Using Marxan and Marxan with Zones to support marine planning

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Abstract

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With the growth in human pressures on the marine environment and the increase in competition for space and resources there has been recognition by many governments of the need to use the marine environment sustainably and allow for its acceptable allocation for each sector. The aim of this thesis is to evaluate the use of Marxan and Marxan with Zones as practical tools to enable the production of marine plans that integrate environmental and socioeconomic data and to suggest best practice in the types of data used. In this thesis three key aspects of data type and integration were identified and evaluated. The resolution and complexity of data required to protected marine biodiversity was assessed. The effects of using different substrate data resolution on the selection of sites to protect a range of biotopes using Marxan are determined. The nature of the data used in marine planning has significant implications for the protection of marine biodiversity. Using less complex data, of any resolution, did not adequately protect marine biodiversity. There is a need to determine what is an acceptable allocation of marine resource to each sector. Two case study areas were used to determine how to integrate conservation and socioeconomic data and objectives in a marine plan. Objectives for all the sectors could not be met completely in a single marine plan and each sector had to compromise. This research highlighted the potential compromises required and indicates that if marine heritage and biodiversity are to be protected each sector will have to change the impact it has on the marine environment. Currently marine conservation assumes that all data on habitats and species presented for use in marine planning are equal, in accuracy, precision and value. This is not always the case, with data based on a wide range of sources including routine government monitoring, specific innovative research and stakeholder based data gathering. A case study area was used to evaluate the impacts of using confidence levels in habitat data on marine biodiversity. It was found that data outputs that best protected marine biodiversity used data over 20% and over 30% confidence. With the data currently available for the UK marine environment it is not possible to be confident that a representative MPA network can be created. Together these studies contribute key recommendations for best practice in marine planning and demonstrate that the use of spatial decision support tools (Marxan and Marxan with Zones) are essential for the integration of data in marine planning, to assess how using different types of data will impact marine planning and marine biodiversity protection and to explore implications of different management actions.

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Authors declaration

At no time during the registration for the degree of Doctor of Philosophy has the author been registered for any other University award without prior agreement of the Graduate Committee.

Work submitted for this research degree at Plymouth University has not formed part of any other degree either at Plymouth University or at another establishment.

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Chapter 1

Introduction

1.1 Setting the scene

With the growing human pressures on the marine environment there has been recognition by many governments of the need to protect the marine environment. This is demonstrated by numerous national and international commitments to improved management of human activities and conservation of the marine environment, such as the Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR) (OSPAR 1992), the EU's Natura 2000 network under the Habitats Directive (European Union 1992) and the UK's Marine and Coastal Access Act 2009 (Marine and Coastal Access Act 2009). A common theme in the implementation of such protection is the designation of marine protected areas (MPAs) as a tool for conservation. These may be identified for a number of reasons including protection of one or a number of species, habitats or biotopes.

The UK has created the Marine and Coastal Access Act 2009 (Marine and Coastal Access Act 2009) to introduce a framework for marine and coastal management in the UK, to balance among other aspects the growing needs of conservation, energy and resource extraction. The Act provides tools to designate a network of Marine Conservation Zones (MCZs), which are marine protected areas of varying levels of protection, for the conservation of rare, threatened or representative habitats and species.

The MCZs will, in conjunction with the Natura 2000 sites, fulfil the UK's commitment, agreed under a number of international declarations including the World Summit for Sustainable Development 2002, the OSPAR Convention and EU directives, to designate an ecologically coherent network of Marine Protected Areas by 2012. The OSPAR Convention (1992) requires the UK to protect and conserve the marine environment and to manage human activities that can have an adverse impact on particular declining/threatened marine species (OSPAR 2004). Under the Marine and Coastal Access Act 2009 (Marine and Coastal Access Act 2009) the UK government has designated 27 MCZs in English waters, out of the 127 recommended by the regional MCZ projects. The UK Government plans to designate further MCZs in two further phases. In the plans for the first phase (Defra 2014) 37 sites have been identified as suitable candidates. The next group of MCZs will be designated in 2015, and the third in 2016.

1.2 Marine spatial planning

As a result of growing pressures and conflicts in the marine environment, the process of Marine Spatial Planning (MSP) has developed to plan and manage all current marine activities, and undertake forward planning (Ehler and Douvere 2009; Schaefer and Barale 2011). MSP has developed because of a growing realisation that managing the marine environment reactively and sectorally was leading to conflict, reducing economic development and causing serious effects to ecosystem goods and services (Foley et al. 2010; Kidd et al. 2011; Commission of the European Communities (CEC) 2008). Over the previous decade MSP has been increasingly used, with marine spatial plans being developed internationally (Douvere and Ehler 2009; Jay et al. 2013). For example, the Great Barrier Reef Marine Park (GBRMP) authority implemented a marine spatial plan with multiple zones, to conserve the GBRMP. MSP has developed from having a conservation focus to a process which integrates all marine activities to work towards an ecosystem approach to marine management (Foley et al. 2010; Katsanevakis et al. 2011; Kidd et al. 2011) that accounts for cumulative impacts (Commission of the European Communities (CEC) 2008).

Through the process of developing a marine spatial plan, data are required to allow consideration of current activities, and how they might change, through the use of scenarios. These scenarios can then be used to evaluate current and potential conflicts. The use of scenarios may indicate how each sector will have to compromise (Ehler and Douvere 2009). It is necessary to ensure that the decisions made as to which compromises are required are made transparently and fairly (Stelzenmuller et al. 2013) and that stakeholders are involved in the planning process

(Ehler and Douvere 2009). However, to do this many datasets need to be incorporated (covering a wide range of topics ranging from conservation to marine energy production and fishing) and to do this it has been recommended that decision support tools are used to assess planning options (Stelzenmuller et al. 2013).

Decision support methods and tools are available to support marine planning which can assess cumulative impacts, aid in prioritisation of sectors, allow users to explore interactions between human use data and biodiversity and those which can be used in site selection. Tools are available that allow the user to explore the interaction between activities and ecosystem components, such as the tool developed by the Crown Estate in the UK: Marine Resource System (MaRS) (Kidd et al. 2011). This tool uses multi criteria analysis (MCA) to generate maps that suggest suitable areas of seabed for a selected activity.

Tools are available to assist in developing impact assessments of management actions on marine activities, and to develop weightings for use in the two types of tool described above. These include MCA where attributes are given a weighting through either expert or stakeholder consultation or through the use of quantitative data. Scenarios can then be run showing how the weightings effect the plan (Villa et al. 2002; MMO and Marine Scotland 2012*a*). Cost benefit analysis can be used to calculate the costs and benefits of different scenarios on a plan in monetary values (Kidd et al. 2011; MMO and Marine Scotland 2012*a*).

1.3 Systematic conservation planning

Systematic conservation planning (SCP) is a structured, quantitative approach to the planning of both single MPAs and networks of reserves; it can be used to identify reserve networks that capture the most biodiversity whilst reducing area or other costs, and it will, in theory, allow for the more effective protection of biodiversity (Margules and Pressey 2000; Sala et al. 2002). In SCP explicit targets are defined for marine habitats and species (or their surrogates), so that MPA networks can be representative of biodiversity and ensure its persistence (Knight et al. 2006; Margules and Pressey 2000). MPAs that are selected in an ad hoc way tend not to be efficient (Pressey 1994) and do not form representative MPA networks (Mills et al. 2012).

Within a network, other MPAs in the surrounding area should be considered in the selection of new sites (Mills et al. 2010; Game et al. 2011). MPA networks that contain fewer larger areas have lower area to edge ratios than networks with many smaller areas. This makes them easier to comply with or enforce (IUCN 2003) and reduces edge effects (Marine Boundary Working Group Federal Geographic Data Committee 2006). Using the planned marine space effectively by protecting a proportion of biodiversity MPA that minimise impact on stakeholders, will reduce potential conflict with other sea users. When planning networks of MPAs socioeconomic costs should be included to minimise conflicts with marine activities (Naidoo et al. 2006).

MPAs not designed systematically tend to have higher associated costs and are less effective at protecting the marine environment than MPAs chosen with stated objectives and in a systematic way (Stewart et al. 2003). Roberts et al. (2003) found that many MPAs have been created based on narrow socioeconomic criteria, often linked to fisheries management, rather than sound environmental data. They conclude this has led to many sub-optimal MPAs which give a false sense of the conservation of the marine environment. Whilst MPA networks can protect some marine biodiversity, if the surrounding environment is not sustainably managed, this degradation of habitats or pollution could mean that the MPA is no longer able to meet its objectives (Agardy et al. 2011). This is why MPAs should be developed at the same time as marine spatial plans to ensure that the ecosystem approach can be applied to all pressures (Kidd et al. 2011).

An issue facing facing those involved in MSP and selection of sites for the UK's MCZ network and others globally is that comprehensive biological data, such as presence/absence data for species or detailed ground-truthed habitat maps, are not available for the majority of the marine and coastal environment (McBreen et al. 2011). Obtaining such data is very expensive and requires considerable time and expertise, therefore, surrogates, such as substrate or other environmental characteristics, are sometimes used to represent marine biodiversity.

In the light of the limited data availability for conservation and many data layers for marine users, it is necessary to use data as effectively as possible in the creation of marine spatial plans and for these reasons decision support tools have been developed to aid in this task. These include tools that can assign areas or sites to zones, with the certain activities allowed or excluded in the zones. One example is Marxan which is a spatial planning decision support tool (Ball et al. 2009; Possingham et al. 2000), frequently used for the design of marine protected areas (Klein et al. 2009; Ball et al. 2009; Delavenne et al. 2012). Marxan with Zones is an extension of Marxan, it allows the inclusion of multiple costs and outputs with more than two zones (Watts et al. 2009). Marxan and Marxan with Zones can be used to identify priority areas for conservation. Marxan with Zones can incorporate many costs and conservation features to suggest priority areas for conservation and for other sectors.

1.4 Thesis aim and objectives

The aim of this thesis is to evaluate the use of Marxan and Marxan with Zones as practical tools to enable the production of marine plans that integrate environmental and socioeconomic data and to suggest best practice in the types of data used.

The objectives of this thesis are:

1. to critically review marine planning and site selection tools, to evaluate appropriate decision support tools and identify gaps in research in marine planning and site selection tools (Chapter 2);

2. to demonstrate the rationale for case study choice, describe the case study areas and the data used in the analysis in the data analysis chapters (Chapter 3);

3. to evaluate the use of Marxan and Marxan with Zones in previous studies and explain the methods used (Chapter 4);

4. to assess the resolution and complexity of data required to protect marine biodiversity using currently available data (Chapter 5);

5. to assess how to integrate biodiversity and cultural conservation with socioeconomic data, and objectives, focusing on recreation and fishing, in a marine plan using Marxan with Zones (Chapter 6);

6. to evaluate the impacts of using confidence levels in habitat data on marine biodiversity protection (Chapter 7);

7. to make suggestions on how this research should influence marine planning (Chapter 8) and
8. to make key recommendations for best practice, focusing on marine biodiversity conservation and the use of Marxan and Marxan with Zones, in marine spatial planning (Chapter 8).

There are many issues that need to be addressed to ensure that marine biodiversity conservation and marine spatial planning can be implemented both effectively and transparently. In this thesis the focus is on the use of Marxan and Marxan with Zones in marine planning, how to use available data most effectively and the integration of conservation and socioeconomic objectives. Some of the important questions requiring further research are listed here:

- Can MPAs protect biodiversity efficiently?
- How can available data best be used to ensure protection of marine biodiversity?
- How can currently available data be used to produce marine spatial plans that account for human activities, including their impacts, use of the marine space and allow for the fair and sustainable use of the marine environment?
- How can data currently available and outputs produced from decision supports tools, such as Marxan, be presented to stakeholders and policy makers so they understand their limitations and inherent uncertainty?
- Can Marxan and Marxan with Zones be used at varying scales in marine planning, from local plans to larger regional plans?
- How should Marxan and Marxan with Zones be developed to enhance their use in marine spatial planning?

This study will use three case study areas to assess how spatial DSTs respond to different types of data. The case study areas are:

- Lyme Bay, a shallow bay situated off the south west coast of England;

- The Sound of Mull, which lies between mainland western Scotland and the Isle of Mull which is relatively sheltered and
- The East Channel, a region from west of the Isle of Wight to Dungeness in the east and out to the mid-line of the English Channel.

These areas vary in scale, the activities that occur in them and the type of data available.

This thesis has nine chapters: the introductory chapter (Chapter 1: Introduction), a literature review (Chapter 2: Marine spatial planning: moving from ideas to implementation), a methods chapter (Chapter 3: Methods), a chapter discussing the case study site rationale and the data used (Chapter 4: Case studies: Lyme Bay, Sound of Mull and East Channel), the first of three data chapters (Chapter 5: Assessing the quality of data required to identify effective protected areas), a data chapter exploring the use of the program Marxan with Zones in marine planning (Chapter 6: Balancing conservation and socioeconomic objectives in marine plans), the final data chapter (Chapter 7: Incorporating modelled data confidence in marine planning), a discussion chapter (Chapter 8: Discussion) and a conclusion chapter (Chapter 9: Conclusion).

Chapter 2

Marine spatial planning: moving from ideas to implementation

2.1 Introduction

In recent years there have been two main approaches put forward to manage the problems of marine activities that conflict spatially: marine spatial planning and marine protected areas. A problem with current approaches to marine management is that they do not take account of cumulative effects on the environment (Cefas (2010*a*), Halpern et al (2008)). Marine spatial planning (MSP) will allow the use and development of the marine environment to be sustainable (Gilliland and Laffoley (2008); Ehler and Douvere (2009); UKMMAS (2010)) and to overcome many of the issues faced by sectoral planning and use. The following review aims to:

- discuss the international development of MSP,
- place marine spatial planning (MSP) in context with previous management approaches,
- discuss potential methods of moving from a mainly conceptual discussion of MSP to implementation of marine spatial plans; to show, using international examples, how marine management is moving from single use zone management to the multiple zones and multiple-use zones of marine spatial planning,
- discuss the future of the data requirements of marine and coastal management and
- discuss the literature on identifying priority areas for conservation and systematic conservation planning.

There are a number of definitions of MSP but a report by UNESCO (Ehler and Douvere 2009) suggested this definition which includes both the management and future planning of marine and coastal activities:
"Marine spatial planning is a practical way to create and establish a more rational organization of the use of marine space and the interactions between its uses, to balance demands for development with the need to protect marine ecosystems, and to achieve social and economic objectives in an open and planned way".

MSP has a background in conservation planning and in the designation of MPAs to protect species and habitats from human activities (Jay et al. 2013). However, over time the goals of MSP have become much broader, with the focus on balancing the needs of all marine users, integration with land planning as well as using the marine environment within its limits (MSPP Consortium 2006; Foley et al. 2010; Gilliland and Laffoley 2008). A major focus of MSP is sustainable development and management using the ecosystem approach (Ehler and Douvere 2009; Kidd et al. 2011; Schaefer and Barale 2011). This is defined in the Convention on Biological Diversity (CBD) in their 5th Conference of the parties in 2000 (CBD COP 2000) as:
"a strategy for the integrated management of land, water and living resources that promotes conservation and sustainable use in an equitable way".
There are 12 ecosystem approach principles identified by the CBD, that focus on stakeholders, ecosystem structure and function, economics and adaptive management (Kidd et al. 2011). These principles promote balance between human uses and marine biodiversity conservation.

There has been a realisation that sectoral management is reducing certainty in developing and using the marine environment to its full economic potential (Ehler and Douvere 2009). Industry and legislation from the EU (European Commission 2010) are recommending MSP to ensure that the marine environment can be used to gain maximum economic benefit. Through a plan led approach, industry will have more certainty and access to more data when applying for consents (MSPP Consortium 2006). MSP, by gathering data on human use, will help to balance the use of marine space between sectors competing for the same space. For example, the renewable energy industry takes up space which is increasing with energy demands and this competes directly with other sectors such as fishing and aggregate extraction. By creating a MSP, containing information on what occurs and where, conflicts can be either foreseen and perhaps minimised, and current conflicts can be addressed (Ehler and Douvere 2009; Maes 2008; MSPP Consortium 2006). Generally MSP is a process led by government, but is guided by stakeholder involvement. This gives stakeholders a forum to discuss issues, resolve conflicts with each others' needs and government requirements (Jay 2010).

The EU is committed to the implementation of MSP, as set out in its Integrated Maritime Policy (IMP) (Commission of the European Communities (CEC) 2007). The IMP states that the EU is committed to sustainable development and that it promotes growth and jobs which may not be compatible with further development. The UK Government has released a Marine Policy Statement (MPS) (HM Government 2011) which states that the UK is committed to using the marine environment sustainably and within environmental limits. The MPS's high level objectives, which will guide the UK's use of its marine environment, focus on maximising sustainable activity and living with environmental limits. In the UK there is considerable uncertainty about the impacts that current activities are having on the marine environment (UKMMAS 2010), therefore increasing uses may not be compatible with sustainable use. The MPS also states that if decision-makers consider impacts to cultural heritage or the environment to be justified, they must be mitigated against. The main key activities chosen for further discussion within this document, which include fisheries, aggregate extraction and energy production (apart from MPAs) can have significant impacts on marine biodiversity. Although the document states that impacts should be minimised, it still recommends these activities should occur, and discusses positive economic impacts. This suggests that there are challenges to meeting the ecological objectives in the MSP because the other high level objectives are placing emphasis on the marine economy and sectors that will further impact the marine environment.

Whilst MSP has many positive socioeconomic benefits for human use, it will also bring positive environmental changes. Through the collection of human use data, methods for estimating cumulative impacts on the marine environment can be developed (Cefas 2010*b*). By establishing a MSP, clear environmental protection objectives can be set and a monitoring regime implemented

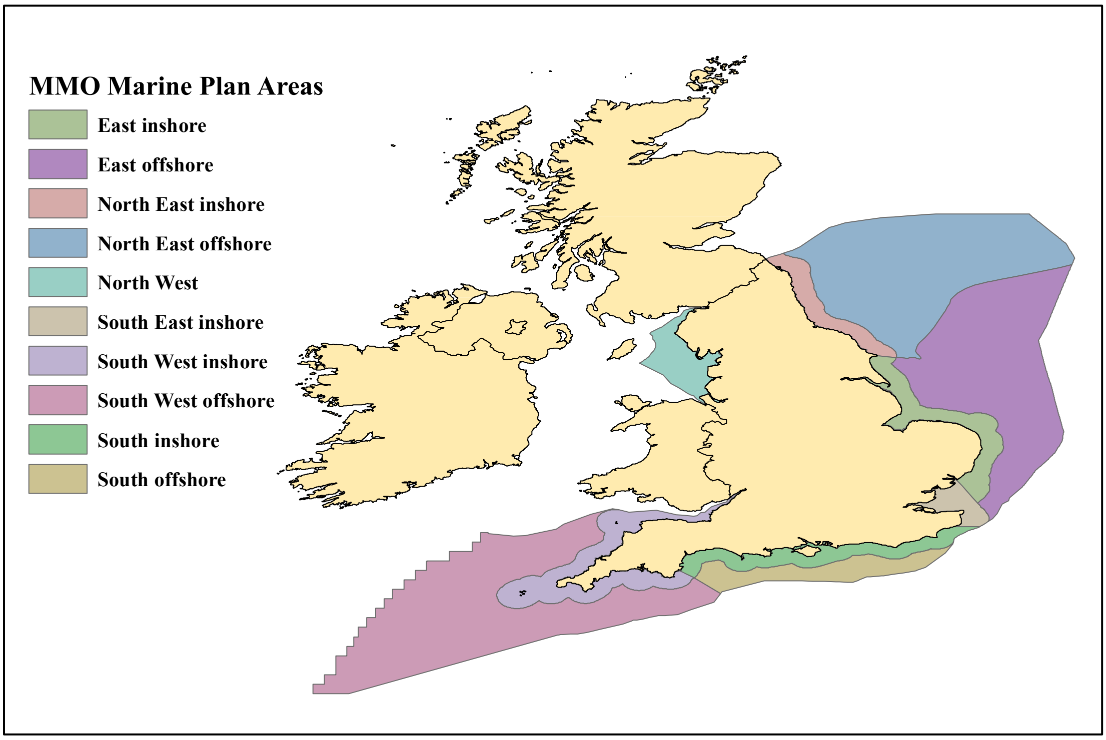


Figure 2.1: The ten English marine plan areas

to ensure targets are met (MSPP Consortium 2006). This will ensure that management of human activities is keeping impacts within environmental boundaries so that ecosystem goods and services can be maintained (Foley et al. 2010; Kidd et al. 2011).

