their occurrences, have been recorded). The following strategy can be applied:

1. when only few (5^{th}-10^{th} percentile of the distribution frequency of the numbers of occurrences of each type of feature of conservation importance) occurrences are known, include them all in the MPA network;
2. for features of conservation importance sampled in a higher number of points, decrease the target proportionally (down to 30-40% of the points for the habitats sampled more frequently).

An additional percentage target, dependent on the habitat specific level of threat, can be added to the baseline target defined above following the same procedure described for EUNIS habitat types.

4.2.3 Minimum site size, number of replicates, and connectivity

The most rigorous method to produce guidelines for at least rough estimates of the minimum size of each protected site, the minimum number of replicates of a biotope or habitat type to be included in the MPA network, and the minimum level of connectivity needed, is to select key ecological processes that need to be protected by the MPA network. Once these processes are listed, three further pieces of information should be explicitly worked out: the spatial scale of each process; the association of each process with habitat types (if any); and the association of each process with other spatial features (e.g. topography). In the absence of quantitative data all these pieces of information should be assessed on the basis of expert knowledge.

The spatial scale of the processes to be conserved can be used as a guideline to quantify the minimum size of protected sites. Given the constraint of the overall proportion of each biotope and habitat type to be conserved, the minimum size of protected sites will determine also the approximate number of replicates for each habitat type in the MPA network. This should be considered only as a guideline, because the decision of creating a small reserves can still be taken e.g. to protect a small fragment of a rare habitat type in an area where large reserves are unfeasible. Yet the knowledge of the spatial scale of each target process allows clear predictions on what processes are expected or not expected to be protected by a reserve of a given size. For example, in setting targets for ecological processes in the South African succulent karoo, Pressey *et al* (2003) listed specialist pollinator relationships among the processes that can be conserved even in very small reserves, and predator-prey processes that involve large predators as processes that can only be protected by large or very large reserves.

Some target processes will require the adjacency of two or more different habitat types, while others will require that habitat types be connected (e.g. by currents). The decisions on the level of adjacency and connectivity between habitat types in the MPA network should be guided by the knowledge of these requirements.

Some of the target ecological processes will be linked to particular elements of the seascape (e.g. high productivity canyons, seamounts). For example, Lombard *et al* (2007) in a conservation plan for the Prince Edward Islands decided that the entire area included between the coastline and the 500 m isobath should be protected in order to capture the shelf-related processes. Such elements of the seascape should be added to the network of MPAs, and if their number is small there may be no spatial options at all but to include all of them in the MPA network.

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Appendix 1. EUNIS level 3 marine habitat types

EUNIS Level	EUNIS code	EUNIS name
2	A1	Littoral rock and other hard substrata
3	A1.1	High energy littoral rock
3	A1.2	Moderate energy littoral rock
3	A1.3	Low energy littoral rock
3	A1.4	Features of littoral rock
2	A2	Littoral sediment
3	A2.1	Littoral coarse sediment
3	A2.2	Littoral sand and muddy sand
3	A2.3	Littoral mud
3	A2.4	Littoral mixed sediments
3	A2.5	Coastal saltmarshes and saline reedbeds
3	A2.6	Littoral sediments dominated by aquatic angiosperms
3	A2.7	Littoral biogenic reefs
3	A2.8	Features of littoral sediment
2	A3	Infralittoral rock and other hard substrata
3	A3.1	Atlantic and Mediterranean high energy infralittoral rock
3	A3.2	Atlantic and Mediterranean moderate energy infralittoral rock
3	A3.3	Atlantic and Mediterranean low energy infralittoral rock
3	A3.7	Features of infralittoral rock
2	A4	Circalittoral rock and other hard substrata
3	A4.1	Atlantic and Mediterranean high energy circalittoral rock
3	A4.2	Atlantic and Mediterranean moderate energy circalittoral rock
3	A4.3	Atlantic and Mediterranean low energy circalittoral rock
3	A4.7	Features of circalittoral rock
2	A5	Sublittoral sediment
3	A5.1	Sublittoral coarse sediment
3	A5.2	Sublittoral sand
3	A5.3	Sublittoral mud
3	A5.4	Sublittoral mixed sediments
3	A5.5	Sublittoral macrophyte-dominated sediment
3	A5.6	Sublittoral biogenic reefs
3	A5.7	Features of sublittoral sediments
2	A6	Deep-sea bed
3	A6.1	Deep-sea rock and artificial hard substrata
3	A6.2	Deep-sea mixed substrata
3	A6.3	Deep-sea sand
3	A6.4	Deep-sea muddy sand
3	A6.5	Deep-sea mud
3	A6.6	Deep-sea bioherms
3	A6.7	Raised features of the deep-sea bed
3	A6.8	Deep-sea trenches and canyons, channels, slope failures and slumps on the continental slope
3	A6.9	Vents, seeps, hypoxic and anoxic habitats of the deep sea

Appendix 2. List of UK marine habitat of particular conservation importance

Priority habitat	**Multilateral Environmental Agreement**
Blue mussel beds	BAP
Intertidal *Mytilus edulis* beds on mixed and sandy sediments	OSPAR
Carbonate mounds	BAP & OSPAR
Coastal saltmarsh	BAP
Cold-water coral reefs	BAP & OSPAR
Coral Gardens	OSPAR
Deep-sea sponge aggregations	BAP & OSPAR
Estuarine rocky habitats	BAP
File shell beds	BAP
Fragile sponge & anthozoan communities on subtidal rocky habitats	BAP
Intertidal boulder communities	BAP
Intertidal mudflats	BAP & OSPAR
Littoral chalk communities	BAP & OSPAR
Maerl beds	BAP & OSPAR
Modiolus modiolus beds	BAP & OSPAR
Mud habitats in deep water	BAP
Sea-pen and burrowing megafauna communities	OSPAR
Ostrea edulis beds	OSPAR
Peat and clay exposures	BAP
Sabellaria alveolata reefs	BAP
Sabellaria spinulosa reefs	BAP & OSPAR
Saline lagoons	BAP