The Marine and Coastal Access Act (2009) has committed the UK to the creation of marine plans around England. There will be 10 marine plans: five onshore, five offshore and the plan for the northwest being combined on and offshore (Figure 2.1). The plans will be created and implemented over the next six years with the first marine plan process (Eastern area) completed in 2014 and the second, the Southern area inshore and offshore underway. The Marine Management Organisation (MMO) was set up under the Marine and Coastal Access Act to bring together fisheries management, management of marine protected areas (MPAs) and to create a new simpler licensing regime.

Planning in the marine environment is different to land-use planning, in the UK, because the Crown Licensing Authority owns virtually the entire seabed out to the UK 12 nautical mile territorial limit, including rights to exploit the natural resources (excluding oil, gas and coal, which are governed by the Department of Energy and Climate Change in the UK). The Crown Estate do not govern public rights such as marine fisheries and navigation, these are governed by the International Maritime Organisation (navigation) and the European Union (Common Fisheries Policy). Also implicit in the idea of MSP is management and regulation of ongoing activities as well as the regulation of proposals to change (Ehler and Douvere 2009). Once a planning process has been completed on land, for example, a chemical plant has been built, another department or authority takes over the management. Whereas with marine plans the authority that helped create the plan will also manage this activity, in England this will be the MMO. Also in the marine environment many activities, such as fishing, will move over time because of natural processes, the areas used for various activities may change over time, so zones will have to change or be moved and the MSP will need revising, unlike on land where things are more fixed, for example farmland cannot be moved from year to year.

Marine plans can be directly related to land-use plans as they both try to keep conflicting activities spatially differentiated. For example, a chemical plant that releases polluting, potentially dangerous fumes, would not be sited next to a housing estate. Also, it is not possible to have arable production in the same space as an ancient woodland and so it is with the seabed. For example, long lived sessile species will not occur in an area that is regularly scallop dredged (Attrill et al. 2011). Land plans can be used for guiding development and making decisions. The marine plans developed during the Scottish Sustainable Marine Environment Initiative do not zone activities but consist of high level objectives and policies.

Previous approaches to the management of the marine environment in the UK include sectoral developments, such as shipping traffic separation lanes and the Common Fishing Policy. Each sector follows their own legislation and roles, without the full consideration of the existing or potential users and without any conception of the impacts on the functioning of the marine ecosystem (Tyldesley 2004; Gilliland et al. 2004). Previous approaches to conservation focused on conserving a single species, but the focus is now on the sustainable use of the marine environment. Conservation based approaches typically focus on restricting activity in a specific, often fairly small area, such as Special Areas of Conservation (SACs) and Special Protection

Areas (SPAs). These restrictions can also be voluntary such as the Wembury Voluntary Marine Conservation Area. This is a single zone area which is protected as a result of voluntary agreements between all users, to ensure sympathetic use of the area. It has been shown that this approach does protect biodiversity (Halpern 2003) but only protects the habitat and species within the protected area, with limited effects spilling over to the wider environment (Kaiser 2005; Shears et al. 2006).

Halpern (2003) found that the relative effect of MPAs was independent of their size. But the absolute effect of a large reserve is proportionally larger, for example, doubling the fish population in a small reserve, from 10 to 20 fish, is substantially different from a large reserve population doubling from 1000 to 2000 fish. This led Halpern to suggest that smaller MPAs may be limited in the number of organisms that leave the protected area and move into the surrounding ecosystem. This would be something that would need to be considered if a protected area was designated as part of a fisheries management plan. Another issue to consider is edge effects, such as, fishermen fishing right up to the edge of marine reserves because of an increase in target species near the edge of reserves (Goni et al. 2006); smaller reserves would be more affected because they have proportionately larger border to area ratios than larger reserves.

A study undertaken by Hoskin et al (2009) investigated the effects of the designation of a no-take zone of Lundy Marine Nature Reserve and found that in the no-take zone the abundance of lobsters (*Homarus gammarus*) was significantly higher than outside the no-take zone, both in the near and far field control sites within the first year of establishment of the highly protected marine reserve (HPMR). Lobster numbers increased by 76% within the highly protected marine reserve and there were three times as many above landing size, when compared to control sites outside the highly protected marine reserve (Hoskin et al. 2004). This shows that whilst the lobsters were protected in marine reserve, outside the protected area there was little effect on lobster numbers. However, more lobsters of breeding size may be beneficial to populate areas outside of the marine nature reserve.

When the Lundy Marine Nature Reserve was first designated it had a single zone, in 2003 it was re-zoned to five zones: a no-take zone; a refuge zone (no fishing except potting or angling);

a recreational zone (restrictions as for the Refuge Zone but be aware of other water users); a zone containing legally protected wrecks and a general use zone in which all activities are allowed except spearfishing. Another example of this type of management approach is the Teign estuary management plan, which has multiple zones including conservation zones and fishing zones. These show how marine planning has developed from single zones in which activities are excluded to multiple zones where some activities can take place but others are restricted.

These approaches, i.e. sectoral, single-use conservation based zones and multiple zone plans covering small areas, are moving towards MSP but still have problems. For example, the plans cover far too small areas for sustainable development, they are too simplistic, difficult to enforce, they are ad hoc (Stewart et al., 2003) or based on the opinions of the stakeholders who were most involved with the project. Previously developed marine plans have tended to be inshore or close to shore hence enforcement is possible. They all have the same basic problem in that most marine management is based on limited data or no data at all. A report from the Marine Spatial Planning Consortium (MSPP Consortium 2006) concluded that one of the most significant outstanding issues in MSP related to data availability and in the same report it stated that the datasets that were available, were of vastly differing resolutions and scales.

Decision support tools are required that assist with integrating spatial social, environmental and economic data and that, having integrated the data, will create potential plans using these different types of data, quickly and transparently. This will assist in producing marine plans that are simple to use and that employ the best available use of space.

2.2 Development of MSP

Marine spatial planning has developed from sectoral management and zoning (Jay 2010; Ehler and Douvere 2009). The first example of of marine spatial planning was in the Great Barrier Reef Marine Park (GBRMP). When the GBRMP Authority developed a zoning plan from 1979-1988 that covered 98.5% of the park (Kenchington and Day 2011). MSP also has its roots in sectoral zoning. For example, in fisheries seasonal closures and areas designated for use by static fisheries, and in shipping lanes designated by the International Maritime Organisation.

The United Nations Convention on the Law of the Sea (UNCLOS) provided a framework for nations to use and manage the marine environment surrounding their nations (*United Nations Convention on the Law of the Sea* 1982). UNCLOS gives nations full sovereignty out to 12 nautical miles. Under UNCLOS exclusive economic zones (EEZ) can be declared out to 200 nautical miles, although ships still have the right of innocent passage within this zone, so that nations have the right to exploit natural resources, apply nature conservation and undertake scientific research (Jay 2010). Allowing countries to exploit the resources within their seas, has increased their interest in managing their territorial waters (Jay 2010).

Within Europe there have been been agreements and legislation at the regional level. For example there are agreements on the use of MSP including the 5th North Sea Ministerial Conference (Bergen) (Bergen Declaration 2002), which adopted the Ecosystem Approach (HELCOM & OSPAR 2003) and also requested that OSPAR research using MSP for marine management and for international cooperation (OSPAR 2005).

The EU has recognised the need for improved coordination of marine activities at both the European and national level. Integrated Coastal Zone Management (ICZM) was introduced across Europe in the 1980s and 1990s and as a result there was a demonstration project for ICZM from 1996-1999. This project brought together a range of different regions in which a form of ICZM was practised. The project explored methods, tools and approaches to coastal management of marine areas. From this project, in 2002 the EU adopted recommendations on ICZM. These have acted as a stimulus for wider marine management in the EU but in the process ICZM has been somewhat left behind. The 2002 recommendations do not mention MSP but are part of the EU's move towards better coordination of all uses of the marine environment. Following the recommendations for ICZM it could be seen these recommendations covered a relatively limited area, which led the EU to adopt the Integrated Maritime Policy (IMP). The IMP (Commission of the European Communities (CEC) 2007), adopted in 2007, considers MSP to be a key tool to implement this policy. The EU has developed a Roadmap for MSP (Commission of the European Communities (CEC) 2008) to facilitate the development of MSP by member states. The Roadmap has 10 key principles to support MAP implementation across the EU (Schaefer and Barale 2011).

These key principles cover when to use MSP, how to develop a marine spatial plan, stakeholder participation, coordination within and between member states, how to ensure legal effectiveness of national MSP, the incorporation of monitoring and evaluation, the need to achieve coherence between land and sea planning and the need to have good data and a sound knowledge base. The Roadmap has influenced the drawing up of the Maritime Spatial Planning Directive (2014/89/EU).

The Marine Strategy Framework Directive (MSFD) (European Commission 2008), is the environmental arm of the IMP and recommends adopting the use of MSP to ensure sustainable use of the marine environment, to ensure good environmental status and to apply the ecosystem approach. This directive does not directly regulate marine activities, but their impact must be taken into account for member states to determine if their marine environment has good environmental status. The MSFD will work alongside the MSP directive and together they will continue the work of the EU to manage the marine environment sustainably.

The latest EU legislation which relates to MSP is the Directive on Maritime Spatial Planning (2014/89/EU). This directive identifies MSP as a tool to apply the ecosystem-based approach to promote sustainable development and growth. The directive also states that member states should establish and implement plans. When undertaking the marine planning process the directive states that it is essential to consult with stakeholders, authorities and the public to promote sustainable development. The plans need to be implemented by 2021 and reviewed every 10 years.

The UK has used Integrated Coastal Zone Management from the 1990s onward but the majority of the management of the marine environment has developed on a sectoral basis in the UK (Boyes et al. 2003) and has largely evolved in a policy vacuum (Tyldesley 2004; Peel and Lloyd 2004) until 2009. The UK has moved towards marine planning because it identified that the state of the marine environment was being degraded and the current approach to marine management was not addressing this. Also there were calls for an increase in development in the marine environment from industries such as marine renewable energy. This pushed the UK government to implement the Irish Sea Pilot (Boyes et al. 2005) as a case study on planning. On the findings of the Pilot they developed the Marine and Coastal Access Act (2009). Since 2009 UK governments enacted the Marine and Coastal Access Act (2009) (covering England and Wales), Marine (Scotland Act) and the Marine Act (Northern Ireland). These acts commit the UK to the creation of marine plans. The UK government has introduced the Marine Policy Statement (MPS) (HM Government 2011) as a framework for the production and implementation of these marine plans. The Scotland (Marine) Act (2010) provides a framework to balance the competing demands on its marine environment. The Act makes reference to the drawing up of national and regional marine plans.

All of the above EU and national legislation refer either explicitly to the ecosystem approach to manage the marine environment, or indirectly through terms such as sustainable development.

2.3 Marine spatial planning - moving from concepts to implementation

It is hoped that the marine plans that are currently being developed in England will simplify marine legislation and enable data to be gathered on the activities and impacts affecting the marine environment. The Marine Management Organisation have collected data on the recreational activities, industrial activities and potential future activities for this plan area. Data have already been collected nationally for the MCZ process and this will also be used during the marine planning process in England.

MSP is a fairly recent concept in the UK. The MMO is currently creating 10 marine spatial plans around the coast of England so that the marine environment can be used sustainably. MSP will, by using a linked system of plans, allow for the marine environment to be managed using the ecosystem approach. Current drivers in the UK for the implementation of MSP include various international treaties, which have been ratified and legislation that has been passed at national, European and international levels (Table 2.1). The UK is implementing these agreements through the Marine and Coastal Access Act (2009).

There have been a number of studies in the UK in recent years on how to implement MSP and the challenges associated with it (Stevens et al. 2007; Robinson et al. 2011; Rees et al. 2012). A

Table 2.1: International and EU Policy Drivers and the date adopted or entered into force for marine spatial planning

International Commitments International Maritime Organisation conventions and protocols including: 1973 and modified in 1978 - the Convention for the Prevention of Pollution from Ships (MARPOL 73/78), 1992 - Convention on Biological Diversity (CBD), 1992 - Chapter 17 of Agenda 21 – this provides the international basis upon which to pursue the protection and sustainable development of the marine and coastal environment and its resources; 1992 - OSPAR Convention, Entered into force in 1994 - The United Nations Agreement for the Implementation of the Provisions of the United Nations Convention on the Law of the Sea of 10 December 1982 relating to the Conservation and Management of Straddling Fish Stocks and Highly Migratory Fish Stocks, 1995 - UN Fish Stocks Agreement, and the FAO Code of Conduct for Responsible Fisheries, 1995 - Global Programme of Action for the Protection of the Marine Environment from Land-Based Activities, 2002- 5th North Sea Conference - The Bergen Declaration, 2002 - World Summit for Sustainable Development.
EU Initiatives 1979 - EC Birds Directive, 1992 - EC Habitats Directive and European Union's Natura 2000, 2000 - EC Water Framework Directive, 2000 - European Recommendation concerning the implementation of Integrated Coastal Zone Management in Europe (COM/00/545 of 8 Sept. 2000), 2001 - EC Directive on Environmental Assessment of Certain Plans and Programmes (2001/42/EC) (SEA Directive), 2002- European Commission Communication "Towards a strategy to protect and conserve the marine environment" (COM2002(539)), 2002 – 2012 6th Environmental Action Programme, 2007 - Integrated Maritime Policy, 2008 - Marine Strategy Framework Directive "to protect more effectively the marine environment across Europe", 2014 – Maritime Spatial Planning Directive.

major study, based on the Irish Sea, described potential mechanisms for MSP in the UK (Boyes et al. 2005), which is described as an international example in this review. Four MSP case study areas based in Scotland were developed through the Scottish Sustainable Marine Environment Initiative. There are European and international cases where MSP has been implemented, in Australia (Day 2002) and Belgium (Douvere et al. 2007). There is a general agreement that MSP (Ehler and Douvere 2009; Stevens et al. 2007; Calado et al. 2012; Gopnik et al. 2012) is a good approach for the UK and as the English Eastern Plan area has now been implemented the process to create marine spatial plans is being developed by the MMO.

2.4 Data requirements for marine spatial planning

Marine plans are produced for a variety of reasons, such as, for biodiversity conservation, ship routing and sustainable development, so the first thing that required when producing a plan is to identify and state the reason why the plan is required and what its aims and objectives are. Once this has been done, then work on the data required can begin.

To ensure that the plan is representative of its objectives, it needs relevant data to support it. So one of the first tasks of a planning process must be to decide on the data required (Day et al., 2008). The requirements of a plan must include social, economic and environmental data, to ensure that the plan results in the area being used in a sustainable manner (Ehler and Douvere 2009; Rees et al. 2013; Cefas 2010*a*). Examples of the kind of data required are:

- environmental - habitat data and sediment type;
- social data - areas that could be potential wind/wave farm sites, and
- economic data such as fishing activity data - what species fished for, where and when the area is fished (see Figure 2.2).

Potential future uses such as wind farms, sea-level rise and discharges must also be taken into consideration.

In the UK the major uses of the sea have mapped with the MMO continuing to gather more data. In England Finding Sanctuary (South West region MCZ project) have mapped fishing use and

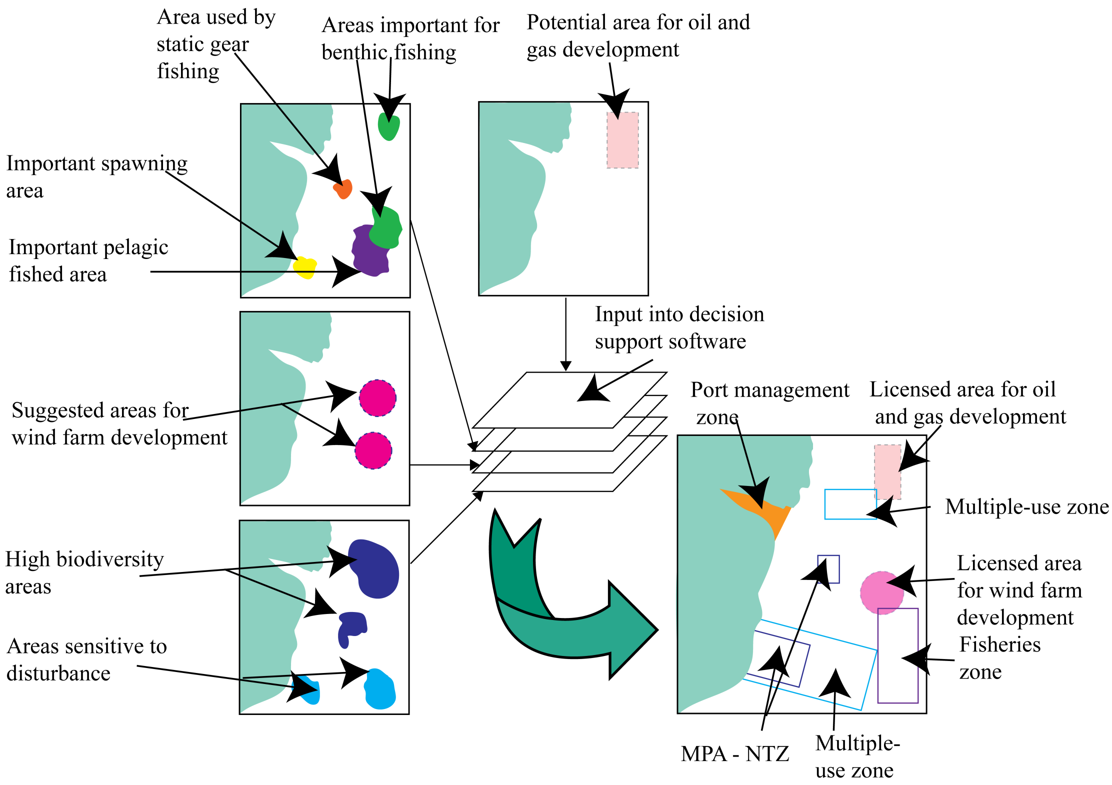


Figure 2.2: Example of hypothetical data layers that have been integrated to form a marine spatial plan (adapted from Gubbay (2004) and Stevens (2007))

timing data. The Finding Sanctuary project, along with three other regional projects, was set up to collect socioeconomic data and to develop a network of MCZs around England. The MMO are also collating data on recreational activities. Internationally, Scholz et al (2006) collected fishing use and timing data for use in the production of an MPA network, off California. Klein et al (2008) used this data to reduce the impact of the network of MPAs to fishermen by including them in a Marxan analysis.

In the UK high resolution environmental data, such as species and habitat data, are not widely available. However, modelled data on substrate level around the UK are now available (e.g., EUNIS and UKSeaMap 2010). There is some evidence to show that using substrate data as a proxy for habitat is acceptable (Stevens and Connolly 2004). However, data are required at the scale of the zones of both the habitat and the marine plan; if too coarse data are used there is the potential for plans to be unrepresentative (Stevens et al. 2007). If possible this data should be available for a marine plan but, if data are not available, a plan should still go ahead using the precautionary principle, a plan should not be held up waiting for 'ideal' data conditions.

Once obtained, data may need to be manipulated so that they are suitable for use in the plan and in the software used to design the plan. For example, environmental data may be categorized as high, medium and low biodiversity so as to show areas that should be protected from disturbance. Once the data has been collected and manipulated, then the next stage is to study how the various data sets relate to each other and how the area to be planned is used. Decision support tools (DST) can be useful for this.

2.5 Identifying priority areas for systematic conservation planning

MPAs have been designated for the protection of marine biodiversity for many decades, in recent years many more are being created (National Research Council 2001). This is because of an increasing awareness of human impacts on marine ecosystems. When single MPAs are created it can be in response to local stakeholder lobbying, an area's use for recreation or it may be a remote or lightly used area (Pressey 1994). There has been a growing realisation that MPA networks should be planned systematically. Ad hoc creation of MPAs is unlikely to lead to networks that are representative and that will persist (Margules and Pressey 2000). It has also been demonstrated that choosing sites in an ad hoc way can have significant opportunity costs. For example, Stewart et al. (2003) compared the current MPAs in South Australia waters with a representative network of MPAs created in Marxan. The study found that over half of the current MPAs were not contributing efficiently to a representative network of MPAs. Mills et al. (2012) compared an ad hoc approach to MPA designation with a systematic approach using Marxan with Zones. The study found that the ad hoc approach achieved approximately half of its conservation objectives, whereas, the systematic approach met most of it targets, with both methods protecting a similar sized area.

As a result of the problems described above, systematic conservation planning (SCP) was developed (Margules and Pressey 2000). SCP is used to identify priority areas for conservation that ensures representation of biodiversity and its persistence, and incorporates socioeconomic costs to reduce impacts on stakeholders (Knight et al. 2006). SCP ensures that decisions are made on which features are appropriate to be used as surrogates for marine biodiversity, that targets are set and explicit methods are used to design additional MPAs (Margules and Pressey 2000). SCP also requires new MPAs to be complementary to existing MPAs, with regard to which features they contain (Ferrier 2002), which is termed complementarity.

When using surrogates in SCP, how surrogates are chosen to represent marine biodiversity is important, because it is impossible to measure all biodiversity (Margules et al. 2002). Various surrogates have been developed, including environmental factors, to measure biodiversity. Studies have shown that a combination of abiotic and biotic data sets better represent biodiversity (Araujo et al. 2001; Ban 2009; Rodrigues and Brooks 2007) than abiotic alone. Grantham et al. (2010) found that the ability of surrogates to represent biodiversity was dependent on study area and taxa. Further research is required on the development and use of surrogates for the selection of priority areas.

SCP requires that targets are set for the protection of conservation features (Margules and Pressey 2000). These targets provide a transparent basis for decisions. Targets are often set by policies, the CBD recommends 10% of the marine environment is protected by 2020, and the IUCN recommend 20-30%. A review by Carwardine et al. (2009) identified that these sociopolitical targets are indefensible. The study recommended that targets should be set by including factors such as vulnerability of conservation features to human pressures and natural rarity. Metcalfe et al. (2013) used a method to model the species area relationship for each habitat type in the eastern English Channel, to establish targets for use in conservation. These targets were compared to targets set for the region by government, and were found to be lower and would need less area to reach the targets. The targets developed in this study were scientifically defensible and would ensure the presence of habitats within a MPA network.

Rondinini and Chiozza (2010) reviewed quantitative methods that can be used to set targets for habitat types in conservation planning. The study concludes that no ideal method for target setting currently exists, although if more data are available more rigorous methods should be used. From the studies discussed above it can be seen that further research on developing methods for targets is required. Further work is also needed to encourage decision makers not to use only policy driven targets.

An important consideration within SCP is the incorporation of socioeconomic costs, so that the impacts of conservation to human activities can be minimised (Margules and Pressey 2000). Studies have shown that using socioeconomic costs can significantly reduce impacts on stakeholders (Adams et al. 2011; Carwardine et al. 2009; Ban and Klein 2009). Costs can be estimated in a number of ways. The simplest cost metric is area, using this metric limits the area covered by priority areas. The assumption made when using this cost is that there is a direct link between size of an MPA and its impacts on human activity. This has been demonstrated not always to be the case (Carwardine et al. 2008). A further cost estimate is the relative importance of an area to an activity. Klein et al (2008) used this type of cost as a surrogate for commercial fishing effort. The study found that using this metric in an MPA network designed in Marxan reduced the impact on commercial fishers when compared to networks that were produced without using this cost. Carwardine et al. (2008) found that not using costs estimates that are closely linked to conservation could lead to increased economic costs when setting up a protected area network. Further research is required on how to incorporate costs in SCP and how the cost estimates should be chosen and weighted.

Within the SCP field there is an "implementation crisis" (Knight et al. 2006). This crisis is due to SCP research focusing on optimising how to prioritise areas (Naidoo et al. 2006) and not studying operational models to discover better ways to implement plans. Studies that highlight this crisis (Knight et al. 2006, 2008; Naidoo et al. 2006) stress the importance of stakeholder engagement, including socioeconomic costs within conservation planning and researchers getting more involved in the planning process. One area of research which has lead to real world applications is informed opportunism.

Informed opportunism is when SCP is used to dynamically assess and direct the selection of priority areas as opportunities arise (Game et al. 2011; Roberts 2000). Game et al. (2011) undertook a Marxan with Zones analysis with stakeholders from the Solomon Islands. The analysis locked in current MPAs and, using targets set by the stakeholders, identified areas that could be prioritised for conservation. The analysis could be easily updated so when new MPAs were created they could be added and the process re-run, to assess if the additional MPA had changed the recommended priority areas. It would be preferred if all MPAs could be designed optimally, but it is better if there is some protection that is not optimal but is still informed by science (Roberts 2000).

MPAs on their own will not lead to sustainable management of the marine environment. Although they may protect the biodiversity within their boundaries, activities that occur outside an MPA may affect its ability to meet its objectives (Agardy et al. 2011). Placing SCP within the MSP process will allow for a fuller analysis of the impacts of displacement and ensure marine conservation planning is embedded within regional and national policies.

2.6 MSP international examples

The following four international examples of marine planning initiatives have been chosen for an in-depth analysis to highlight methods that can be applied to marine planning. These four examples were chosen because the marine planning process was well-documented in each case and showed a wide-range of scale, use of decision support tools, human use and drivers. The examples are taken from Australia and the UK. Both countries have well-developed marine planning processes. Two examples were chosen from the UK because the focus of this thesis is

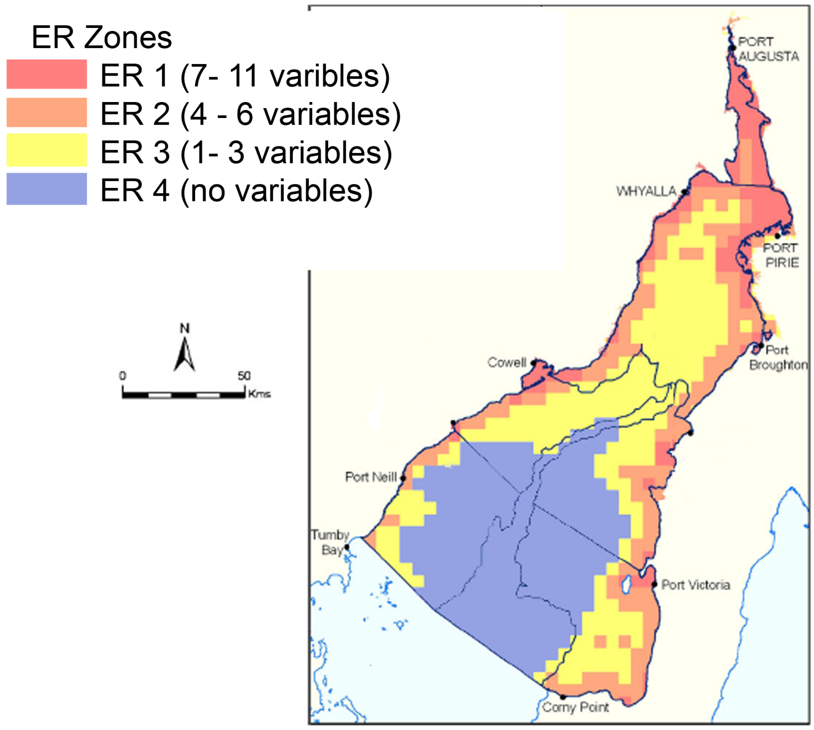


Figure 2.3: Spencer Gulf marine planning area with ecologically rated zones (adapted from Day et al 2008)

the UK. The Irish Sea pilot study has highlighted the complexity of legislation already applied in the marine environment off the UK coast and how by using current legislation and data, marine plans can be created. The Scottish Sustainable Marine Environmental Initiative (SSMEI) project was created to trial four marine plans in Scotland to test different approaches to the sustainable and integrated management of the marine environment. The Firth of Clyde marine spatial plan will be examined in more detail here.

2.6.1 Marine Planning Framework for South Australia

The state government of South Australia adopted a strategy for ecologically sustainable use of its marine environment in 2004. One initiative to come from this was the Marine Planning Framework for South Australia (2006) which was a new large-scale, ecosystem-based zone policy for the management and use of the marine environment (Government of South Australia, 2006b). There was a need to streamline the governance of activities in the marine environment because there were at least 27 separate pieces of legislation in the State of South Australia for governance of marine activities (Day et al. 2008).

The Marine Planning Framework was underpinned by three key principles: ecologically sustainable development, ecosystem-based management and adaptive management. Assumptions were developed, based on managing activities within the assimilative capability of the ecosystem, in order to guide the development of the marine planning model. The key assumptions were: data availability that reasonably reflect the ecological parameters, important to the functioning of the ecosystem and its biological diversity and spatial distribution of the ecological parameters of the ecosystem is known (Day et al. 2008). The Framework provides for the development of six Marine Plans covering the eight marine regions in South Australian waters.

A pilot study of Spencer Gulf marine planning area (11,540km^2) was chosen because of its 'broad and complex range of marine uses and habitats in the region' (Paxinos et al. 2008). A data collection exercise was carried out to collate environmental, social and economic uses. The marine plan was developed using GIS software. Spencer Gulf area (Figure 2.3) was divided into a grid of 5 x 5km^2 Planning Units (PUs) because this simplified the large planning area and decreased spatial errors due to the resolution of the ecological data.

The planning area was grouped into four ecologically rated (ER) zones using habitat and species data layers as described in Paxinos et al (2008). Each zone has a different level of ecological importance, with one zone developed for areas with little data, ER 4 (Figure 2.3). Each zone has specific goals and objectives that guide use and development within it. There are some limitations to this method; the solution is only as comprehensive as the data. There was no weighting of the layers, so a PU with only one habitat would be rated as low but this does not take into account the importance of this habitat.

An impact analysis was carried out to identify potentially affected areas or areas that were already experiencing adverse impacts (Day et al. 2008) with activities that could affect the marine environment . The area was zoned into very high, high, medium and low impact (Figure 2.4). The impact analyses had the limitations of assuming each impact had the same effect on the marine environment and did not take into consideration cumulative impacts.

From this information, the Spencer Gulf Marine Plan (Government of South Australia, 2006a)

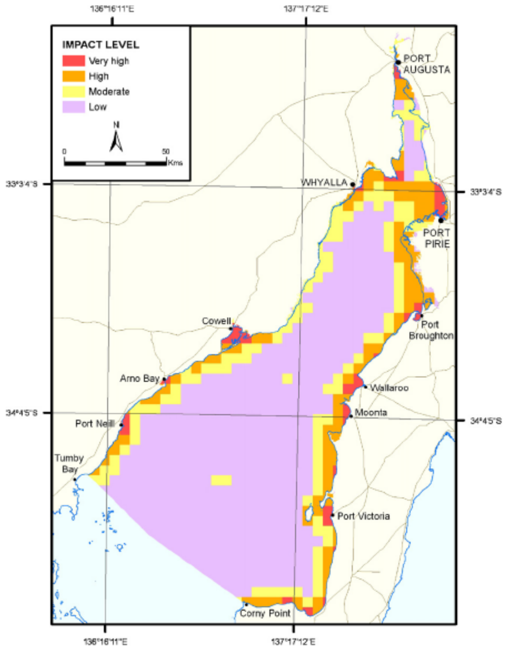


Figure 2.4: Potential and present impacts map (adapted from Day et al 2008)

has been produced containing:

"..an explanation of the goals, objectives, and strategies of the zoning system; a series of maps showing the zoning based on the above model example in Figure 2.3; a map representing the potential and present impacts; and tables explaining the reason for zoning and current activities or impacts by biounit".

The marine plans will be easy to use and will allow the decision making authorities to make consistent decisions. A Performance Assessment System (Department and Heritage for Environment 2006) has been produced to allow for consistent monitoring, to review the effectiveness of the plan and to allow for adaptive management of the area.

This study used a simple cumulative impact scale to identify areas highly affected by human activities. A similar scale has been developed for the UK (Cefas 2010*b*) using low resolution broad-scale habitats and six pressures. These scales assumed that each pressure caused the same impact and could be improved by identifying more damaging activities and giving them a higher weighting.

The high level objectives in the Marine Planning Framework (Government of South Australia

Table 2.2: The zones used in the GBRMP and the activities allowed or excluded from each zone (from Great Barrier Reef Marine Park Authority (2005))

ACTIVITIES GUIDE (see relevant *Zoning Plans* and *Regulations* for details)

	General Use Zone	Habitat Protection Zone	Conservation Park Zone	Buffer Zone	Scientific Research Zone 2	Marine National Park Zone	Preservation Zone
Aquaculture	Permit	Permit	Permit 1	✗	✗	✗	✗
Bait netting	✓	✓	✓	✗	✗	✗	✗
Boating, diving, photography	✓	✓	✓	✓	✓ 2	✓	✗
Crabbing (trapping)	✓	✓	✓ 3	✗	✗	✗	✗
Harvest fishing for aquarium fish, coral and beachworm	Permit	Permit	Permit 1	✗	✗	✗	✗
Harvest fishing for sea cucumber, trochus, tropical rock lobster	Permit	Permit	✗	✗	✗	✗	✗
Limited collecting	✓ 4	✓ 4	✓ 4	✗	✗	✗	✗
Limited spearfishing (snorkel only)	✓	✓	✓ 1	✗	✗	✗	✗
Line fishing	✓ 5	✓ 5	✓ 6	✗	✗	✗	✗
Netting (other than bait netting)	✓	✓	✗	✗	✗	✗	✗
Research (other than limited impact research)	Permit	Permit	Permit	Permit	Permit	Permit	Permit
Shipping (other than in a designated shipping area)	✓	Permit	Permit	Permit	Permit	Permit	✗
Tourism program	Permit	Permit	Permit	Permit	Permit	Permit	✗
Traditional use of marine resources	✓ 7	✓ 7	✓ 7	✓ 7	✓ 7	✓ 7	✗
Trawling	✓	✗	✗	✗	✗	✗	✗
Trolling	✓ 5	✓ 5	✓ 5	✓ 5,8	✗	✗	✗

2006) focus on using the marine environment sustainably, reducing human impacts and conservation. In the UK the high level objectives in the Marine Policy Statement (HM Government 2011) also include sustainable development but addresses heritage assets and societal benefits.

2.6.2 Rezoning of Great Barrier Reef Marine Park in 2003

The Great Barrier Reef Marine Park (GBRMP) is 345,000 km^2 and extends from the coast seaward from 100km^2 to 300km^2 offshore and is run by the GBRMP Authority. The Great Barrier Reef Marine Park Act was passed in 1975. The GBRMP Authority manages the park in accordance with the park goal:

"..to provide for the protection, wise use, understanding and enjoyment of the Great Barrier Reef in perpetuity through the care and development of the Great Barrier Reef Marine Park."

The park uses a suite of management tools including zoning plans (Day 2002). The park uses a multiple zone approach to separate conflicting activities and determine the appropriateness of activities in certain areas (Table 2.2).

The GBRMP was rezoned in 2003 because of an increased awareness of connectiveness, the ecosystem approach and interconnected habitats (Pattison et al. 2004). The Representative Areas Program (Great Barrier Reef Marine Park Authority 2005) was set up to develop a network of protected areas in the park. The Authority used a variety of inputs to rezone the park, including expert opinion, stakeholder approaches and analytical approaches. Two sets of operating principles were developed to guide the rezoning: biophysical principles, which included recommendations regarding the size, replication and amount of each habitat to ensure representativeness, and social, economic and cultural principles, to address placement issues in order to minimise user conflicts and ease of enforcement.

The rezoning was facilitated by the use of Marxan, a GIS based decision support tool (DST). Marxan is a software tool that supports decisions made for reserve system design (Ball et al. 2009; Possingham et al. 2000). Marxan uses a randomization method known as simulated annealing, to find the most efficient solution to site selection. Based on defined criteria for biodiversity targets, the model calculates a cost for each potential solution and attempts to minimise this cost, while generating a near optimal solution. Thousands of possible scenarios can be run and compared, so that many outcomes and spatial patterns can be evaluated. Marxan was also important in presenting the potential rezoning plans to stakeholders in a few days, to ensure full stakeholder engagement.

Marxan was important in rezoning the park but has limitations. It requires technical expertise to operate the model, it cannot take in preferences for spatial configurations or a specific reserve size and in the absence of sufficient good data, the model can produce a false "optimum" result (Pattison et al., 2004). The Park Authority overcame this by using other tools, including additional spatial analyses that were non-automated, such as data layers being projected for use in structured round-table planning discussions that drew on in-house expertise (Fernandes et al. 2005).

2.6.3 Proposed multiple-use zoning scheme for the Irish Sea

One of the key recommendations of the 2001 interim report of the UK Government's Review of Marine Nature Conservation Working Group was a proposed pilot scheme at a regional sea

Table 2.3: Derived management and protection zones for the Irish Sea (adapted from Boyes et al. (2007))

Proposed zones	**Level of protection and use of proposed zones**
Zone 1	General use zone—in which there are the subzones of Zone 1A. Minimal Management (MM) and Zone 1B. Targeted Management (TM)
Zone 2	Conservation Priority Zone (CPZ)
Zone 3	Exclusion Zone (EZ)—in which there are the sub-zones of Zone 3A. Limited Exclusion (LE) and Zone 3B. Significant Exclusion (SE)
Zone 4	Protected Zone (PZ)

scale, to test the proposed framework for nature conservation. This pilot scheme would be used to see how much of this framework could be delivered by existing legal, administrative and enforcement systems (Tyldesley 2004). At the time of this project there was no comprehensive marine planning system used by any country bordering the Irish Sea. Using the data from the Irish Sea Pilot (Vincent et al. 2004) on the presence of marine landscapes, which was further developed in a study by Boyes et al (2005), the UK part of the Irish Sea was chosen as a study area to produce a zoning scheme by Boyes et al (2007). Boyes et al (2007) demonstrated a multiple-use zoning scheme of marine activities at the regional scale by using existing legal mechanisms.

The Irish Sea has many legally permitted activities that compete for space, such as aggregate extraction, nature conservation, sea fisheries and windfarm developments. Boyes et al (2007) derived four zones (Table 2.3) with the majority (35,500km^2 out of 44,600km^2) of the Irish Sea being Zone 1A.

Boyes et al (2007) showed that it was possible to create a zoning scheme of the Irish Sea Pilot Area by summarising and mapping the existing area-based legislation and regulations. The main UK legislation and regulations that applied at the time, which are relevant to the marine environment and activities that take place within it, were identified. Where this information had a spatial element it was mapped in a Geographic Information System (GIS) which allowed the data to be looked at in relation to each other. This information was then reviewed and assessed

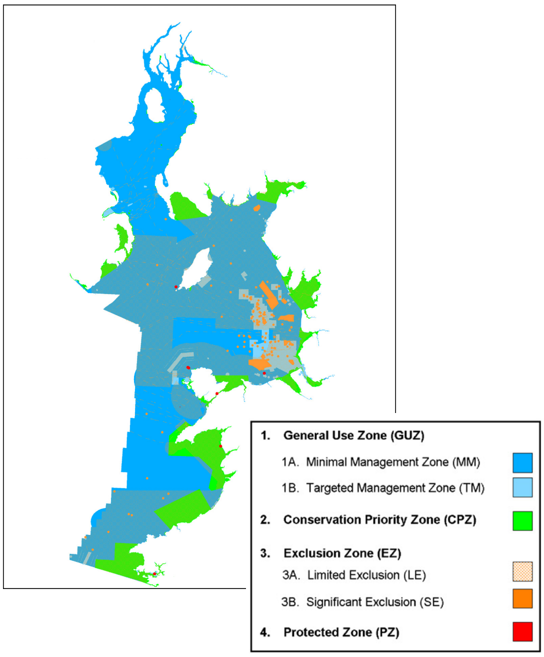


Figure 2.5: Proposed multiple-use zoning map for the Irish Sea - adapted from Boyes et al (2007)

by the nominated offices of their partner bodies (Scottish Natural Heritage, Country Council for Wales and English Nature). After this, a zoning map was proposed which defined the various zones (Table 2.3 and Figure 2.5). This was not to be a definitive plan but a proposal for discussion and will be modified by future work and by new data. Boyes et al (2007) showed that current legislation and statutory sectoral measures could be summarised in a zonation scheme and concluded that existing legislation does not provide adequate protection to important nature conservation features.