Priority habitat	**Multilateral Environmental Agreement**
Seamounts	BAP & OSPAR
Serpulid reefs	BAP
Sheltered muddy gravels	BAP
Subtidal chalk	BAP
Subtidal sands and gravels	BAP
Tide-swept channels	BAP

Appendix 3. Summary of papers reviewed

Conceptual papers

Authors	Title	Year	Citation	Comments
Agardy, T., Bridgewater, P., Crosby, M.P., Day, J., Dayton, P.K., Kenchington, R., Laffoley, D., McConney, P., Murray, P.A., Parks, J.E. and Peau, L.	Dangerous targets? Unresolved issues and ideological clashes around marine protected areas.	2003	Aquatic Conservation-Marine and Freshwater Ecosystems 13: 353-367	This manuscript seeks to initiate an open and objective discussion regarding the differing views about MPAs that are present and growing in the international marine conservation community. It can be used for the introduction, general background regarding MPA and spatial target generally adopted (pro and cons of 20%).
Carwardine, J., Klein, C.J., Wilson, K.A., Pressey, R.L. and Possingham, H.P.	Hitting the target and missing the point: target-based conservation planning in context.	2008	Conservation Letters	The authors investigate the perceived limitations of target-based conservation planning, and find that most have resulted from poor communication and misuse of targets, leading to misconceptions and misunderstanding.
Edgar, G.J., Langhammer, P.F., Allen, G., Brooks, T.M., Brodie, J., Crosse, W., De Silva, N., Fishpool, L.D.C., Foster, M.N., Knox, D.H., McCosker, J.E., McManus, R., Millar, A.J.K. and Mugo, R.	Key biodiversity areas as globally significant target sites for the conservation of marine biological diversity.	2008	Aquatic Conservation-Marine and Freshwater Ecosystems 18: 969-983	Description of the KBA approach and its application to MPAs. Criteria (Vulnerability and Irreplaceability) and thresholds provisionally considered appropriate for the identification of marine KBAs.
Eken, G., Bennun, L., Brooks, T.M., Darwall, W., Fishpool, L.D.C., Foster, M., Knox, D., Langhammer, P., Matiku, P., Radford, E., Salaman, P., Sechrest, W., Smith, M.L., Spector, S. and Tordoff, A.	Key biodiversity areas as site conservation targets.	2004	Bioscience 54: 1110-1118	KBA concept: sites are selected using standardized, globally applicable, threshold-based criteria, driven by the distribution and population of species that require site-level conservation. The criteria address the two key issues for setting site conservation priorities: vulnerability and irreplaceability. They also propose quantitative thresholds for the identification of KBAs meeting each criterion, based on a review of existing approaches and ecological theory to date.

Authors	Title	Year	Citation	Comments
Fernandes, L., Day, J., Lewis, A., Slegers, S., Kerrigan, B., Breen, D., Cameron, D., Jago, B., Hall, J., Lowe, D., Innes, J., Tanzer, J., Chadwick, V., Thompson, L., Gorman, K., Simmons, M., Barnett, B., Sampson, K., De'ath, G., Mapstone, B., Marsh, H., Possingham, H., Ball, I., Ward, T., Dobbs, K., Aumend, J., Slater, D. and Stapleton, K.	Establishing representative no-take areas in the Great Barrier Reef: Large-scale implementation of theory on marine protected areas.	2005	Conservation Biology 19: 1733-1744	The authors discuss the success factors that led to establishing a large, comprehensive, adequate, and representative network of no-take marine protected areas in the Great Barrier Reef Marine Park (GBRMP).
Hastings, A. and Botsford, L.W.	Comparing Designs of Marine Reserves for Fisheries and for Biodiversity.	2003	Ecological Applications 13(1 Supplement): S65-S70	The authors compare and contrast the design of networks of marine reserves for two different, commonly stated goals: (1) maintaining high yield in fisheries and (2) conserving biodiversity, in an idealized setting using simple models. Meeting the fisheries goal is ultimately more costly because it suggests a larger area of the coastline should be in reserves, but it also improves on conservation goals by enhancing sustainability for species dispersing longer distances.
Hayes, A.Y., Berliner, D. and Desmet, P.	Eastern Cape Biodiversity Conservation Plan Handbook.	2007	Department of Water Affairs and Forestry Project No 2005-012, King William's Town	The ECBCP is intended for use by technical users and decision-makers in the spheres of planning, development and environment.

Authors	Title	Year	Citation	Comments
Klein, C.J., Steinback, C., Scholz, A.J. and Possingham, H.P.	Effectiveness of marine reserve networks in representing biodiversity and minimizing impact to fishermen: a comparison of two approaches used in California.	2008	Conservation Letters 1: 44–51	We compared the effectiveness of marine reserve networks designed using a numerical optimization tool with networks designed by stakeholders at representing biodiversity and minimizing estimated negative impacts to fishermen. Networks of marine reserves designed with numerical optimization tools represented the same amount of each habitat, or more, and had less of an estimated impact on commercial and recreational fisheries than networks designed by the stakeholders. The involvement of stakeholders is necessary as additional factors important to reserve design.
Langhammer, P.F., Bakarr, M.I., Bennun, L.A., Brooks, T.M., Clay, R.P., Darwall, W., De Silva, N., Edgar, G.J., Eken, G., Fishpool, L.D.C., da Fonseca, G.A.B., Foster, M.N., Knox, D.H., Matiku, P., Radford, E.A., Rodrigues, A.S.L., Salaman, P., Sechrest, W. and Tordoff, A.W.	Identification and Gap Analysis of Key Biodiversity Areas: Targets for Comprehensive Protected Area Systems.	2007	IUCN	Guidelines for the identification of KBAs. KBA concept, criteria and targets.
Nicholson, E. and Possingham, H.P.	Objectives for Multiple-Species Conservation Planning.	2006	Conservation Biology Volume 20 (3): 871–881	The author's objective is to translate the broad goal of maximizing the viability of species into explicit objectives for use in a decision-theoretic approach to conservation planning. They formulated several objective functions based on extinction risk across many species and illustrated the differences between these objectives with simple examples.