2.6.4 Firth of Clyde Marine Spatial Plan

The Firth of Clyde marine spatial plan was developed under the Scottish Sustainable Marine Environment Initiative (SSMEI) (SSMEI 2010*a*). The Firth of Clyde is on the west coast of Scotland and contains protected habitats and species including common and grey seals, with large areas of salt-marsh and mudflat important for many species of wading birds. The main activities in this area are recreational yachting and angling, shipping, mariculture and commercial prawn fishing (*Nephrops norvegicus*).

The marine spatial plan was developed over three years (2006-2009) in consultation with stakeholders. The main aims of the plan are:

- to maintain and enhance the biodiversity, landscape and seascape of the Firth of Clyde, by protecting and improving its natural resources,
- to provide a framework that supports current economic activity, opportunities for growth and attracts investment and
- maintain the well-being and cultural diversity of coastal communities.

The resulting marine spatial plan is non-statutory and is not a series of zones which allow different activities but a number of high-level objectives for the sustainable use and development of the Firth of Clyde. Some activities are restricted in parts of the Firth, for example a no take zone has been created in Lamlash Bay, to protect vulnerable species and there are fishing restrictions in other areas to protect breeding stocks. The DSTs tools used to develop this MSP were the spatial mapping and interaction of activities and the use of GIS to assess likely impacts on the marine environment. Modelled habitat data were created to allow the potential impacts of activities to be assessed.

The examples shown here demonstrate that marine spatial planning occurs for a variety of reasons and that the way it is implemented is diverse. In the GBRMP rezoning process, one of the main reasons for the rezoning was increasing the protection of marine biodiversity (Kenchington and Day 2011). In contrast the development of the Firth of Clyde MSP had a number of aims including protection of biodiversity but the framework set up by the MSP also supported economic activity and attracting investment. The Spencer Gulf plan had similar aims of sustainable use and development. Other marine planning processes tend to have similar aims of sustainable use and development, whilst protecting the marine environment (Douvere and Ehler 2009; Jay et al. 2012, 2013). For example, the main aims of the MSP developed in the Netherlands were to have a healthy sea, a safe sea and a profitable sea (Douvere and Ehler 2009). The German MSP was set up to coordinate the growing conflicts between uses of the marine environment and has five main objectives: the importance of maritime trade to the German economy, coordinating different uses, promotion of offshore wind energy, sustainable use and protection of natural resources and systems (Jay et al. 2012). This highlights the range of goals for setting up a marine planning process but most have an emphasis on sustainable development, reduction in conflict between users of the marine environment and protection of biodiversity.

The four examples above showed a wide range in scale: Great Barrier Reef Marine Park 345,000km^2, Marine Planning Framework for South Australia 11,540km^2, Irish Sea Pilot 44,600km^2 and Firth of Clyde Marine Spatial Plan 3650km^2. This highlights that marine spatial planning can occur successfully at a range of scales.

The four examples presented above resulted in different types of zone. The Firth of Clyde MSP created two zones, it zoned one small area to create an MPA and restricted fishing in other areas. The Irish Sea Pilot derived four zones from current uses of the Irish Sea, with much of the planning area given over the minimal management zone, with the other three zones having some level of exclusion of activities and two zones for conservation protection. The GBRMP resulted in seven zones from the general use zone which allowed most activities, although some (aquaculture, and some fishing activities and tourist programme) required a permit. The other six zones had more of a focus on conservation or scientific research and therefore restricted human uses. The Spencer Gulf plan has four zones based on biodiversity, each with a range of objectives. The objectives range from allowing small impacts on the marine environment to a precautionary approach on areas where little is known. Other marine plans have used zones with a variety of objectives. For example, the Norwegian marine plans have created zones for international shipping and the petroleum sector (Jay et al. 2013). The German MSP defined priority areas (zones) where certain activities would have priority over other sectors, these included shipping, pipeline and cables, research and wind energy (Jay et al. 2012; Douvere and Ehler 2009). The plan included areas already designated for nature conservation, natural resources, shipping and military use but did not add to them. Zones are created for different uses, with most zones within marine plans focused on the priorities of human activities, and their conflicts.

Each of the four examples described above undertook investigations to assess how much of the marine environment within the plan area was impacted by human activities, and in some cases evaluated cumulative impact. In the Spencer Gulf MSP process a simple method of assessing cumulative impact was used, with the number of human activities occurring in a area being calculated, with the assumption being that all human impacts are the same (Day et al. 2008). The GBRMP rezoning process collected human activity data and assessed their likely impact. This information was used to guide the placement of zones, to minimise impact on users (Great Barrier Reef Marine Park Authority 2005). The Irish Sea Pilot collected human use data and data to investigate links between conservation features and industry (Vincent et al. 2004). During this process marine landscapes were described and assign into naturalness categories based on trawling intensity (Lieberknecht et al. 2004). During the Firth of Forth MSP process the data available on marine biodiversity was reviewed, with a plan policy being to map sensitivities and pressures. In the Norwegian marine plan, environmental impact assessments were undertaken on shipping, petroleum and fishing, these were then aggregated to assess cumulative impacts (Jay et al. 2013). It was identified that there were no commonly used methods to produce cumulative impact assessments (Jay et al. 2013). A report commissioned by Defra (Cefas 2010*b*) evaluated the assessment of cumulative impacts of six human activities. GIS-based Multi-Criteria Analysis was used, to quantify risk of cumulative impacts. Four scenarios were evaluated using different weightings, including linear and logistic. Although there was considerable uncertainty in the results and differing impacts between the scenarios, each scenario indicated similar areas where there were increased risks of cumulative impacts, suggesting the methodology developed could be useful in marine planning.

The four international examples collected and used socioeconomic data when producing their plans, to reduce the impact of human activities on the marine environment and to identify conflicts between sectors. In the Irish Sea Pilot data were collected but as no plan was produced there were no impacts on human activities. The Spencer Gulf marine plan used human activity data to assess cumulative impacts and to define objectives for each of the zones. The GBRMP used this data to minimise impacts on human activities. The Firth of Clyde plan used this data to identify conflicts between sectors and to develop high level objectives. This highlights the importance of using human use data within marine planning. During the German MSP process socioeconomic data was used to reduce conflict between new and traditional sectors and conservation (Jay et al. (2012); Douvere and Ehler (2009)). During the Portuguese marine planning process a spatial analysis was undertaken to identify current and potential conflicts between sectors (Jay et al. 2013).

The four international examples have different mechanisms for implementation. The GBRMP authority is legally responsible for management of the GBRMP, the legislation also includes the production of a zoning plan (Kenchington and Day 2011) and the plan is legally enforced. The Spencer Gulf plan is a strategic guide, as is the Firth of Clyde MSP, and the Irish Sea Pilot has been used to develop marine planning in the UK. This suggests that there are various ways that MSPs can be implemented. In the UK, the Marine and Coastal Access Act requires that all public authorities must make decisions in accordance with marine plans and the Marine Policy Statement, with many other European countries (e.g. Germany, Belgium and Netherlands) bringing in legislation to make their plans statutory (Douvere and Ehler 2009; Jay et al. 2013).

The main challenges identified through the international examples are how can different sectors' activities and goals be met in a single marine plan, the importance of including socioeconomic data in marine planning and how to measure cumulative impacts.

The above examples of marine planning have shown the value of GIS and GIS based DSTs in marine spatial planning and their importance in producing marine spatial plans. The Irish Sea Pilot Project (Vincent et al. 2004) used Marxan as a part of the planning process to identify nationally important marine biodiversity areas (Lieberknecht et al. 2004). Site selection tools can be used in more than one part of the marine planning process (Figure 2.6).

2.7 Use of decision support methods and tools in marine planning

During the marine planning process a great deal of information has to be processed to produce a marine spatial plan and decisions have to be made in a transparent and well-documented way. Decision support tools can assist in the marine planning process in a number of ways:

- integrate spatial data, environmental and socioeconomic, to evaluate potential conflicts,

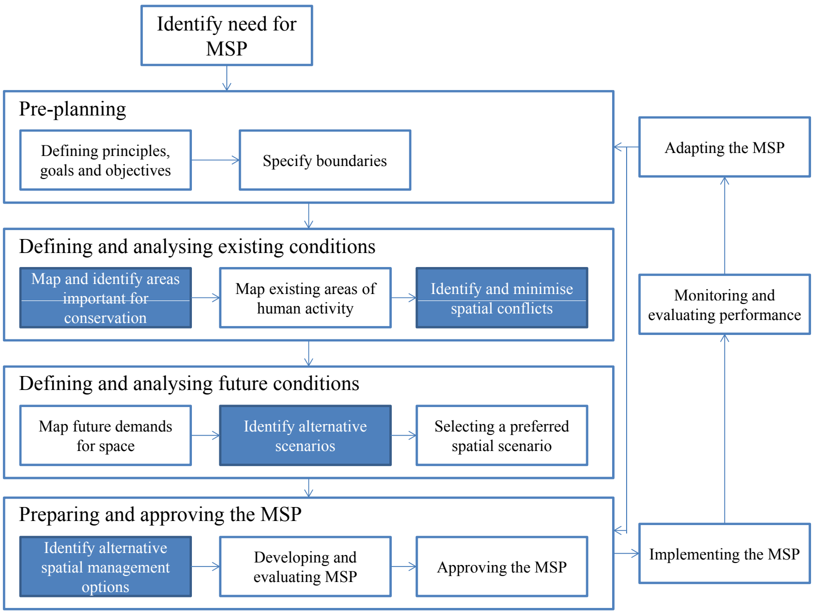


Figure 2.6: A step-by-step process of marine spatial planning. The blue boxes are where site selection tools can aid the marine spatial planning process. Adapted from Ehler and Douvere (2009)

- assess impacts of current and future uses, on the environment and human activities,
- identify priority areas for sectors including conservation,
- aid with stakeholder engagement,
- develop weighting and valuations and
- develop scenarios, to assess the compromises required to meet a plan's objectives.

There are many types of decision support methods and tools that can be used in marine planning, in this review four types are reviewed: tools that can assess cumulative impact of human impacts on the environment, tools that can provide weighting and prioritisation, interactive tools and site selection tools. These four types of were chosen because they have been identified as being the most relevant to marine spatial planning (Ehler and Douvere 2009; MMO and Marine Scotland 2012*a*; Stelzenmuller et al. 2013).

As has been discussed in the previous section, there is a need for the development of methods and tools that provide information on the impacts of human activities on the marine environment. In particular, methods are required that can assess cumulative impacts. Using tools that assess cumulative impacts would allow decision makers to identify highly impacted areas of the marine environment, and take action to prevent further degradation. Evidence of highly impacted areas could allow decision makers to conclude that an area was highly damaged and allow activities to continue rather than move activities to a different area which would damage further areas. Also European legislation (European Commission 2008) requires that the condition of protected species be assessed.

Impacts from human activities can interact in various ways (i) no cumulative impact, (ii) accumulative, additional pressures increase impacts, but not as much as each pressure individually and (iii) cumulative impact Halpern et al (2008). Tools and methods have been developed at a range of scales from global Halpern et al (2008), to the UK marine area (Cefas 2010*b*) to the local scale (Day et al. 2008). A method was developed during the Spencer Gulf Marine Plan (Day et al. 2008). This method assumed all human activities had the same impact and that the impacts were additive. This tool provided some information on likely cumulative impacts, but only measured the occurrence of human activity and linked this to cumulative impacts. A study in the UK (Cefas 2010*b*; Stelzenmuller et al. 2013) has developed a methodology for assessing cumulative of six activities using a variety of weightings. This methodology has been developed into a GIS tool (Create Pressure Layer Tool) (Stelzenmuller et al. 2013) which if increased activities were included could be used to develop a marine plan. Halpern (2008) created a global map of human impacts on the marine environment that included cumulative impacts. This study is useful for indicating areas that require improved management but is too large scale to be used in producing marine plans.

Tools are required that can help decision makers and stakeholders identify how activities should be weighted and prioritised within a marine plan. These tools can be used to explore how prioritising one/or several sectors can effect other human uses of the sea. Several methods have been developed to assist in this (Stelzenmuller et al. 2013) during the marine planning process. Multi criteria analysis (MCA) allows stakeholders and decision makers to develop weightings for uses of the marine environment. These can then be used to develop scenarios to evaluate which sectors gain under each regime of marine management and those that gain (MMO and Marine Scotland 2012*a*). MCA does not use monetary values and so minimal economic knowledge is required to participate. Cost benefit analysis (CBA) is similar to MCA, with the difference being monetary values are generated during the process (Kidd et al. 2011). This method can be costly and time consuming, with much uncertainty introduced when non-monetary goods and services are valued. Environmental valuation can be undertaken as part of CBA to give monetary values to environmental assets (Kidd et al. 2011). Trade off analysis can be used with stakeholders so that multiple objectives and conflicts can be resolved (MMO and Marine Scotland 2012*a*). Scenarios can be evaluated with weightings and costs generated by stakeholders.

Although the above methods have been used in marine planning (Villa et al. 2002; Stelzenmuller et al. 2013) no generic tools have been developed for this use (Stelzenmuller et al. 2013). These methods can still be applied through stakeholder consultation. The DST MaRS (Marine Resource System), uses MCA to identify areas for prioritisation, but it has been designed for the UK marine environment and is not a generic transferable tool for marine planning. A prototype tool has been devised that uses MCA to identify cumulative impacts (Cefas 2010*b*) which is currently useful for identifying risk of environmental impact for some pressures.

Tools that allow users to view spatial data related to marine planning online are important for engaging stakeholders. The UK has a number of these tools. The Marine Planning Portal, maintained by the MMO, allows the user to view data sets related to marine planning. The JNCC has created the MCZ portal, from which users can view data generated during the MCZ projects. Scotland has two portals (i) Scotland's National Marine Plan interactive where users can view data and (ii) Marine Scotland Interactive where data sets can be download to view offline but not viewed online. MaRS is an online web portal that provides users access to view data, maps and perform analysis. This enable uses to identify areas available and suitable for their interest and potential conflicts.

Site selection tools are used to identify a network of sites that fulfil the targets and objectives chosen by the user. These tools integrate spatial data layers with targets to identify priority sites for conservation or other sectors. Currently many of these tools have been generated from SCP (Moilanen et al. 2009), although these tools are now being used more in marine spatial planning (Stelzenmuller et al. 2013). To identify priority sites these tools use algorithms to select sites that fulfil the targets or objectives set.

Marxan and Marxan with Zones integrate cost data with targets set to protect conservation features to produce multiple suggestions of site configuration. These programs have a number of front ends to make them more user friendly and to expand the outputs they can produce including CLUZ. CLUZ (Conservation Land-Use Zoning) is a program that works together with Marxan (Smith 2004). CLUZ can be used to set up Marxan scenarios and to interactively amend plans that have been created using Marxan. When sites are added or removed information on how the new plan meets conservation targets is generated. The program Zonation aims to maximise conservation benefits at a set cost defined by the user (Delavenne et al. 2012). This program does not include human use costs, so the outputs provide information about conservation value (Moilanen et al. 2009). C-Plan was developed to calculate irreplaceability of sites in conservation as described in Pressey (Pressey et al. 1994). Other site selection tools have been created (e.g. MarineMap and MaRS) but these tools are specific to a particular area and are not able to be applied widely in marine planning.

Decision support tools have proved useful in marine conservation planning and in the production of marine plans. Further research is required as to the use of these tools for the design of marine plans. Research needs to be focused on the data required to produce satisfactory marine plans. Also the sensitivity to the types, levels and confidence of data needs to be assessed. Further work needs to be undertaken on how to incorporate socioeconomic costs in marine planning fairly and how to identify the compromises required to ensure sustainable management.

Chapter 3

Methods

3.1 Introduction

Marxan is a spatial planning decision support tool (DST) (Ball et al. 2009; Possingham et al. 2000), frequently used for the design of marine protected areas (Pattison et al. 2004). It performs 'n' randomised iterations and selects the outcomes that best meet preset criteria to select appropriate sites for marine reserves, if relevant habitat and species data are available.

Marxan has been used to produce outputs to support the re-zoning of the Great Barrier Reef Marine Park multiple-use plan in Australia (Fernandes et al. 2005). There were comprehensive data in this study for only a few habitats and species. Therefore, a bioregional approach combined with expert option was used to mitigate against only protecting sites that had been sampled, as species or habitat data would only be available for those sites.

Lieberknecht et al. (2004) used Marxan to test the draft criteria for the identification of nationally important biological marine areas as part of the Irish Sea Pilot (Lieberknecht et al. 2004; Tyldesley 2004). Marxan has also been used to determine a network of fishing sites needed to sustain the commercial fishing industry that works off the Pacific coast of British Columbia, selecting areas required for fishing with the other areas available as marine reserves (Ban 2008).

Site selection decision support tools can integrate the large amounts of data need in marine planning and ensure that when compromises have to be made, this can be done in a fair and open way. Integrating a variety of datasets and activities into a marine plan is complex, particularly because each activity or sector will have different ways of assigning costs to losing access to marine resources such as frequency of use of an area or the cost per unit of an area, (Table 3.1).

Table 3.1: Three examples of socioeconomic costs that can be applied in marine spatial planning. Each activity has an example of a cost that could be applied in the planning process and the potential impact of using this cost on the MSP/MPA.

Activity	Cost	Impact	Reference
Rock lobster fishery	Relative importance of area to the fishery	Reduction by a third of MPA network on the rock lobster fishery without compromising conservation goals	Stewart and Possingham (2005)
Recreational use	Potential loss of revenue from recreational use of an area	Reduced the impact of a marine plan on the recreation sector (Study in Chapter 6 of this thesis)	Rees et al. (2010)
Commercial fishing	Potential loss of commercial fishing revenue	Use of finer-scale revenue reduced the impact of MPA network in comparison to coarse scale data	Richardson et al. (2006)

Marxan is one of the most commonly used conservation site selection tools in the world and Marxan with Zones is an extension of this software (Watts et al. 2009). Marxan does not have the ability to use multiple costs, such as area, frequency of various fishing activities and potential management costs, unless they are incorporated into a single figure, which reduces the transparency of the outputs. Marxan with Zones allows the inclusion of multiple costs to be considered when designing a marine plan and use of different zones.

Ban and Klein (2009) performed a literature review on peer-reviewed papers that had incorporated multiple costs using systematic conservation planning software, such as Marxan with Zones. They found no peer-reviewed papers on studies that had incorporated transactions or management costs in the design of marine protected areas using systematic conservation software. Studies that had used systematic conservation software had focused on fisheries activity as an opportunity cost. One study by Watts et al. (2009) showed that Marxan with Zones had been used to produce a solution for a multiple-use marine park off Western Australia (Rottnest Island) that had areas with conflicting uses. The study highlighted three conflicting uses: conservation, non-extractive recreational activities and recreational fishing. By using the frequency of the non-extractive recreational activities and recreational fishing as costs, the conflicting uses were separated into zones and the activities were further separated by the use of buffer zones. This resulted in a plan that would be more likely to be accepted by all stakeholders and could reduce potential conflicts.

Two studies published in the grey literature have incorporated multiple costs. Watts et al. (2008) applied the economic relative importance of individual fisheries as a cost in a Marxan with Zones study of the north central coast of California. The cost applied was the relative importance of a planning unit to each fishery. The value of the costs applied are from 0 (not used by a fishery) to 1 (the most important planning unit to a fishery). This study highlighted the difficulty of meeting both conservation and fisheries targets. Either fisheries were heavily impacted and conservation targets were met or vice versa. A draft marine spatial plan was developed in St Kitts and Nevis using Marxan with Zones (Agostini et al. 2010). Multiple factors were considered including activities from tourism, fishing, industrial transportation and habitat protection. Each of the activities was added a feature and a target set for inclusion in a particular zone/zones. The study suggested the reason that individual feature targets were not met was because goals were set too high or the planning units required were locked into a different zone.

California's Marine Life Protection Act (1999) mandates the design of a network of marine protected areas in its State waters (out to 3 nautical miles) to protect its natural environment. A study in California by Klein et al. (2009) highlighted the increased functionality of Marxan with Zones, in comparison with Marxan, by incorporating zones that allowed different activities to occur. Whereas, in contrast, Marxan creates a two zone, i.e. unprotected zone and protected zone, marine protected area network. The potential MPA networks produced by Marxan had 10-30% proportion of fishing value lost. In the Marxan with Zones analysis four zones were used which allowed different levels of activities to be applied in each of the zones. This led to 2-10% proportion of fishing value lost. Using Marxan with Zones allowed for the inclusion of targets for each fishery which further reduced the impact on fishing activity. The study further discovered that for 80-90% of conservation goals to be met, fishers lost less than 10% of their fishery value. When almost all of the fishery value was preserved (96%) many of the biodiversity features (16-44%) were not represented in the resulting MPA. This study highlights that the use of Marxan with Zones can make explicit the compromises needed to balance competing sectors' requirements.

A literature review was performed on the various methodological approaches which can be used in the marine planning process. It became apparent that the issue of data sensitivity, that is, how marine planning outputs respond to using data of different types, and the impact of using these data on marine biodiversity protection was an important one (National Research Council 2001; Stevens 2005; Banks and Skilleter 2007; Ban 2009; Carvalho et al. 2010). A further point was how to integrate the various types of data available on marine biodiversity and human activities, in a fair and transparent way (Margules and Pressey 2000; Smith et al. 2009; Watts et al. 2009; Adams et al. 2010). It was also considered important to combine the two points.

It became apparent that the marine biodiversity and human activity data would need to be combined in a single program and then have costs and weightings associated with them. Other researchers (Klein et al 2008) have successfully combined habitat and activity data in site selection tools. Rodrigues et al (2007) had tested the data sensitivity and potential impacts on marine biodiversity protection.

Other programs were considered, e.g. Zonation, but it was concluded that for the type of data available and the solutions required that the algorithm (simulated annealing) used in Marxan and Marxan with Zones would produce efficient MPA networks (Kirkpatrick et al. (1983)). Also Marxan and Marxan with Zones allow costs to be incorporated in the analysis in a transparent way.

Three case study areas, as described in the chapter 4, were used to evaluate some of the current issues in marine planning and to suggest potential solutions. The areas of particular interest were data sensitivity and availability, and the integration of social, economic and conservation objectives. The three case study areas were chosen because:
i) the three case study sites had different areas (110km^2, 2460km^2 and 12620km^2) which represented marine plans at varying scales. The case study sites were used to evaluate the ability of Marxan and Marxan with Zones to effectively create marine plans at different scales and with planning units of varying sizes.

ii) The case study sites had data (biological and socioeconomic) available that could be used in Marxan and Marxan with Zones. Therefore, Marxan and Marxan with Zones could be assessed on their ability to integrate data of different types, e.g. habitat and human activity data. Multiple costs could be applied simultaneously, to evaluate whether Marxan and Marxan with Zones could still produce useful solutions.
iii) The Lyme Bay case study area currently has an area designated for conservation. Studies have found that using current MPAs that have been designated in the non-systematic way may increase the opportunity costs and area required for the protection of marine biodiversity (Pressey 1994; Stewart et al. 2003). This case study was used to assess the changes in marine biodiversity protection and area required when a currently designated MPA was used as basis for a marine protected area network.
iv) Data were available on the confidence that could be placed in habitat data, for the East Channel study area and high quality recently collected habitat data. Studies have investigated the problem of uncertainty in marine data (Wilson et al. 2005; Halpern et al. 2006; Beech et al. 2008) and how to incorporate it during the marine planning process. These data were used to evaluate how using data of varying percentages of confidence impacted the protection of marine biodiversity.

It was considered that the case studies chosen were able to provide a useful evaluation of Marxan and Marxan with Zones in marine planning.

3.2 Using Marxan and Marxan with Zones in marine planning

Some of the key terms associated with Marxan and Marxan with Zones have defined (Table 3.2).

3.2.1 Marxan

Marxan uses a randomization method known as simulated annealing, to find the most efficient solution to site selection (Ball et al. 2009; Possingham et al. 2000). Based on defined criteria for biodiversity targets, the program calculates a cost for each potential solution and attempts to minimise this cost, while generating a near optimal solution. Thousands of possible scenarios

Table 3.2: The definitions of key terms associated with Marxan and Marxan with Zones

Planning units (PU)	The planning area is divided into planning units. Marxan assigns the planning units to a zone. The planning unit will contain information on the distribution of species and habitats to be protected and associated costs.
Conservation feature	Conservation features or features are the species/habitats that are to be protected.
Boundary length modifier (BLM)	The BLM is a parameter that Marxan uses to weight the importance of the fragmentation of a MPA network. If a higher value is used Marxan will attempt to increase the clumping of protected areas and therefore reduce the boundary length.
Costs	Each PU can be assigned a single cost (Marxan) or multiple costs (Marxan with Zones). These costs can reflect the costs of buying or managing the PU or the potential economic value lost because an activity will not take place.
Feature penalty cost	Marxan applies this cost when the target set for protection is not met.
Objective function	Marxan uses the objective function to compare alternative solutions. Marxan calculates the value of a solution using the costs, BLM and feature penalty costs.
Solution	Marxan assigns planning units to a specific zone, in order to meet the targets and constraints set up by the user. This is often called a solution. One is produced for each Marxan run.
Best output	The solutions with the lowest objective function value.
Summed solution and selection frequency	Marxan sums how often a PU is assigned to each zone in the total number of runs (summed solution). If Marxan is set to Run 100 times and a PU is selected 50 times it will have a selection frequency of 50.
Run	The user sets the number of repeats of the analysis that has been set up. When Marxan is set to Run a 100 times it will produce 100 solutions.

can be run and compared, so that many outcomes and spatial patterns can be evaluated. Marxan uses simulated annealing which iteratively improves the selection of planning units to gradually reduce the objective function (see below) whilst meeting the targets set, it also initially allows some bad moves (the addition or removal of planning units that leads to an increase in the objective function) to avoid local minima (Game and Grantham 2008).

Simulated annealing is an algorithm that uses iterative improvements but randomly (stochastic) acceptance of changes (both additions and removals) that increase the objective function. This means that Marxan and Marxan with Zones (which both use simulated annealing) are far less likely to get stuck at local minima than programs which use greedy algorithms (Kirkpatrick et al. 1983), and can produce multiple optimum reserve systems (Ball et al. 2009; Possingham et al. 2000). Local minima are reached when adding PUs that decrease the objective function or removing PUs that increase the objective function no longer improve the objective function value. In an analysis with many PUs there are many potential solutions, local minima may be reached when the objective function is a long way from an optimum value (McDonnell et al. 2002).

In Marxan the annealing process runs for the number of iterations defined by the user. At each iteration a planning unit is chosen at random. The chosen planning unit may or may not already be in the reserve system. The change in the objective function is calculated for the addition of removal of the chosen planning unit. The change is used in conjunction with a parameter called temperature to decide if the change to the chosen planning unit should be accepted. The temperature parameter is gradually decreased during the analysis. This means that to begin with any change in planning unit may be accepted but the longer the process is run the chance that a solution which increased the objective function may be accepted is reduced.

The case study areas were divided into hexagonal planning units. The coastlines of each of the case study areas have smaller planning units because of their irregular outlines. Hexagons were chosen as the planning unit shape because they help create reserves with low edge to area ratio.

Marxan's objective function was set to minimise the cost of protection where costs can include the costs of establishing and maintaining planning units as a reserve and the penalties. Thus, the objective function was to minimise the total score of the sites selected where:

Total score = PU cost + (B cost x BLM) + (FP cost x FP factor)

where:
PU = Planning Unit
B = Boundary
FP = Feature Penalty
BLM = Boundary Length Modifier

The objective function is used by Marxan to compare solutions, that is sets of planning units, to each other. The objective function is combination of all the costs of a reserve system and penalties for any targets not met. The score comprises three costs, all with potentially different units and so it is not assigned units. In Marxan lower values for a reserve system tend to mean better solutions. There are three basic parts to the objective function which allow Marxan to produce useful potential reserve networks.

1) The cost of the network. In Marxan this is the cost of each planning unit within the reserve system. In Marxan this is a single number for each planning unit, in Marxan with Zones multiple costs may be applied. The costs of a planning unit can be based on a wide variety of measures. The simplest one is the area of a planning unit. This reflects the assumption that the larger the reserve size the more it impacts human activities and cost more to manage and enforce. Monetary values, e.g. the amount of money lost through an activity not taking place, or frequency of use can also be used. By including this in an analysis Marxan will attempt to avoid including planning units with higher associated costs in the reserve network, if other planning units can be used instead. This will reduce the impact of MPAs on human activities.

2) Marxan uses a parameter called the boundary length modifier (BLM) to weight how impor-

tant it is to have an unfragmented reserve system. Reserves that are more fragmented will have a greater boundary length compared to area. Reserves that are more fragmented are considered to be more costly to manage and enforce. Marxan calculates the boundary cost of the reserve by summing the lengths of all the boundaries between planning units that are in the reserve and those that are not. This is then multiplied by the BLM and added to the objective function. If the BLM value is 0 the boundary size will not affect the analysis. Whereas if a high value is given to the BLM, Marxan may prioritise having a compact reserve over other targets. The value for the BLM which provided a desirable level of clumping was assessed for each of the data chapters, using methods of Ardron et al. (2008) and Stewart and Possingham (2005). The level of clumping is decided by the MPA designers - this could be stakeholders, managers or technical staff.

3) The third part of the objective function is the penalty for not meeting conservation feature targets. Marxan calculates the cheapest way a conservation feature could be represented, by adding together the costs of planning units which would form the lowest cost to achieve the target set. This is what forms the basic penalty for the conservation feature (Game and Grantham 2008). Marxan uses this figure to calculate the penalty if a conservation feature meets half of its target then half of this penalty is added to the objective function. Marxan calculates this for each conservation feature and then sums these values and adds them to the objective function. Conservation features that have met their targets have no penalty and therefore do not increase the objective function.

The file preparation was completed in ArcGIS, Excel and Notepad. The process described in Figure 3.1 was followed to ensure that good quality outputs were generated for each of the scenarios. Apart from the references made to socioeconomic data and the costs file, which were only used in scenarios that used socioeconomic data. In particular the calibration step ensures that Marxan is generating appropriate responses from the data before the plan is created.

Locking-in and excluding planning units

Marxan can be set to include PUs in the reserved area (locking in) or exclude PUs from the reserved area (locking out). A PU can be defined in four ways for inclusion in a reserve system.

1) It may or may not be included in either the initial reserve system or final reserve system. A PU is set this way by default.
2) A PU will be included in the initial reserve system but may or may not be in the final reserve system.
3) A PU is fixed in the reserve system, it will be included in the initial reserve system and the final reserve system (locked in). This can be used for current MPAs although Marxan may use current MPAs as hubs around which new PUs can be added to the reserve system.
4) A PU can be set to be excluded in the initial and final reserve system (locked out). This can be used when PUs will never be available for inclusion in a reserve.

Marxan with Zones has the facility to lock in or lock out PUs of multiple zones. For example, a PU can be included in zone 1 and excluded from zones 2 and 3.

3.2.2 Marxan with Zones: key improvements over Marxan

Marxan with Zones builds on the site selection ability of Marxan, the two key improvements are (a) it is capable of assigning planning units to a variety of zones and (b) Marxan with Zones also allows the user to incorporate multiple costs when designing a marine plan.

Marxan can only assign planning units to two zones, either inside or outside a reserve system. This limits the use of Marxan in real-world situations where zones are a commonly used management tool to designate areas for either a specific purpose or to exclude activities from areas (Day 2002; Airame et al. 2003; Evans and Russ 2004; Jay et al. 2012). Marxan with Zones can be used to designate more than two zones so that multiple objectives can incorporated into an analysis (Watts et al. 2009; Ball et al. 2009). This allows the user to create a marine plan that can take into consideration conservation, social and economic objectives.

Marxan with Zones allows for the definition of preferred spatial relationships between zones. By using multiple zones the user can recommend that Marxan with Zones creates a buffer of partially protected zone around a highly protected zone.

Targets can be set for each zone for each conservation feature. The proportion representation for each species for each zone can be set. If a species is present in a highly protected zone it will represent 100% of how much is protected in the species and zone target, if it is present in a non-protected zone 0% goes towards the target and in a lightly protected zone the proportion can be set to a different percentage. For example, if a habitat was protected with the area 1 and the proportional amount to be included towards the target was 50%, Marxan with Zones would put 0.5 towards the target.

In Marxan with Zones many costs can be used within the analysis, in Marxan only one can be applied. The costs of allocating each PU to a specific zone can be defined. For example, fisheries costs could be applied in zones that restrict fisheries and not apply them in zones with no fishing restrictions. These costs are weighted as more or less important in each zone using the zone specific multiplier. The costs for each planning unit in each zone are calculated and added to the objective function.

It is recommended (Watts et al. 2009) that the number of iterations in each Marxan with Zones analysis is increased proportionally to the number of zones included. If x number of iterations are used in a Marxan analysis (two zones), after calibration to check this number produces a good variety of solutions and avoids local minima, then an analysis using similar data or for the same area in Marxan with Zones with four zones should use 2x number of iterations.

3.2.3 Data required for a Marxan or Marxan with Zones analysis

There are a range of files that need to be prepared before a Marxan or Marxan with Zones analysis can be run (Table 3.3). Figure 3.2 represents the files required for Marxan and Marxan with Zones analysis.

Boundary file

The Boundary file holds the costs associated with the boundary between each planning unit. This is commonly the length between planning units. Marxan uses the boundary length in a parameter called the boundary length modifier (BLM). The BLM controls how much importance Marxan puts on minimising the costs associated with boundary length. If the length of boundary between planning units is used the higher the value of the BLM the less fragmented the resulting output.

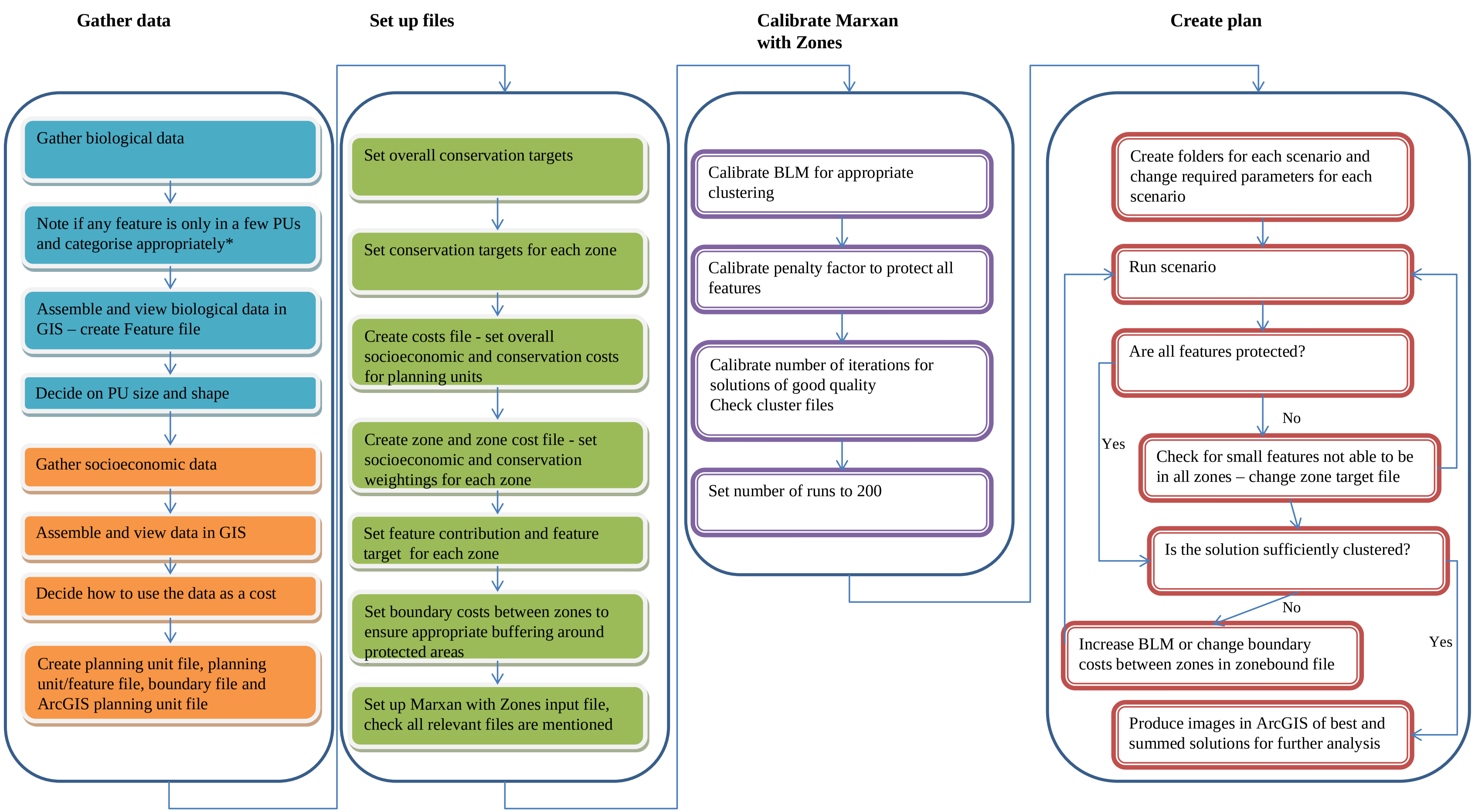


Figure 3.1: Step by step guide of the systematic planning process required when using Marxan with Zones to produce a MPA network or to run a simplified marine planning exercise. Using conservation feature data with percentage targets with recreation and fishing data as costs.*If a feature is present in fewer than ten planning units it will need to be treated differently in the analysis. It may only be able to be present in one or two zones, this will show up in the calibration.

Table 3.3: The files required for a Marxan with Zones analysis and a description of what the files contain and/or how they are used. PU = planning unit

File	**Description**
Boundary file	The length or other associated cost between each planning unit
Costs file	The ID and name of each cost
Feature file	The amount or proportion of each conservation feature to be protected and the associated penalty factor for each feature
Input file	Marxan/Marxan with Zones is instructed where to find the data layers, how many iterations and runs to perform, which algorithm to run, the boundary length modifier, the available zone and which output files to produce
PU File	Contains the planning unit ID and the costs associated with each planning unit
PU layer shapefile	Planning unit ID and associated costs for each planning unit in an ArcGIS shapefile (for using with Zonae Cogito)
Puvsfeature file	The amount of each conservation feature within each planning unit
Zone file	The ID and name of each zone
Zone boundary cost file	This file allows for the buffering or separation of the zones
Zone contribution file	This file tells Marxan which zones are protected and therefore when a feature is included in a zone whether it should count as being protected or not
Zone costs file	How each of the costs will be applied in the zones
Zone target file	How much of each feature is to be included in each zone
Optional file	
Locking PUs into zones file	Allows for PUs to always be included/excluded in a certain zone in the output or initial reserve system

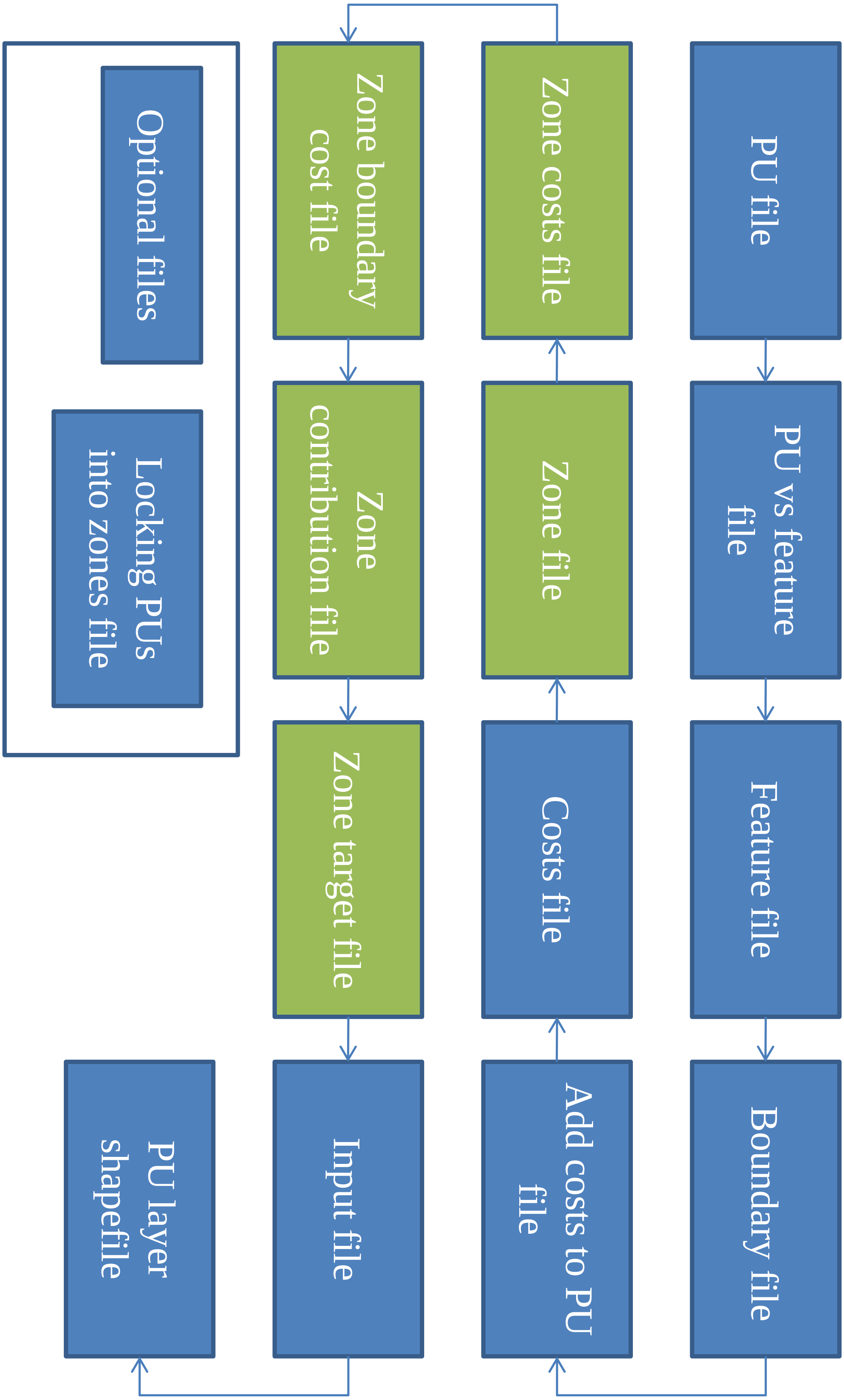


Figure 3.2: The files required for a Marxan and Marxan with Zones analysis in the order they should be created. Green boxes are files that are not required when using Marxan for analysis.