Authors	**Title**	**Year**	**Citation**	**Comments**
Opdam, P., Pouwels, R., van Rooij, S., Steingröver, E. and Vos, C.C.	Setting biodiversity targets in participatory regional planning: introducing ecoprofiles.	2008	Ecology and Society 13(1): 20-36	The authors infer a set of prerequisites for the effective use of biodiversity goal-setting methods in multi-stakeholder decision making. The decision making must also be enriched with local ecological knowledge. The current methods for setting biodiversity targets lack crucial characteristics— in particular, flexibility—and often require too high a level of ecological expertise. The ecoprofile method we designed combines an ecosystem base with spatial conditions for species metapopulations.
Roberts, C.M., Andelman, S., Branch, G., Bustamante, R.H., Castilla, J.C., Dugan, J., Halpern, B.S., Lafferty, K.D., Leslie, H., Lubchenco, J., Mcardle, D., Possingham, H.P., Ruckelshaus, M. and Warner, R.R.	Ecological Criteria for Evaluating Candidate Sites for Marine Reserves.	2003	Ecological Applications 13(1 Supplement):S199-S215	This paper sets out a procedure grounded in current understanding of ecological processes that allows the evaluation and selection of reserve sites in order to develop functional, interconnected networks of fully protected reserves that will fulfil multiple objectives. Candidate sites for reserves are evaluated against 12 criteria focused toward sustaining the biological integrity and productivity of marine systems at both local and regional scales.
Roberts, C.M., Branch, G., Bustamante, R.H., Castilla, J.C., Dugan, J., Halpern, B.S., Lafferty, K.D., Leslie, H., Lubchenco, J., McArdle, D., Ruckelshaus, M. and Warner, R.R.	Application of Ecological Criteria in Selecting Marine Reserves and Developing Reserve Networks.	2003	Ecological Applications 13(1 Supplement):S215-S228	The authors developed a series of criteria that allow preliminary evaluation of candidate sites according to their relative biological values in advance of the application of socioeconomic criteria.
Sanderson, E.W., Redford, K.H., Vedder, A., Coppolillo, P.B. and Ward. S.E.	A conceptual model for conservation planning based on landscape species requirements.	2002	Landscape and Urban Planning 58: 41-56	This paper focuses on the landscape species concept. It outlines a conceptual strategy for focusing conservation activities through the landscape species concept as implemented by WCS.

Authors	Title	Year	Citation	Comments
Tear, T.H., Kareiva, P., Angermeier, P.L., Comer, P., Czech, B., Kautz, R., Landon, L., Mehlman, D., Murphy, K., Ruckelshaus, M., Scott, J.M. and Wilhere, G.	How much is enough? The recurrent problem of setting measurable objectives in conservation.	2005	Bioscience 55: 835-849	The authors developed guidelines to help steer conservation biologists and practitioners through the process of objective setting. They provided three case studies to highlight the practical challenges of objective setting in different social, political, and legal contexts.
Warman, L.D., Sinclair, A.R.E., Scudder, G.G.E., Klinkenberg, B. and Pressey, R.L.	Sensitivity of systematic reserve selection to decisions about scale, biological data, and targets: Case study from Southern British Columbia.	2004	Conservation Biology 18: 655-666	This study explores the sensitivity of systematic reserve selection by altering values of three essential variables (selection unit size and shape, features of biodiversity, and area conservation targets for each biodiversity feature).
Wilhere, G.F.	The How-Much-Is-Enough Myth.	2008	Conservation Biology 22(3): 514–517	This is an essay that explains the "how-much is-enough" myth.

Literature review

Authors	Title	Year	Citation	Comments
Akçakaya, H.R. and Sjögren-Gulve, P.	Population viability analysis in conservation planning: an overview.	2000	Ecological Bulletins 48:9-21.	This overview provides guidelines for choosing a PVA model among three categories, from data-intensive individual-based population models to simple occupancy metapopulation models.
Carr, M.H., Neigel, J.E., Estes, J.A., Andelman, S., Warner, R.R. and Largier, J.L.	Comparing Marine and Terrestrial Ecosystems: Implications for the Design of Coastal Marine Reserves.	2003	Ecological Applications 13 (1Supplement): S90-S107	The objective is to provide an overview of some fundamental similarities and differences between terrestrial and marine ecosystems with the aim of understanding their implications for reserve network design in marine systems.
Day, J.C. and Roff, J.C.	Planning for Representative Marine Protected Areas: A Framework for Canada's Oceans.	2000	World Wildlife Fund Canada, Toronto	This report discuss the general principles for designing a hierarchical framework and outlines the proposed national framework for marine conservation, as well as the various assumptions, limitations and caveats that also need to be considered.
Egoh, B., Rouget, M., Reyers, B., Knight, A.T., Cowling, R.M., van Jaarsveld, A.S. and Welz, A.	Integrating ecosystem services into conservation assessments: A review.	2007	Ecological Economics 63: 714-721	This study contributes towards the development of integrating ecosystem services into conservation planning through a review of conservation assessments and the extent to which they include ecosystem services. This study includes also an analysis of the constraints and opportunities for the integration of ecosystem services into conservation assessments.
Gell, F.R. and Roberts, C.M.	The Fishery Effects of Marine Reserves and Fishery Closures.	2005	WWF US, editor, Washington, DC	Fisheries have been shown to benefit from reserves. The report analyzes this body of evidence, drawing upon studies of reserves and fishery closures and describes experiences that prove that success of marine reserves is not contingent on habitat type, geographical location, the kind of fishery involved, or the technological sophistication of management.

Authors	**Title**	**Year**	**Citation**	**Comments**
Leslie, H.M.	A synthesis of marine conservation planning approaches.	2005	Conservation Biology 19: 1701-1713	Review of conservation planning cases.
Lourie, S.A. and Vincent, A.C.J.	Using biogeography to help set priorities in marine conservation.	2004	Conservation Biology 18: 1004-1020	The authors review the current status of marine biogeography, assess ways in which current marine conservation projects incorporate biogeographic information into their planning, and provide recommendations for the future use of biogeography in marine planning.
Neigel, J.E.	Species-Area Relationships and Marine Conservation.	2003	Ecological Applications 13(1, Supplement): S138-S145	Application of the SPAR in the design of marine reserves and differences between the terrestrial and marine realms.
Poiani, K.A., Baumgartner, J.V., Buttrick, S.C., Green, S.L., Hopkins, E., Ivey, G.D., Seaton, K.P. and Sutter, R.D.	A scale-independent, site conservation planning framework in The Nature Conservancy.	1998	Landscape and Urban Planning 43: 143-156	The paper overview site conservation planning in The Nature Conservancy and offer a practical, and efficient method for conservation planning that is applicable at all spatial scales and levels of complexity.
Redford, K.H., Coppolillo, P., Sanderson, E.W., Da Fonseca, G.A.B., Dinerstein, E., Groves, C., Mace, G., Maginnis, S., Mittermeier, R.A., Noss, R., Olson, D., Robinson, J. G., Vedder, A. and Wright, M.	Mapping the conservation landscape.	2003	Conservation Biology 17: 116-131	The authors review the approaches currently being implemented by 13 conservation organizations. We examined each of these approaches according to the nature of the conservation target—the object(s) of the conservation action; whether the question addressed is where conservation should be done or how conservation should be done; the scale (both grain and extent) of the approach; and the principles that underlie the approach.
Roberts, C.M., Hawkins, J.P. and Gell, F.R.	The role of marine reserves in achieving sustainable fisheries.	2005	Philosophical Transactions of the Royal Society B-Biological Sciences 360:123-132.	The authors review the role of marine reserves worldwide in fisheries management. Large-scale marine reserves networks must be an integral element of fishery management if we are to achieve sustainable fisheries while maintaining marine biodiversity and ecosystem processes.

Authors	Title	Year	Citation	Comments
Sanderson, E.W.	How many animals do we want to save? The many ways of setting population target levels for conservation.	2006	Bioscience 56: 911-922	The author reviews 18 approaches to setting population target levels (PTLs) for animals, with rules of thumb and analytical recommendations for each approach.
Sarkar, S., Pressey, R.L., Faith, D.P., Margules, C.R., Fuller, T., Stoms, D.M., Moffett, A., Wilson, K.A., Williams, K.J., Williams, P.H. and Andelman, S.	Biodiversity conservation planning tools: Present status and challenges for the future.	2006	Annual Review of Environment and Resources 31: 123-159	This is a review of key concepts of Biodiversity Planning Tools.
Smith, R.J., Eastwood, P.D., Ota, Y. and Rogers, S.I.	Developing best practice for using Marxan to locate Marine Protected Areas in European waters.	2009	ICES Journal of Marine Science 66	The authors discuss two broad topics: technical issues that need to be addressed to ensure the scientific defensibility of any conservation planning project; engagement at an early stage with those responsible for implementation and recognize that reserve selection should be part of a broader conservation planning process centred on a stakeholder-developed implementation strategy.
Svancara, L.K., Brannon, R., Scott, J.M., Groves, C.R., Noss, R.F. and Pressey, R.L.	Policy-driven versus evidence-based conservation: A review of political targets and biological needs.	2005	Bioscience 55: 989-995	The authors reviewed 159 articles reporting or proposing 222 conservation targets and assessed differences between policy-driven and evidence-based approaches. Our findings suggest that the average percentages of area recommended for evidence-based targets were nearly three times as high as those recommended in policy-driven approaches.

Fixed targets

Authors	Title	Year	Citation	Comments	Study area	Target features	Marine/ Terre-strial
Airame, S., Dugan, J.E. Lafferty, K.D. Leslie, H. McArdle, D.A. and Warner, R.R.	Applying Ecological Criteria to Marine Reserve Design: A Case Study from the California Channel Islands.	2003	Ecological Applications 13 (1Supplement): S170-S184	In the Channel Islands, after consideration of both conservation goals and the risk from human threats and natural catastrophes, scientists recommended reserving an area of 30-50% of all representative habitats in each biogeographic region.	California Channel Islands	representative habitats	marine
Ardron, J.A., Lash, J. and Haggarty, D.	Modelling a Network of Marine Protected Areas for the Central Coast of British Columbia. Version 3.1.	2002	Living Oceans Society, Sointula, BC, Canada.	This paper contain the results and methodologies of the modelling science-based networks of marine protected areas for the Central Coast of British Columbia.	Canada	species and habitats	marine
Banks, S.A., and Skilleter, G.A.	The importance of incorporating fine-scale habitat data into the design of an intertidal marine reserve system.	2007	Biological Conservation 138: 13-29	This paper can be used to discuss the reliability of surrogate measures to represent biodiversity and the use of such measures in the design of marine reserve systems. In this study, 'shoreline types', derived using physical properties of the shoreline, were used as a surrogate for intertidal biodiversity to assist with the identification of sites to be included in a representative system of marine reserves.	Queensland	habitats and microhabitats on rocky shores	marine