In Marxan with Zones a zone boundary cost can be used, which tells the program how to arrange the zones in relation to each other. For example, a protective buffer could be created between an unprotected and a protected zone using a partially protected zone.

Costs

This file contains the costs associated with each planning unit. This could be the area covered by the planning unit or other costs such as the cost of buying the planning unit or the amount of money lost when something cannot occur in it. In Marxan with Zones multiple cost data can be applied to planning units. Costs can be applied differently in each zone. For example, in a protected zone where fishing was prohibited fishery costs would be applied, whereas in an unprotected zone where all activities can occur the fishing costs would not be applied.

Feature file

The occurrence of habitats and species to be targeted needs to be spatially mapped to be included in Marxan and Marxan with Zones. Each habitat or species, which are commonly called conservation features, can have a target associated with them. This can be proportion or a numerical value that is part of the amount contained within the planning area. If species A occurred in ten planning units in the area and the target for protection was set at 20%, to meet this target Marxan or Marxan with Zones would be set a target of two or a proportion of 0.2. Each conservation feature can have a separate target or an overall target for all conservation features can be set.

Input file

The Marxan input file sets up the main parameters, which include which outputs Marxan should produce, the input files, the annealing parameters including number of iterations, and general parameters including how many repetitions Marxan should run, the size of the boundary length modifier and what proportion of planning units are in the initial reserve system. In Marxan with Zones this file also includes information on which zone is the available zone, which is the unprotected zone.

Planning units

To use Marxan and Marxan with Zones the planning area must be broken into planning units. These can be any size or shape. They can be regular shapes or areas of habitat. Hexagons are commonly used because they produce areas with reduced boundary size compared to area. Planning unit size can affect Marxan outputs (Nhancale and Smith 2011). The planning units are assigned costs and the amount (area covered or number of occurrences) of the features to be conserved.

Marxan with Zones requires information of the name of the zones used in the analysis to which it can assign the planning units. Marxan and Marxan with Zones can set targets separately for each zone. If the target for inclusion for the protected zones is 20% for a conservation feature, and there are three zones, an unprotected zone, a partially protected zone and a fully protected zone, 10% could be set as a target for the partially protected zone and 10% for the fully protected zone.

Marxan with Zones can allocate planning units to all zones, not just inside or outside a protected area as in Marxan. Therefore it needs to know which zones are protected and if including a planning unit in a certain zone if it will count towards the targets set. This could be useful if a marine plan had three zones with differing levels of protection and a highly sensitive species would only be protected in the most protected zone where activities that damaged it were excluded.

3.2.4 Output files produced by a Marxan or Marxan with Zones analysis

Marxan and Marxan with Zones produce two types of outputs. One output provides the number of times a planning unit is selected out of the total number of runs (selection frequency). For example if Marxan were set to run 100 times the maximum selection frequency would be 100. Planning units selected more than 50% of the time are considered important for meeting the objective Marxan was set (Ardron et al. 2008; Leslie et al. 2003). The total number of runs was set at 200 for each Marxan analysis in this thesis, because this allowed Marxan or Marxan with Zones to fully explore the potential configurations available. Marxan and Marxan with Zones also produce a potential reserve configuration (best output) that meets the objectives set for the lowest total score out of the ’n’ runs. This does not mean it is the best solution but should be seen as a good solution and it is likely to be slightly better than many other solutions.

Marxan and Marxan with Zones produce various output files to describe the results of an analysis. They produce a table for each run, which lists all the PUs selected. Marxan and Marxan with Zones generate a table showing which zone each planning unit is assigned to across all of the runs. The data within this file is commonly called the summed solution. This information indicates how important each PU is for creating an efficient reserve system. A PU selected over 70 percent of the time is likely to be required for a representative/efficient reserve system (Ardron et al. 2008; Ball et al. 2009). Selection frequency is referred to as a proportion of 1. If a PU is selected for the reserve zone in half of the runs, it will have a selection frequency value of 0.5.

Selection frequency is linked to the concept of irreplaceability (Ardron et al. 2008; Leslie et al. 2003). The concept of irreplaceability has developed over the previous 20 years. Pressey et al. (1994) defined it as the percentage of times a PU occurs in the range of possible representative reserve systems. This can be calculated with small datasets but because large datasets have many potential solutions its use is restricted because of the time it would take to calculate. Ferrier (2002) created a statistical approach for predicting the irreplaceability of sites within larger datasets. This technique calculates the irreplaceability of a site for single or multiple features. This technique can also be applied after a site change has been made to a network of protected areas because site irreplaceability can change when a site has been added or removed.

Leslie et al (2003) evaluated irreplaceability as how many times a PU was chosen in a simulated annealing exercise. They concluded that an analysis on selective frequency can be used to prioritise areas which contribute to conservation goals. Although selection frequency is not as robust an indication as irreplaceability, because it only uses the current set of runs not all representative networks, it is still a useful measure of the importance of a site to meeting conservation goals.

3.2.5 How the Zonae Cogito program improves Marxan and Marxan with Zones use

Zonae Cogito is a program that provides an user-interface for Marxan and Marxan with Zones (Segan et al. 2011). It makes using these programs more intuitive and allows, once the files have been set up, for non-technical (not trained in GIS) personnel to produce marine plans. Zonae Cogito shows Marxan outputs within the same window as the input file is manipulated in. This program produces GIS shapefiles of the outputs to allow for quick and easy further investigation of the files produced. This program performs statistical analysis of the outputs produced (dendograms and 2-dimensional plots) to investigate the similarities of the different outputs. A wide spread of outputs demonstrates that the program is exploring a wide variety of solutions.

In this chapter the methodology used in the thesis has been described. In the next chapter the rationale for each of the case studies is demonstrated and the data used in the data analysis chapters are described.

Chapter 4

Case studies: Lyme Bay, Sound of Mull and East Channel

4.1 Introduction

In this chapter the three case study areas: Lyme Bay, situated off the south west coast of England; Sound of Mull (SoM), situated off the west of Scotland and East Channel, situated off Southern England are presented. The case study areas were chosen because they are contrasting sites; in each of the three areas a different range of activities occur and they offer a range of scales from the small-scale local plan to the regional.

4.2 Why the case study sites were chosen

4.2.1 Data availability

The case study areas had significant data resources which allowed the use of site selection approaches and outputs. There were a variety of data available for the Lyme Bay case study site, including three resolutions of substrate data, all suitable for use in site selection tools. Socioeconomic data were also accessible in the correct file format.

A marine spatial plan had recently been produced for the SoM, this meant that various data layers, which the planners were happy to share, were readily available. These data layers were mostly in a suitable format for use in site selection software and had already been digitised into ArcGIS files.

There were two data layers available for the East Channel area which could be used to compare different levels of confidence when creating a marine protected area network. The data layers were in the correct format for use in site selection tools and were available as ArcGIS files.

Other case study site areas were considered (Falmouth and Plymouth Sound) but data layers were not available that were suitable for use in site selection tools.

4.2.2 Scale

The three case study sites vary in size, from the smallest site (SoM) which has less than 1% of the area compared to the largest site (East Channel). The Lyme Bay site has approximately 20% of the area when compared to the East Channel site (Table 4.1). Using sites with different areas, allowed the evaluation of how effectively Marxan and Marxan with Zones created marine plans at varying scales.

4.2.3 Conservation importance

Each of the sites had species and habitats of conservation importance. The SoM had no areas set aside for conservation, although in the the SoM MSP (SSMEI 2010*b*), which is non-statutory, there is a key recommendation that areas where sensitive species occur should not be fished using mobile fishing gear. The other two sites have areas protected for conservation with more areas being recommended for designation (Table 4.1). All of the study sites have designated wrecks. Each of the sites has activity occurring within it which may damage sensitive habitats and unprotected wrecks. The Lyme Bay and SoM case study sites were used to evaluate the current threats from human activity to marine habitats.

4.2.4 Human activities

The case study areas had a wide variety of human activities occurring within them (Table 4.1). By using case studies with many human activities a range of potential impacts were assessed. It also allowed the production of marine spatial plans that had many competing activities.

Table 4.1: Case study site information on scale, main human activities, species/habitats of conservation importance, areas of protection for conservation and wrecks. Table continued on next page

Case study	**Area (km^2)**	**Main human activities occurring in/on the marine environment**	**Benthic species/habitats of conservation importance**	**Conservation designations**
Sound of Mull	110	Tourism - mainly diving, angling and wildlife watching Fisheries – lobster, prawn, queen scallop, scallop, velvet crab Aquaculture -salmon	*File shell beds* (*Limaria hians*) UKBAP Priority Habitat *Horse mussel beds* UKBAP Priority Habitat OSPAR List of Threatened and/or Declining Species and Habitats (entire OSPAR area) Horse mussel beds can also be key features of habitats listed in Annex I of the Habitats Directive *Maerl (calcified red seaweed)* UKBAP Priority Habitat, Listed in Annex I of the Habitats Directive, OSPAR List of Threatened and/or Declining Species and Habitats (Region III – Celtic Sea) *Seagrass (Zostera sp)* UKBAP Priority Habitat, OSPAR List of Threatened and/or Declining Species and Habitats (declining in Region II – North Sea and Region III – Celtic Sea, and threatened in Region V – Wider Atlantic) *Sea pen and burrowing megafauna communities* OSPAR List of Threatened and/or Declining Species and Habitats (Region II – North Sea, Region III – Celtic Sea) The deep water mud on which these communities are found is a UKBAP Priority Habitat and is listed in Annex I Habitats Directive: Large shallow inlets and bays	2 wrecks designated under the Protection of Wrecks Act 1973
Lyme Bay	2460	Tourism - mainly diving, angling and charter boats Fisheries – mainly scallops, trawling and static gear – crab, lobster and whelks	*Eunicella verrucosa* Globally vulnerable on the IUCN Red List UKBAP Priority Species Nationally scarce species Protected under Schedule 5 of the Wildlife and Countryside Act 1981 Species of principal importance for the purpose of conservation of biodiversity under the Natural Environment and Rural Communities Act 2006 *Lyme Bay reefs* Habitats Directive Annex 1 – "habitats where animal and plant communities develop on rock or stable boulders and cobbles", and include examples of species that are nationally rare (sunset coral, *Leptopsammia pruvoti*), ecologically important (ross coral, *Pentapora fascialis*) and at the edge of their northern and eastern range (the pink sea fan, *Eunicella verrucosa*). *Seagrass(Zostera sp)* Same as above	3 designated Marine Conservation Zones 5 Recommended Marine Conservation Zones 2 Special Protection Areas 6 Inshore Special Areas of Conservation 2 wrecks designated under the Protection of Wrecks Act 1973

Table 4.1: Case study site information on scale, main human activities, species/habitats of conservation importance, areas of protection for conservation and wrecks.

Case study	**Area (km^2)**	**Main human activities occurring in/on the marine environment**	**Benthic species/habitats of conservation importance**	**Conservation designations**
East Channel	12620	Shipping – up to 400 ships/day Tourism – mainly yachting and angling Fisheries – *Shellfish* Lobster, edible crab, spider crab, velvet swimming crab, prawns, oysters, scallops, whelks, clams, periwinkles, cockles, mussels and cuttlefish *Finfish* Cod, whiting, Dover sole, plaice, lemon sole, brill, turbot, sea bass, black bream, red mullet, baillon's wrasse, mackerel, herring, sprat, salmon, sea trout, eel, thornback ray and skate 20 areas licensed for aggregate dredging 3 licensed wind farm areas Military practice areas	*Eunicella verrucosa* — pink sea-fan Same as above *Blue mussel beds (Mytilus edulis)* UKBAP Priority Habitat OSPAR List of Threatened and/or Declining Species and Habitats (Region II – Greater North Sea, and Region III – Celtic Sea) Blue mussel beds can also be key features of habitats listed in Annex I of the Habitats Directive *Maerl* Same as above *Seagrass(Zostera sp)* Same as above *Ross worm reefs(Sabellaria spinulosa)* UKBAP Priority Habitat OSPAR List of Threatened and/or Declining Species and Habitats (Region II – North Sea, Region III – Celtic Sea) Listed in Annex 1 of the Habitats Directive: Reefs, and as a feature of Sandbanks which are covered by seawater at all time; Large shallow bays and inlets; and Estuaries	4 designated Marine Conservation Zones 12 recommended Marine Conservation Zones 6 recommended reference areas 2 Special Areas of Conservation with marine components 5 Special Protection Areas with marine components 10 wrecks designated under the Protection of Wrecks Act 1973

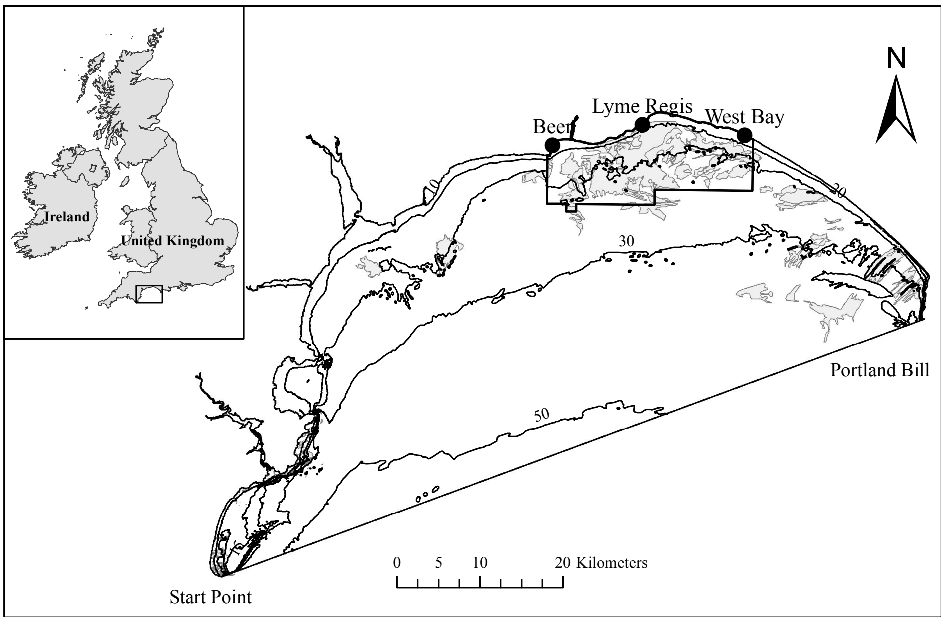


Figure 4.1: Location of Lyme Bay within South West England, with the closed area shown (heavy straight black line), bathymetry, the three ports nearest closed area and rock and mixed gravel substrate (light grey). The closed area is closed to mobile bottom fishing gear (which includes dredging)

4.2.5 Current marine planning activities

Each of the areas had different planning challenges, in Lyme Bay there has been conflict for many years between the scallop fishers and other fisherman, and conservationists. In the Sound of Mull there is a balance required between development (infrastructure and aquaculture) and the protection of the natural environment on which the tourism of the area relies. The East Channel area has many activities competing for space, some of which conflict, including aggregate dredging, fishing, wind farms and recreational boating.

4.3 Lyme Bay

Lyme Bay covers approximately 2460km^2 and is in the western channel area of the United Kingdom (Figure 4.1). The case study area and data described in this section will be used in chapter 5 to assess the resolution and complexity of data required to protect marine biodiversity using currently available data and in chapter 6 to determine how to integrate conservation and socioeconomic data and objectives in a marine plan.

Lyme Bay has been the subject of several projects to study the importance of recreation and fishing activities to the local economy (for example, Stevens et al. (2006, 2007); Rees et al. (2010)) and the regional Marine Conservation Zones project (Finding Sanctuary 2007-2011) collected fishing and recreational activity data. This provided high quality socioeconomic data to apply with the detailed ecological data.

In Lyme Bay there is conflict between the fishing, recreation and conservation sectors. Consequently it makes this area particularly useful to investigate the compromises necessary to create a marine plan that will balance conservation, fishing and recreation objectives. The controversy concerns the impact of bottom fishing, using mobile or towed gear, on the high biodiversity reef areas (Lart et al. 1993; Stevens et al. 2007).

The Devon Wildlife Trust has campaigned since 1992 to protect the reefs in Lyme Bay which are the habitat of the protected species *Eunicella verrucosa* (pink sea fan). In 2002 the Devon Wildlife Trust (DWT) came to a voluntary agreement with the local fishing community to protect two areas of reefs covering approximately 5km^2. The agreement broke down in 2005 when evidence was found to suggest that dredging had occurred within the agreed protected areas (Devon Wildlife Trust 2007). In July 2008 the UK government designated an area which is closed to bottom dredging of 130km^2 focussed around the most important rocky reef area in the bay (Figure 4.1) to protect the pink sea fan and its cobble reef habitat. This led to further animosity between fishers and conservationists (Fleming and Jones 2012).

Fishing is a culturally important activity in Lyme Bay and the combined fisheries were estimated to have a value of £8 - 11.5 million per year in 2006 (Stevens et al. 2007). Recreation and leisure activities contribute approximately £18 million per year to the Lyme Bay economy (Rees et al. 2010) demonstrating its importance to the region.

4.3.1 Data layers

Environmental data

High resolution biotope and substrate data

The high resolution biotope and high resolution substrate data were obtained from the Devon

Biodiversity Records Centre. The high resolution biotope layer contained 22 biotopes (Figure 4.2 and Table 4.2) and was considered to have the highest complexity because of the increased amount of information considered in this classification. 12 of the biotopes have been grouped into four sets under a single biotope code:

Set 1

SS.SSa = (i) Fine sand and (ii) Mud;

Set 2

SS.SMx.CMx = (iii) Sublittoral mixed sediment and (iv) Sublittoral mixed sediment. Clay balls, coarse gravel and sand;

Set 3

LS.LMp.LSgr.Znol = (v) Mudflat & sandflat or seagrass bed. Zostera or mussel bed. LMS; (vi) Seagrass bed. Dense Zostera bed on mud/muddy sand with Cerastoderma, Arenicola, Macoma balthica, Enteromorpha. LMS.Zos.; (vii) Seagrass bed. Dense Zostera on soft sandy mud. LMS.Zos; (viii) Seagrass bed. Sparse Zostera on mud or muddy sand. LMS.Zos;

Set 4

SS.SMp.SSgr.Zmar = (ix) Extensive Zostera marina bed in Torbay. Partially exposed on lowest spring tides.; (x) Zostera marina bed. (xi) Zostera marina bed. Substrate is muddy sand with shells and pebbles. and (xii) Zostera marina beds on lower shore or infralittoral clean or muddy sand.