Authors	Title	Year	Citation	Comments	Study area	Target features	Marine/ Terre-strial
Banks, S.A., Skilleter, G.A. and Possingham, H.P.	Intertidal habitat conservation: identifying conservation targets in the absence of detailed biological information.	2005	Aquatic Conserv: Mar. Freshw. Ecosyst. 15: 271–288	This study explores several reserve design scenarios that incorporate information about cost, reserve boundary length and existing protection of an intertidal habitat surrogate to identify the range of areas that would need to be included in a reserve system.	Queensland	63 intertidal habitats and 30 adjacent littoral zone habitat	marine
Beck, M.W. and Odaya, M.	Ecoregional planning in marine environments: identifying priority sites for conservation in the northern Gulf of Mexico.	2001	Aquatic Conser: Mar. Freshw. Ecosyst. 11: 235–242	The overall aim of this work was to identify sites within the northern Gulf of Mexico that, if protected, would fully represent the biological diversity of the nearshore waters of this ecoregion. As a preliminary goal, it was determined that the set of priority sites should contain at least 20% of the current distribution of each target habitat and species.	northern Gulf of Mexico	Habitats and species	marine
Beck, M.W., Odaya, M., Bachant, J.J., Bergan, J., Keller, B., Martin, R., Mathews, R., Porter, C. and Ramseur, G.	Identification of Priority Sites for Conservation in the Northern Gulf of Mexico: An Ecoregional Plan.	2000	The Nature Conservancy, Arlington, VA	The aim of this work was to identify sites within the northern Gulf of Mexico ecoregion that if protected would fully represent the biological diversity of the nearshore waters of this region.	northern Gulf of Mexico	Habitats and species	marine
Cowling, R.M.	Planning for persistence a systematic reserve design in southern Africa's Succulent Karoo desert.	1999	Parks 9: 17-30	This article includes a conceptual framework and a protocol for designing a reserve system that explicitly considers both natural pattern and process.	Succulent Karoo	flora species	terrestrial

Authors	Title	Year	Citation	Comments	Study area	Target features	Marine/ Terre-strial
Cowling, R.M., Pressey, R.L., Lombard, A.T., Desmet, P.G., and Ellis, A.G.	From representation to persistence: requirements for a sustainable system of conservation areas in the species-rich mediterranean-climate desert of southern Africa.	1999	Diversity and Distributions 5: 51-71	The authors discuss the requirements for establishing a sustainable (retention+persistence) conservation system in southern Africa's Succulent Karoo. They present a protocol for decision-making and apply it by designing a hypothetical system of conservation areas.	Succulent Karoo	species and habitats as surrogates of species	terrestrial
Davis, F.W., Stoms, D.M. and Andelman, S.	Systematic reserve selection in the USA: an example from the Columbia Plateau ecoregion.	1999	Parks 9: 31-41	This study integrates data on species, plant communities, land ownership and other socioeconomic factors, and combined expert opinion with computer-aided site selection modelling.	Columbia Plateau Ecoregion	vegetation alliances (coarse-filter) and rare species and plant associations (fine-filter)	terrestrial
Edgar, G.J., Banks, S., Bensted-Smith, R., Calvopiña, M., Chiriboga, A., Garske, L.E., Henderson, S., Miller, K.A. and Salazar, S.	Conservation of threatened species in the Galapagos Marine Reserve through identification and protection of marine key biodiversity areas.	2008	Aquatic Conservation-Marine and Freshwater Ecosystems 18: 955–968	The authors apply the KBA approach to the Galapagos Marine Reserve.	Galapagos	species	marine

Authors	Title	Year	Citation	Comments	Study area	Target features	Marine/ Terre-strial
Game, E.T., McDonald-Madden, E., Puotinen, M.L. and Possingham, H. P.	Should We Protect the Strong or the Weak? Risk, Resilience, and the Selection of Marine Protected Areas.	2008	Conservation Biology 22: 1619-1629	The authors analytically solved the problem of which marine habitats should be protected, those areas at greatest risk or those at least risk? If the conservation objective was to maximize the chance of having at least one healthy site, then the best strategy was protection of the site at lowest risk. On the other hand, if the goal was to maximize the expected number of healthy sites, the optimal strategy was more complex. If protected sites were likely to spend a significant amount of time in a degraded state, then it was best to protect low-risk sites. Alternatively, if most areas were generally healthy then, counterintuitively, it was best to protect sites at higher risk.	Great barrier reef	reef	marine
Leslie, H.M., Ruckelshaus, M., Ball, I.R., Andelman, S. and Possingham, H.P.	Using Siting Algorithms in the Design of Marine Reserve Networks.	2003	Ecological Applications 13(1, Supplement): S185-S198	The authors demonstrate how siting algorithms can help identify potential networks of marine reserves that comprehensively represent target habitat types. They applied a flexible optimization tool simulated annealing to represent a fixed proportion of different marine habitat types within a geographic area.	Florida Keys	habitat types	marine

Authors	**Title**	**Year**	**Citation**	**Comments**	**Study area**	**Target features**	**Marine/ Terre-strial**
Lombard, A.T., Strauss, T., Harris, J., Sink, K., Attwood, C. and Hutchings, L.	South African National Spatial Biodiversity Assessment 2004: Technical Report. Volume 4: Marine Component.	2004	South African National Biodiversity Institute, Pretoria	This report presents a spatial assessment of the conservation status of selected marine biodiversity patterns in South Africa, at a national scale. Although our data and analyses must be considered as preliminary, they show that to meet internationally recommended targets of ≥ 20% of the extent of habitats, South Africa will have to consider the proclamation of offshore MPAs very seriously. In order to do this, further sampling of the offshore biota will be required.	South Africa	species, intertidal habitats, offshore habitats	marine
Maiorano, L., Bartolino, V., Colloca, F., Abella, A., Belluscio, A., Carpentieri, P., Criscoli, A., Jona Lasinio, G., Mannini, A., Pranovi, F., Reale, B., Relini, G., Viva, C. and Ardizzone, G.D.	Systematic conservation planning in the Mediterranean: a flexible tool for the identification of no-take marine protected areas.	2009	ICES Journal of Marine Science 66: 000–000	The authors propose the use of systematic conservation planning in the Mediterranean context for the identification of no-take marine protected areas (NTMPAs). They suggest a logical framework that should be used for the identification of areas to be targeted for multispecies, spatially explicit conservation actions. Moreover, they consider the potential impact of different conservation plans on existing fishing vessels.	Mediterra-nean	species	marine
Pressey, R.L.	Applications of irreplaceability analysis to planning and management problems.	1999	Parks 9: 42-51	Irreplaceability concept and its application, and a development of a map of irreplaceability for New South Wales.	New South Wales	land systems	terrestrial

Authors	Title	Year	Citation	Comments	Study area	Target features	Marine/ Terre-strial
Richardson, K.S. and Funk, V.A.	An approach to designing a systematic protected area system in Guyana.	1999	Parks 9: 42552	This article describes an approach to designing a protected area system in Guyana based on patterns of species distribution.	Guyana	species	terrestrial
Sala, E., Aburto-Oropeza, O. Paredes, G. Parra, I., Barrera, J.C. and Dayton, P.K.	A General Model for Designing Networks of Marine Reserves.	2002	Science 298: 1991-1993	This study describes a means of establishing marine reserve networks by using optimization algorithms and multiple levels of information on biodiversity, ecological processes (spawning, recruitment, and larval connectivity), and socioeconomic factors in the Gulf of California.	California	Habitats and species	marine
Smith, R.J., Goodman, P.S. and Matthews, W.S.	Systematic conservation planning: a review of perceived limitations and an illustration of the benefits, using a case study from Maputaland, South Africa.	2006	Oryx 40(4): 400-410	Limitations to the conservation planning approach. The authors then illustrate the value of systematic conservation planning to practitioners using a case study that describes a lowcost exercise from Maputaland, South Africa.	Maputaland, South Africa	land cover types	terrestrial

Authors	Title	Year	Citation	Comments	Study area	Target features	Marine/ Terre-strial
Stewart, R.R., Ball, I.R. and Possingham, H.P.	The effect of incremental reserve design and changing reservation goals on the long-term efficiency of reserve systems.	2007	Conservation Biology 21: 346-354	The authors investigate how changing percentage targets affect the contribution of individual planning units to efficient reserve design. For the majority of planning units, changing targets led to a change in their conservation value indicating, for example, that planning units identified as high-value sites at a low-percentage conservation target may be of lesser importance when targets are increased. Despite the variability in the value of individual planning units at different targets, there was no loss in efficiency from incremental design of reserve systems based on systematic methods compared with purpose-built reserve systems.	Australia	habitat types, species	terrestrial
Stewart, R.R., Noyce, T. and Possingham, H.P.	Opportunity cost of ad hoc marine reserve design decisions: an example from South Australia.	2003	Marine Ecology-Progress Series 253: 25-38	Configuration of exploratory marine reserve systems, using the software MARXAN, to examine how efficiently South Australia's existing marine reserves contribute to quantitative biodiversity conservation targets.	South Australia	derived from biophysical layers	marine
Ward T.J., Vanderklift, M.A., Nicholls, A.O. and Kenchington, R.A.	Selecting Marine Reserves using habitats and species assemblages as surrogates for biological diversity.	1999	Ecological Applications 9(2): 691-698	The authors compare the value of using habitat categories and species as surrogates for marine biodiversity in the context of choosing a set of representative areas for a marine reserve network.	Australia	species, habitats	marine

Authors	Title	Year	Citation	Comments	Study area	Target features	Marine/ Terre-strial
Wiersma, Y.F. and Nudds, T.D.	Conservation targets for viable species assemblages in Canada: Are percentage targets appropriate?	2006	Biodiversity and Conservation 15: 4555-4567	The authors carried out an analysis for representation of mammals within sites that are predicted to allow for their persistence, across eight ecologically defined regions in Canada to test whether we see similar consistent patterns emerging. They found that percentage targets varied with the different permutations of the reserve selection algorithms, both within and between the study regions. The use of percentage targets is not an appropriate conservation strategy.	Canada	mammal species	terrestrial
Wood, L.J.	The Global Network of Marine Protected Areas: developing baselines and identifying priorities.	2007	The University of British Columbia	The author applies a rarity-complimentarily heuristic place prioritisation algorithm (PPA) to a dataset consisting of 1038 global species distributions, under ten scenarios devised to reflect the global targets. Global priority areas for protection are identified for each scenario, which may be used to identify where regional-scale protected areas network design efforts might be focused.	Global	species	marine

Variable target (case studies in bold)

Authors	Title	Year	Citation	Comments	Study area	Target features	Method	Marine/ terrestrial
Berliner, D. and Desmet, P.	Eastern Cape Biodiversity Conservation Plan: Technical Report.	2007	Department of Water Affairs and Forestry Project No 2005-012	This study uses systematic conservation planning to map critical biodiversity areas required for biodiversity persistence and to use this information to inform protected area planning and rural land-use planning.	Eastern Cape province, South Africa	vegetation types, breeding sites or habitat ranges for species, river types, fish species	Biodiversity targets follow conventions used in other systematic planning studies conducted in South Africa as well as SANBI guidelines. For the vegetation types they used NSBA targets, expert mapped areas, 20% of the ecoregion for the freshwater environment, and sliding scale target related to number of mapped occurrence for fish species.	terrestrial