The high resolution substrate layer (Figure 4.3) contained seven substrate types and was less complex than the biotope data. These data layers were created from a variety of data sets but the majority of the data came from a 2005 grab survey with spot samples obtained at 133 sites taken with a resolution (Table 4.3) from 0.4km to 4.7km, with an average resolution of 3.5km (Devon Wildlife Trust 2005).

EUNIS data

The European Nature Information System (EUNIS) habitat classification is a hierarchical pan-European system that has been created to ensure that habitat names are uniform across Europe. EUNIS data were produced using a predictive model by the Joint Nature Conservation Committee MESH (Mapping European Seabed Habitats) project, using substrate, depth, tidal bed stress, light reaching seabed and wavelength data at a variety of scales and has been modelled on to 1.85km (1 nautical mile) grid (Coltman et al. 2008). The data used here for the medium resolution substrate data were EUNIS level 3, where substratum, depth and incident energy were combined to predict the distribution of broad scale habitats, and had 16 substrate types (Figure 4.4).

UKSeaMap

The UKSeaMap substrate dataset was downloaded from the Joint Nature Conservation Committee website(accessed 5 November 2009) for use as the low resolution substrate data and has 13 substrate types. This dataset was the least complex because it took into account the lowest resolution data and considered the least amount of information. This dataset is an interpreted broad scale map of the dominant seabed features and is based on geological, physical and hydrographical data (Connor et al. 2006). The data are based on an approximate grid of 2km but some of the underlying data are on coarser grids of 7 or 12km (Table 4.3). A new version of UKSeaMap was released in 2010 which used higher resolution data but for the purpose of the Lyme Bay case study, which is to explore the use of data with different resolutions the 2006 release is most appropriate. All mentions of UKSeaMap in chapter 5 refer to the UKSeaMap 2006 data (Figure 4.5).

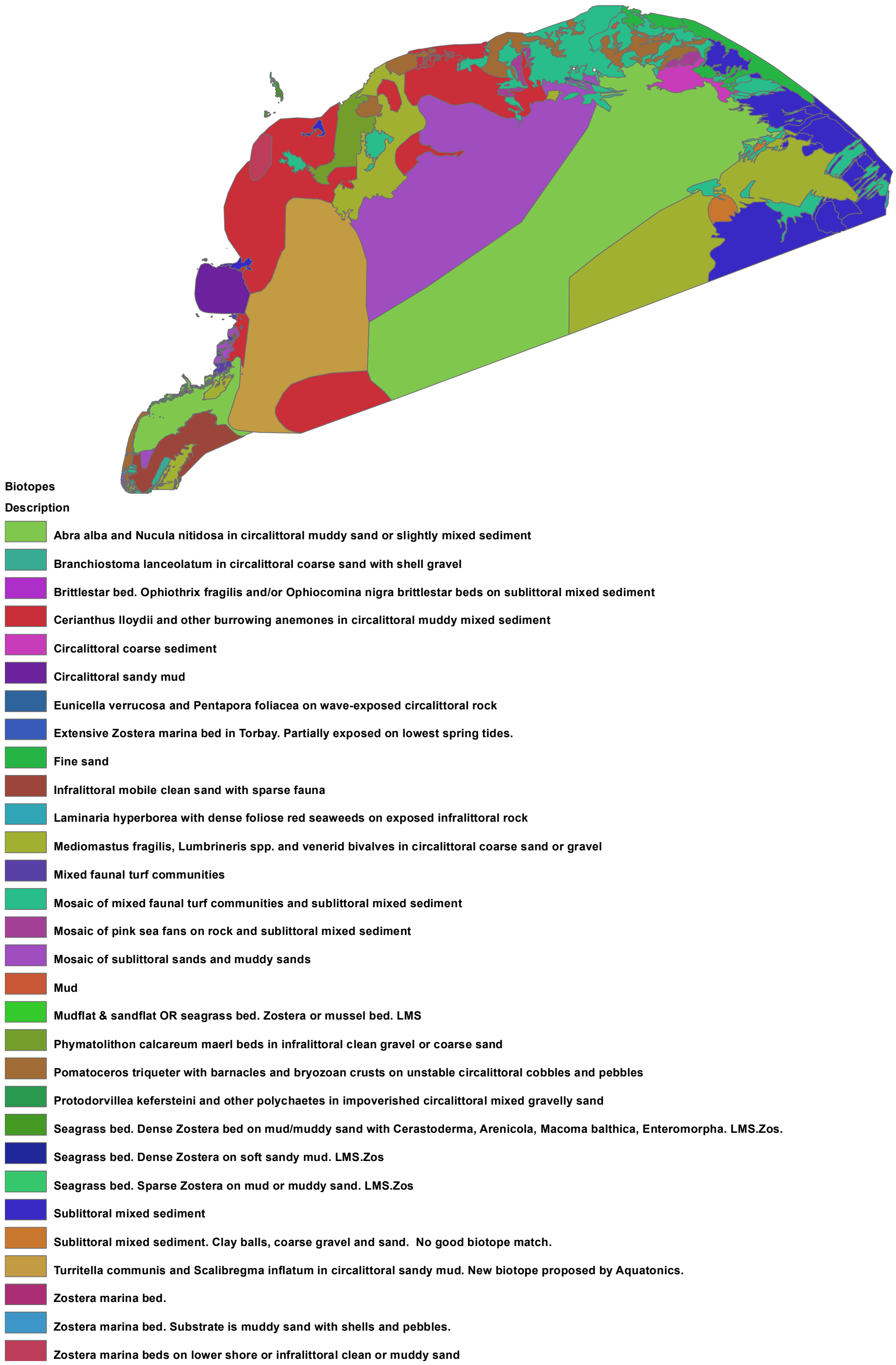


Figure 4.2: High resolution biotopes used in the Lyme Bay analysis. Data source Devon Biodiversity Records Centre.

Table 4.2: Description of the biotopes used in the study

Biotope	**Description**
CR.HCR.Xfa	Mixed faunal turf communities
CR.HCR.Xfa and SS.SMx.CMx	Mosaic of mixed faunal turf communities and sublittoral mixed sediment
CR.HCR.XFa.ByErSp.Eun	*Eunicella verrucosa* and *Pentapora foliacea* on wave-exposed circalittoral rock
CR.HCR.XFa.ByErSp.Eun and SS.SMx.CMx	Mosaic of pink sea fans on rock and sublittoral mixed sediment
IR.HIR.KFaR.LhypR	*Laminaria hyperborea* with dense foliose red seaweeds on exposed infralittoral rock
SS.SCS.CCS	Circalittoral coarse sediment
SS.SCS.CCS.Blan	*Branchiostoma lanceolatum* in circalittoral coarse sand with shell gravel
SS.SCS.CCS.MedLumVen	*Mediomastus fragilis*, *Lumbrineris spp*. and venerid bivalves in circalittoral coarse sand or gravel
SS.SCS.CCS.Pkef	*Protodorvillea kefersteini* and other polychaetes in impoverished circalittoral mixed gravelly sand
SS.SCS.CCS.PomB	*Pomatoceros triqueter* with barnacles and bryozoan crusts on unstable circalittoral cobbles and pebbles
SS.SMp.Mrl.Pcal	*Phymatolithon calcareum* maerl beds in infralittoral clean gravel or coarse sand
LS.LMp.LSgr.Znol	*Zostera noltii* beds in littoral muddy sand
SS.SMp.SSgr.Zmar	*Zostera marina/angustifolia* beds on lower shore or infralittoral clean or muddy sand
SS.SMu.CsaMu	Circalittoral sandy mud
SS.SMu.CSaMu.TcomSinf	*Turritella communis* and *Scalibregma inflatum* in circalittoral sandy mud. New biotope proposed by Aquatonics.
SS.SMx.CMx	Circalittoral mixed sediment
SS.SMx.CMx.ClloMx	*Cerianthus lloydii* and other burrowing anemones in circalittoral muddy mixed sediment
SS.SMx.CMx.OphMx	Brittlestar bed. *Ophiothrix fragilis* and/or *Ophiocomina nigra* brittlestar beds on sublittoral mixed sediment
SS.SSa	Sublittoral sands and muddy sands
SS.SSa and SS.SMu.CSaMu	Mosaic of sublittoral sands and muddy sands
SS.SSa.CMuSa.AalbNuc	*Abra alba* and *Nucula nitidosa* in circalittoral muddy sand or slightly mixed sediment
SS.SSa.IFiSa.IMoSa	Infralittoral mobile clean sand with sparse fauna

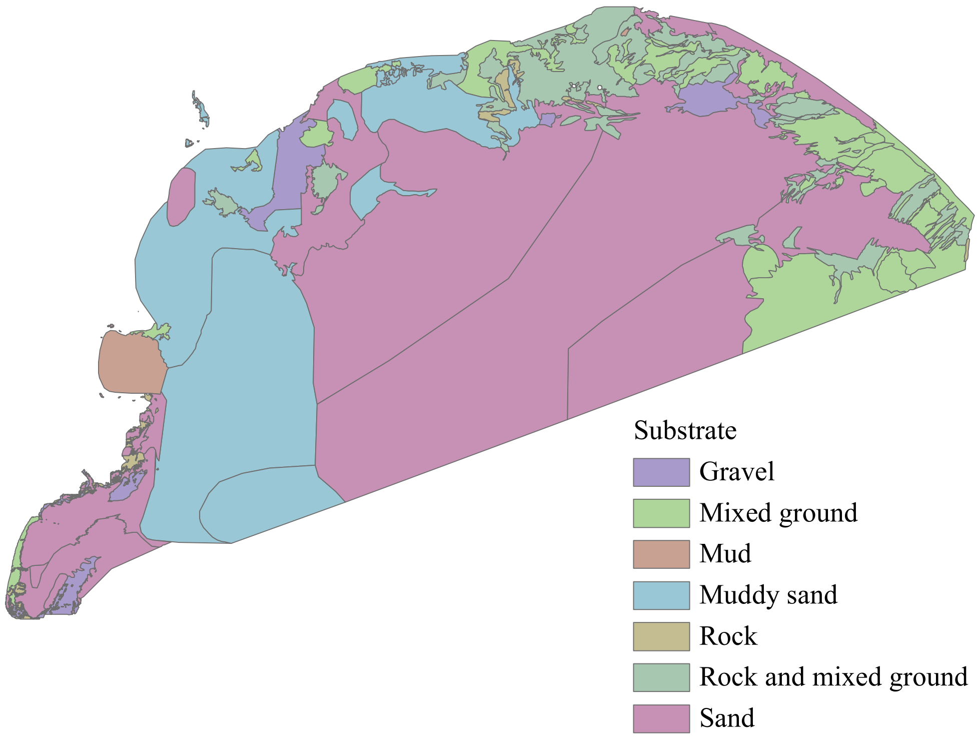


Figure 4.3: High resolution substrate Lyme Bay data. Data source Devon Biodiversity Records Centre.

Table 4.3: The type, range and source of the data layers used in the Lyme Bay study

Layer name	Data type	Range	Source
High resolution biotope	JNCC biotopes	0.4km to 4.7km with an average resolution of 3.5km.	Devon Biodiversity Records Centre
High resolution substrate	JNCC substrate	0.4km to 4.7km with an average resolution of 3.5km.	Devon Biodiversity Records Centre
Medium resolution substrate	European Nature Information System (EUNIS) substrate Level 3	Data used ranges from 1-2km to 9km grid, some modelled. The data is interpolated to a 1.85km grid	JNCC MESH project. EUNIS data
Low resolution substrate	UKSeaMap substrate	Basic grid 2km but some of the underlying data on grids of 7 or 12km	Joint Nature Conservation Committee website (accessed 5 November 2009)
No data	None	N/A	N/A

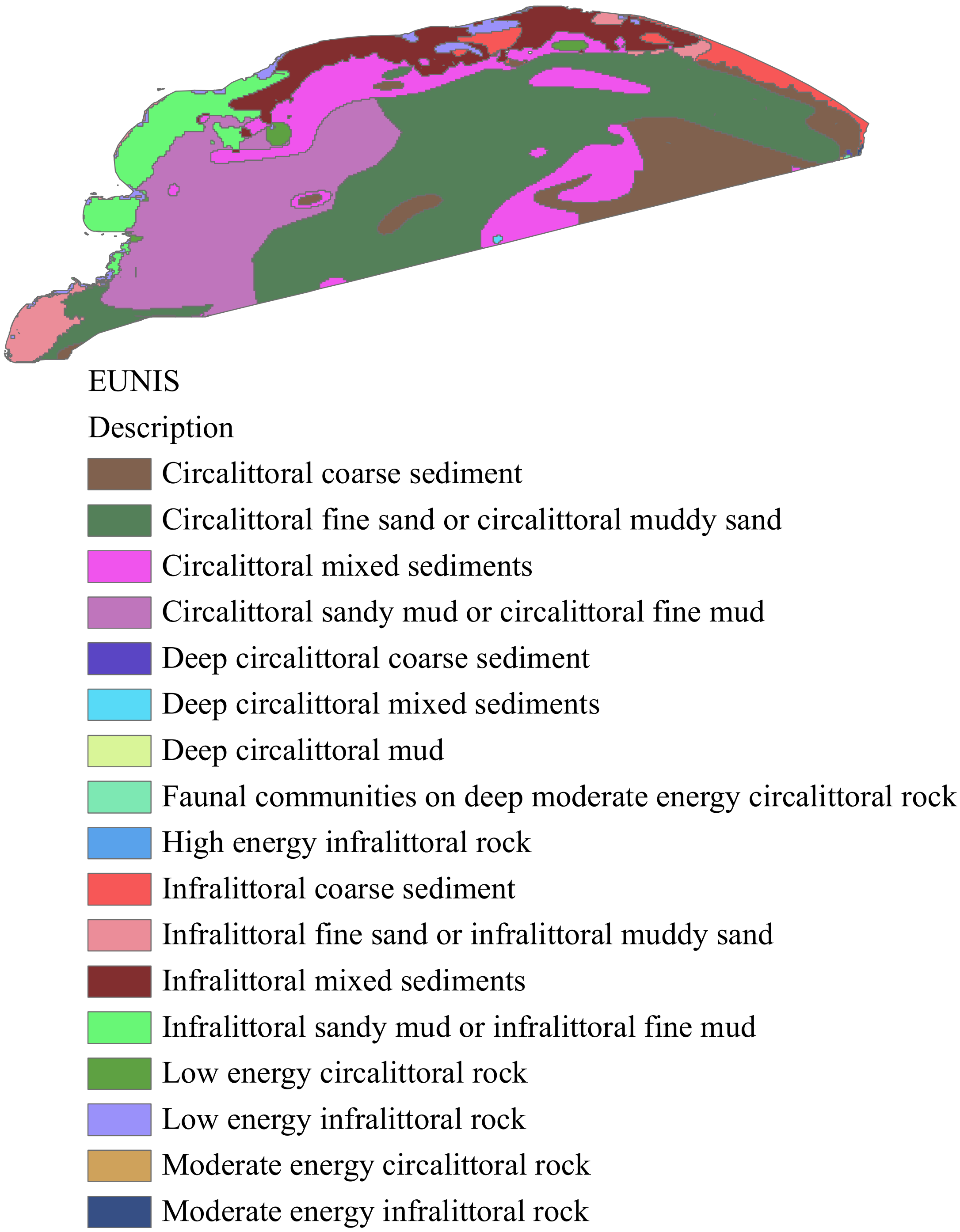


Figure 4.4: Medium resolution European Nature Information System (EUNIS) data used in the Lyme Bay study

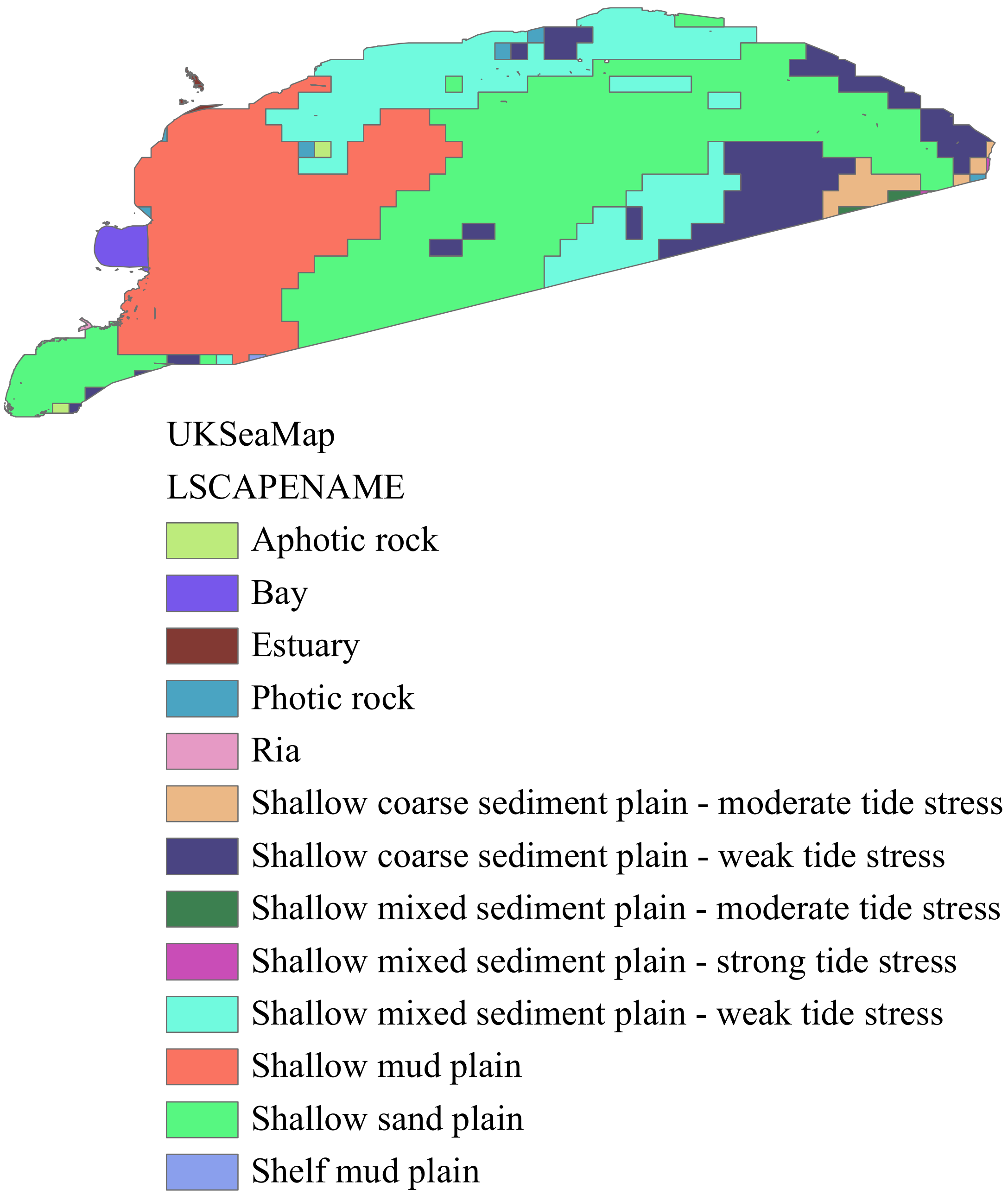


Figure 4.5: The low resolution UKSeaMap data used in the Lyme Bay study

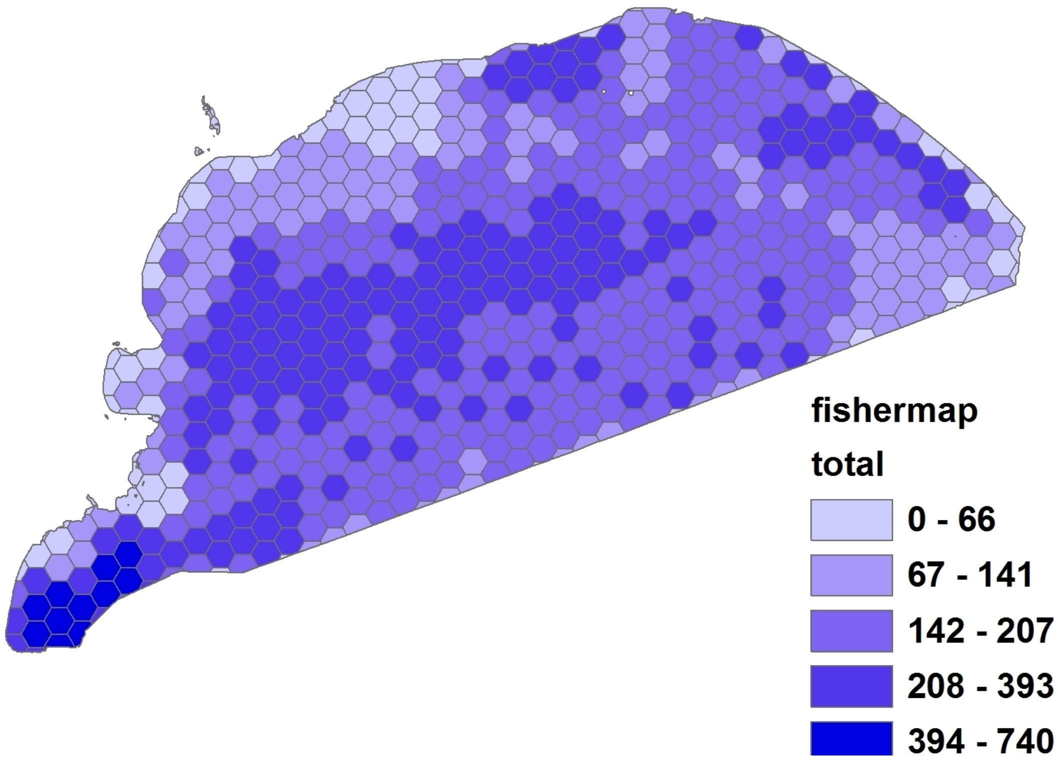


Figure 4.6: The frequency of fishing activity in Lyme Bay from the Fishermap data.