Authors	Title	Year	Citation	Comments	Study area	Target features	Method	Marine/ terrestrial
Bohnsack, J.A., Causey, B., Crosby, M.P., Griffis, R.B., Hixon, M.A., Hourigan, T.F., Koltes, K.H.J., Maragos, E., Simons, A. and Tilmant, J.T.	A rationale for minimum 20-30% no-take protection.	2000	9th International Coral Reef Symposium	This study provides a rationale for using 20-30% minimum no-take protection to conserve coral reef ecosystems. Support comes from reproductive theory, knowledge about the vulnerability of reef species to exploitation, analysis of fishery failures, and empirical and modelling studies of reserve.	USA	reef fish species	Reproductive theory provides support for minimum 20-30% spatial protection because this range is well above the inflection point of the risk and compensation curves, where small changes in Spawning Potential Ratio (SPR) have large impacts on risk of stock collapse and egg survival compensation. The key assumption linking SPR to area is that the proportion of the fish population protected is proportional to area protected.	marine

Authors	Title	Year	Citation	Comments	Study area	Target features	Method	Marine/ terrestrial
Burgman, M.A., Possingham, H.P., Lynch, A.J.J., Keith, D.A., McCarthy, M.A., Hopper, S.D., Drury, W.L., Passioura, J.A. and Devries, R.J.	A method for setting the size of plant conservation target areas.	2001	Conservation Biology 15: 603-616	The authors outline a set of concepts and formulas to estimate the protected areas required to provide desirable conservation outcomes for a suite of threatened plant species. They used expert judgment of parameters and assessment of a population size that results in a specified quasiextinction risk based on simple dynamic models. The area required to support a population of this size is adjusted to take into account deterministic and stochastic human influences, including small-scale disturbance, deterministic trends such as habitat loss, and changes in population density through processes such as predation and competition. They set targets for different disturbance regimes and geographic regions.	Queensland	plant species	They developed a simple population models for setting targets to ensure the persistence of vascular plants.	terrestrial

Authors	Title	Year	Citation	Comments	Study area	Target features	Method	Marine/ terrestrial
Carroll, C., Noss, R. F., Paquet, P.C. and Schumaker, N.H.	Integrating population viability analysis and reserve selection algorithms into regional conservation plans.	2003	Eco logical Applications 13: 1773-1789	Population viability analyses may incorporate detailed demographic data, but often lack sufficient spatial detail or are limited to too few taxa to be relevant to regional conservation plans. The authors developed a regional conservation plan for mammalian carnivores using both a reserve selection algorithm (SITES) and a spatially explicit population model (PATCH). The main objective is to protect highest quality habitat and source areas to maintain viable populations of carnivores.	Rocky Mountains	vertebrate species	PVA	terrestrial

Authors	Title	Year	Citation	Comments	Study area	Target features	Method	Marine/ terrestrial
Chan, K.M.A., Shaw, M.R. Cameron, D.R., Underwood, E.C and Daily, G.C.	Conservation planning for ecosystem services.	2006	Plos Biology 4: 2138-2152	This paper explores the trade-offs and opportunities for aligning conservation goals for biodiversity with six ecosystem services. Targeting ecosystem services directly can meet the multiple ecosystem services and biodiversity goals more efficiently but cannot substitute for targeted biodiversity protection. Strategically targeting only biodiversity plus the four positively associated services offers much promise. The authors present an initial analytical framework for integrating biodiversity and ecosystem services in conservation planning.	Central Coast eco-region of California	biodiversity and ecosystem services	Heuristic on habitats to protect ecosystem service.	terrestrial
Cowling, R.M., Pressey, R.L., Rouget, M. and Lombard, A.T.	A conservation plan for a global biodiversity hotspot - the Cape Floristic Region, South Africa.	2003	Biological Conservation 112: 191-216	The main objective of this study is to create a conservation plan that promotes the "persistence of the region's documented biodiversity".	Cape Floristic Region	land classes, species, processes	Heuristic (see Pressey *et al* 2003)	terrestrial

Authors	Title	Year	Citation	Comments	Study area	Target features	Method	Marine/ terrestrial
Desmet, P. and Cowling, R.	Using the species-area relationship to set baseline targets for conser-vation.	2004	Ecology and Society 9:	This paper demonstrates how the power form of the Species–Area Relationship (SAR) can be used to set conservation targets for land classes using biodiversity survey data. It also provides suggestions for extrapolating the estimated z-values to other land classes within a bioregion that lack sufficient survey data, using the relationship between z-values and remotely determined landscape variables such as habitat diversity (topographic diversity) and geographic location (latitude and longitude).	Succulent Karoo	land classes	The Species-Area Relationship (SAR) is used for setting conservation targets expressed as % of vegetation type required to represent a given % of plant species occurring in that vegetation type.	terrestrial

Authors	Title	Year	Citation	Comments	Study area	Target features	Method	Marine/ terrestrial
Ferrar, T.A. and Lötter, M.C.	Mpumalanga Biodiversity Conservation Plan Handbook.	2007	Mpumalanga Tourism and Parks Agency, Nelspruit	The main objective of this Plan is intended to guide conservation and land-use decisions in support of sustainable development. The Plan uses the NSBA targets for vegetation types, except for forests. The NSBA targets are based on the species diversity within each vegetation type: higher species diversity corresponds to a higher target. For the vegetation types that occur in Mpumalanga, targets range from 19% to 28% of the original area of each vegetation type. Targets for forests are taken from the DWAF national systematic conservation plan for forests. These targets range from 59.5% to 71.7%. Species targets vary widely, up to 100% for Critically Endangered species localities.	Mpumalanga province, South Africa	vegetation types, species	Species-Area Relationship (SAR)	terrestrial

Authors	Title	Year	Citation	Comments	Study area	Target features	Method	Marine/ terrestrial
Justus, J. Fuller, T. and Sarkar, S.	Influence of represent-ation targets on the total area of conservation-area networks.	2008	Conservation Biology 22: 673-682	The authors examined how the total area of conservation-area networks depends on percentage targets ranging from 5% to 95%; and assessed the effect of spatial resolution on the target-area relationship. Most of the data sets showed a linear relationship between representation targets and total area of conservation-area networks that was invariant across changes in spatial resolution. The slope of this relationship indicated how total area increased with target level, and our results suggest that greater surrogate representation requires significantly more area. One data set exhibited a highly nonlinear relationship. The results	6 different regions analyzed	different surrogates (species, vegetation types, environ-mental para-meters)	The target-area function assigns amounts of land at different target levels. This function can be used to provide a justification for target selection.	terrestrial

Authors	Title	Year	Citation	Comments	Study area	Target features	Method	Marine/ terrestrial
				for this data set suggest a new method for setting targets on the basis of the functional form of target-area relationships. In particular, the method shows how the target-area relationship can provide a rationale for setting targets solely on the basis of distributional information about surrogates.				
Lombard, A.T., Reyers, B., Schonegevel, L.Y., Cooper, J., Smith-Adao, L.B., Nel, D.C., Froneman, P.W., Ansorge, I.J., Bester, M.N., Tosh, C.A., Strauss, T., Akkers, T., Gon, O., Leslie, R.W. and Chown, S.L.	Conserving pattern and process in the Southern Ocean: designing a Marine Protected Area for the Prince Edward Islands.	2007	Antarctic Science 19:39–54	This study employs systematic conservation planning methods to delineate a MPA within the EEZ that will conserve biodiversity patterns and processes within sensible management boundaries, while minimizing conflict with the legal toothfish fishery.	Prince Edward Islands	species, benthic habitats and ecosystem processes	Heuristic on habitats to protect ecological processes.	marine

Authors	Title	Year	Citation	Comments	Study area	Target features	Method	Marine/ terrestrial
Neely, B., Comer, P., Moritz, C., Lammert, M., Rondeau, R., Pague, C., Bell, G., Copeland, H., Humke, J., Spackman, S., Schulz, T., Theobald, D. and Valutis, L.	Southern Rocky Mountains: An Ecoregional Assessment and Conserv-ation Blueprint.	2001	The Nature Conservancy with support from the U.S. Forest Service, Rocky Mountain Region, Colorado Division of Wildlife, and Bureau of Land Management.	This report presents the results of an ecoregional conservation assessment of the Southern Rocky Mountains. This ecoregional conservation assessment process involved compilation and analysis of the most up-to-date biological data on the location and quality of conservation targets.	Southern Rocky Mountains	species, communities and ecological systems	Heuristic on habitats as species containers. The team considered the spatial pattern and distribution of ecological systems relative to the ecoregion (Anderson *et al* 1999). Conservation goals were expressed in different forms, depending on the typical spatial pattern of the target occurrence. For species, in order to establish initial goals, the team used the target's conservation status and distribution relative to the ecoregion as primary factors.	terrestrial

Authors	Title	Year	Citation	Comments	Study area	Target features	Method	Marine/ terrestrial
Pressey, R.L., Cowling, R.M. and Rouget, M.	Formulating conservation targets for biodiversity pattern and process in the Cape Floristic Region, South Africa.	2003	Biological Conservation 112: 99-127	The authors formulate quantitative targets, discuss these in the context of the general role of targets in conservation planning, the inadequacy of commonly used standard targets such as 10% of features or whole regions, and the uncertainties around setting targets for land type.	Cape Floristic Region	land types; locality records for plant species, species of reptiles, amphibians and freshwater fish; estimated distributions and densities of large and medium-sized mammals; and six types of spatial surrogates for ecological and evolutionary processes	Heuristic on habitats to protect ecological processes.	terrestrial

Authors	Title	Year	Citation	Comments	Study area	Target features	Method	Marine/ terrestrial
Rouget, M.	Measuring conservation value at fine and broad scales: implications for a diverse and fragmented region, the Agulhas Plain.	2003	Biological Conservation 112: 217-232	This study explores the implications of spatial scale for conservation planning in the Agulhas Plain, South Africa. This study addresses the implications of broad-scale planning for fine-scale implementation.	Agulhas Plain, South Africa	land classes	The authors set baseline targets as 10% of original (pre-transformation) area for vlei and forest vegetation types, 15% for lowlands vegetation types and 25% for montane vegetation types.	terrestrial
Rouget, M., Reyers, B., Jonas, Z., Desmet, P., Driver, A., Maze, K., Egoh, B., Cowling, R.M., Mucina, L. and Rutherford, M.C.	South African National Spatial Biodiversity Assessment 2004: Technical Report. Volume 1: Terrestrial Component.	2004	South African National Biodiversity Institute, Pretoria	This report deals with the terrestrial component of the South African National Spatial Biodiversity Assessment.	South Africa	vegetation types, wetlands, estuaries and species	Species-Area Relationship (SAR). Representation targets for South African vegetation types were calculated using the species-area relationship method developed by Desmet and Cowling.	terrestrial

Authors	**Title**	**Year**	**Citation**	**Comments**	**Study area**	**Target features**	**Method**	**Marine/ terrestrial**
Smith, R.J. and Leader-Williams, N.	The Maputaland Conservation Planning System and Conservation Assessment.	2006	Durrell Institute of Conservation and Ecology	Conservation Assessment of Maputaland (South Africa).	Maputaland, South Africa	land cover types, species, ecological processes	Species-Area Relationship (SAR). The landcover type targets were based on SAR adopted also by SANBI; fort species the authors used Minimum viable populations and proportion of metapopulation; the ecological process targets were based on expert review.	terrestrial
Solomon, M., Van Jaarveld, A.S., Biggs, H.C. and Knight, M.H.	Conservation targets for viable species assem-blages?	2003	Biodiversity and Conservation 12: 2435–2441	Authors analyzed spatially explicit abundance data from the Kruger National Park to determine the area requirements for sampling viable populations of a herbivore assemblage.	South Africa	species	They used data on species abundance to assemble selection units (grid cells) that contained a range of minimum population sizes. The percentage area required to conserve viable populations of the full assemblage of herbivores was 50% on average, and was consistent for all desired population sizes.	terrestrial