Socioeconomic data

Fishing activity data - Fishermap

The fishing activity data layer used was collected by the Finding Sanctuary Marine Conservation Zone Project (www.finding-sanctuary.org/) for use in the creation of a Marine Conservation Zone network in the seas around the South West region. Studies have shown that fishing data contributed by fishers are robust (Hoare et al. 2011; Volstad et al. 2011). These data, called Fishermap, were collected by interviewing fishermen on where they fished, the activity they were doing and the frequency of use of each area. Information on five types (potting, netting, line fishing, dredging and bottom dredging) of fishing was recorded in the study area. The frequency of use polygons were combined, for each of the fishing activities, into the planning unit hexagons to give a frequency of use for each planning unit (Figure 4.6). For further information see the Fishermap Final report (des Clers et al. 2008).

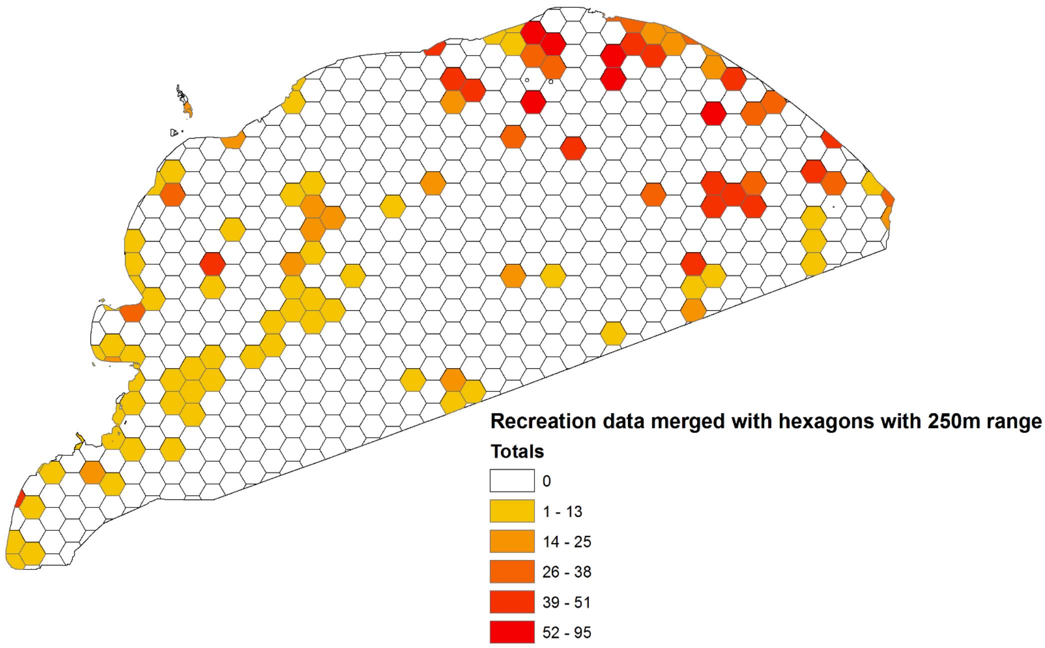


Figure 4.7: Recreation frequency data converted into planning unit hexagons with 250m buffer used in the Lyme Bay study from data published in Rees et al. (2010).

Recreation data

The recreation data collection method is described in fully Rees et al. (2010). In Lyme Bay 171 sites known to be used by the four groups surveyed: dive businesses, dive clubs, sea anglers and charter boat operators, were identified. The sites were categorised as reef, wreck or shore. Respondents were asked to identify sites they visited in 2008 and how often they visited, 1 = rarely visited to 5 = frequently visited. This data were combined into one feature for the analysis in this thesis. In ArcGIS using a 250 metre buffer this feature was combined with the planning unit hexagons to give a frequency of use for each of the hexagons (Figure 4.7). The dataset does not cover all of the recreational activities that occur in Lyme Bay, for example, the activities of divers or anglers who use their own boats may not have been recorded.

4.4 Sound of Mull

The Sound of Mull (SoM) is between mainland western Scotland and the Isle of Mull (Figure 4.8) and is approximately 110km^2. The case study area and data described in this section will be used in chapter 6 to determine how to integrate conservation and socioeconomic data and objectives in a marine plan. The Sound is relatively sheltered. It has many small bays and inlets; in the centre and at either end the narrow channel is wider. The Sound has a deep channel running through it, that is between 40-140 metre depth. The seabed slope to the central channel is variable with steep underwater cliffs in the east, whereas in other areas there are tidal flats. The deep, sheltered channel acts as major shipping route from North Argyll to the Outer Hebrides and the Atlantic. The Sound of Mull has a small resident population (approximately 2200 in the 2001 census) but is an important tourist area. The economy of the Island of Mull is based on tourism, forestry, fisheries and aquaculture with the public sector being the largest employer.

The Sound of Mull and its coastline have many important and protected species and their habitats, including haul out areas for the common seal, seagrass beds, maerl and minke whale. It is also an important area for many seabirds.

Sound of Mull Marine Spatial Plan

The Sound of Mull marine spatial plan was set up as part of the Scottish Government's Scottish Sustainable Marine Environment Initiative (SSMEI). Four pilot projects were conducted under the SSMEI, Berwickshire, Firth of Clyde, Shetland and Sound of Mull, which were set up to inform future marine policy. The Sound of Mull MSP was an example of a local level plan.

An assessment of the activities that take place within the SoM took place in 2007-2009 (Magill et al. 2009). Known sites of historic or conservation importance were included within the plan.

The area was split into six areas: North, South, Loch Aline, Inninmore, Tobermory and Craignure (Figure 4.9). Each area was given a list of priorities and key policies to guide development (Table 4.4). The MSP is a voluntary plan and its recommendations are advisory, in part because planning controls only extend to low water spring tides. The marine spatial plan will be used as guidance by local authorities and to assist the Scottish Government in developing future marine spatial plans.

4.4.1 Data layers

Environmental data

Biotope data

The biotope data layer is taken from a data layer that covers almost all of the Highland, Hebrides and Orkneys (Figure 4.10). The data used to build the modelled data are:
(i) raster bathymetry data with 10 metre contours that were gridded to 250 metre grids and classified into six depth classes;
(ii) topographic data that were derived from the gridded bathymetric data to show the locations of steep coasts and submarine features, for example, sea lochs;
(iii) exposure classes were derived from data on tidal currents, wave heights, orientation with land and depth. Exposure had three categories: low, moderate and high;
(iv) seabed sediment data were on a 250 metre grid and
(v) some species data were used but these did not have a complete coverage. There was a higher coverage in nearshore areas, for example, rocky habitats and sea lochs.

Each of the five data layers was rasterised (turned into a GIS raster layer) with a grid of 250 metres. The exposure, depth and sediment layers were combined to produce a single raster layer. Each combination of exposure class, depth class and sediment type was given a numeric code. Each of the codes was then linked to a likely biotope. This was then adjusted for the likely occurrence of habitats in certain geographic regions and tested against (if data available) biotopes known to occur in each pixel (Leakey 2010; Foster-Smith 2010).

Table 4.4: Key development objectives and policy guidance for each of the areas in the SoM marine spatial plan. Table continued on next page

Sub-area of Sound of Mull marine spatial plan	**Key development objectives and policy guidance**
North	Safeguarding of the shipping route and navigation aids which are present is highly important, given the level of daily boat traffic that transits the area. Also important for safeguarding are the many sites of important habitats and species. Discouraging mobile gear fishing in the known locations of sensitive marine species would help in this regard. The area surrounding the Stirks has been identified as an important local fishing ground and precedence to this activity should be acknowledged at this site. Given the variety of recreational activities present in the area, the development of more publicly accessible infrastructure would be desirable. The popular wreck dive sites could benefit from the installation of permanent mooring blocks and shot lines - to reduce damage to the wrecks which can be caused by repeated deployment and recovery of shot lines, and to allow easier diver access. Potential for expansion of the finfish farming operations at Bloody Bay and Fiunary, and the development of mainly medium-scale shellfish farming in several areas.
South	The most important priority here is to safeguard the shipping route and navigation aids which are present. There is a significant level of daily boat traffic, including lifeline local ferry services, which passes through the-area. The preservation of the historic features and the landscape settings, particularly of Torosay and Duart Castles is important, as these sites have significant visitor appeal and provide a valuable economic contribution to the local economy. Safeguarding of the many sites of important habitats and species. Discouraging mobile gear fishing from known locations of sensitive marine species. Public infrastructure allowing access to the Sound of Mull is lacking and developments which provide this should be encouraged. The development of an existing pier at Fishnish Bay would potentially allow for timber/ bulk cargo transfer from Mull, reducing impacts on roads in the region. The popular wreck dive sites could benefit from the installation of permanent mooring blocks and shot lines - to reduce damage to the wrecks which can be caused by repeated deployment and recovery of shot lines, and to allow easier diver access. Potential for the expansion of finfish operations in Fishnish Bay, and the development of new finfish and shellfish aquaculture sites.
Loch Aline	Loch Aline contains a number of internationally and nationally listed species and habitats, and nationally important historic sites which are priorities for safeguarding. The need to maintain navigational access for the ferry and locally-based boat and visitor traffic is important, as is effective management of the space in this confined sea loch. Improved infrastructure for recreational boat users would benefit this area by boosting visitor numbers. Potential for small-scale, discreetly-located shellfish farming
Inninmore	Safeguard the special landscape character, designated species and habitats, and historic features which are present in this area. Discourage fishing with mobile gear where File Shell beds are known to be present and in the vicinity of the protected wrecks and popular wreck dive sites.

Table 4.4: Key development objectives and policy guidance for each of the areas in the SoM marine spatial plan

	Encourage the installation of mooring blocks at popular dive sites in the area to prevent damage from repeated deployment of shot lines. Presumption against aquaculture development in this area to safeguard its special landscape character and value as a reserve of wild land
Tobermory	Safeguard landscape/ seascape setting, and built heritage around the foreshore of Tobermory township is of high importance as Tobermory is an important draw for visitors to the region. Safeguarding of the navigational routes and aids servicing the harbour is paramount. The development of a dedicated freight handling area would benefit multiple sectors, particularly fishing as the existing piers have limited access to road transport. Expansion of onshore and pontoon berth yachting facilities and MacBrayne's pier. Mobile gear fishing activity is discouraged around the southern end of Calve Island, where eelgrass beds, knotted wrack and maerl beds are known to be present to safeguard these sensitive marine habitats. Presumption against new Aquaculture developments, and expansion of existing developments to safeguard landscape and built heritage characteristics.
Craignure	Safeguard the navigation aids, infrastructure and ferry route associated with the Oban – Craignure ferry. Proposals located at the south end of Craignure Bay for development, or redevelopment of existing facilities that provide access and amenity for recreational boating users would be considered favourably. Presumption against any Aquaculture development in this Sub-area to safeguard navigation and amenity.

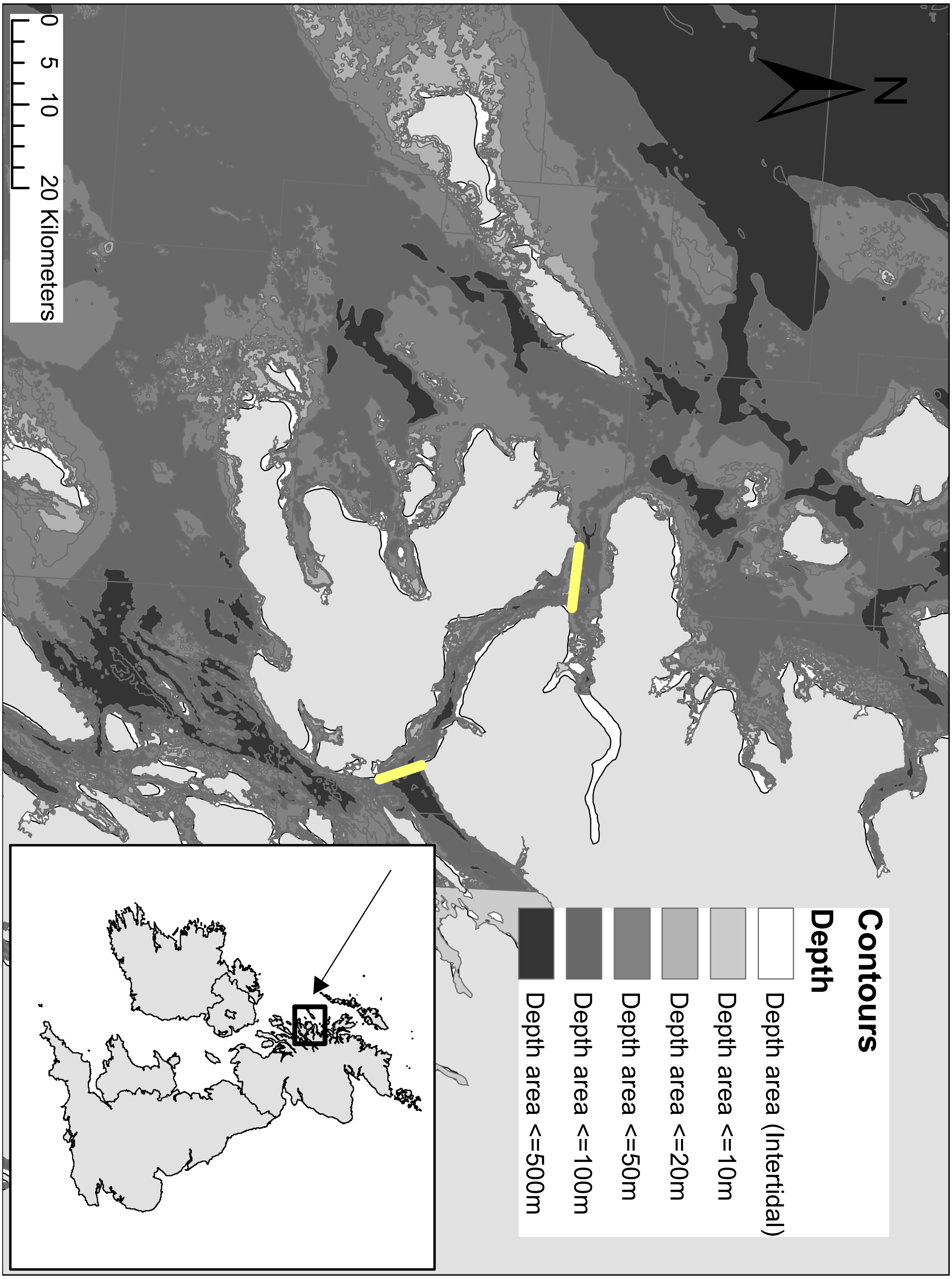


Figure 4.8: Sound of Mull case study area is shown within the two yellow lines with bathymetry shown in metres. In the right-hand figure the position of the Sound of Mull is shown on the west coast of Scotland.

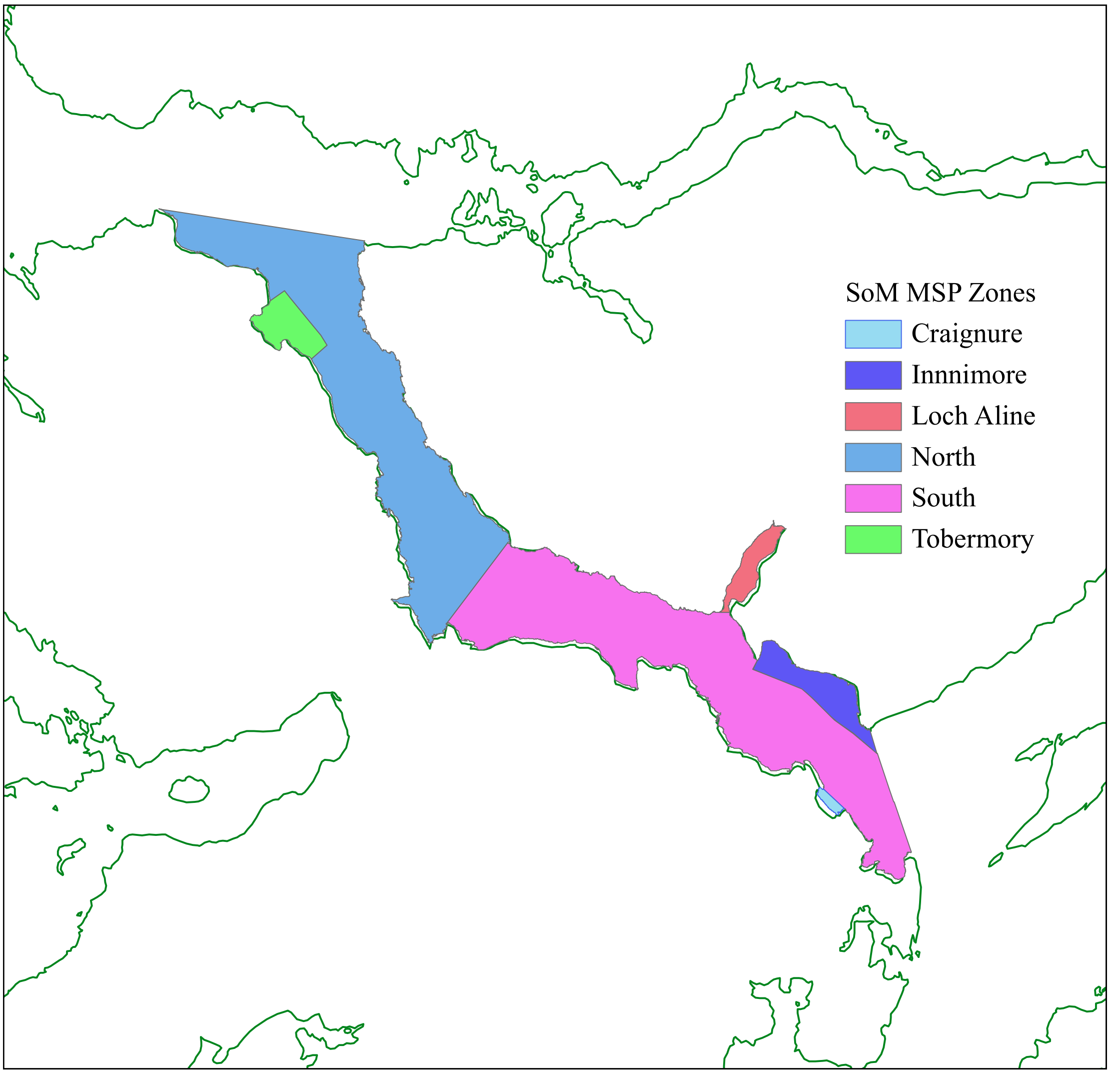


Figure 4.9: The Sound of Mull marine spatial plan with the six zones indicated. This study uses the same area as the Sound of Mull marine spatial plan.

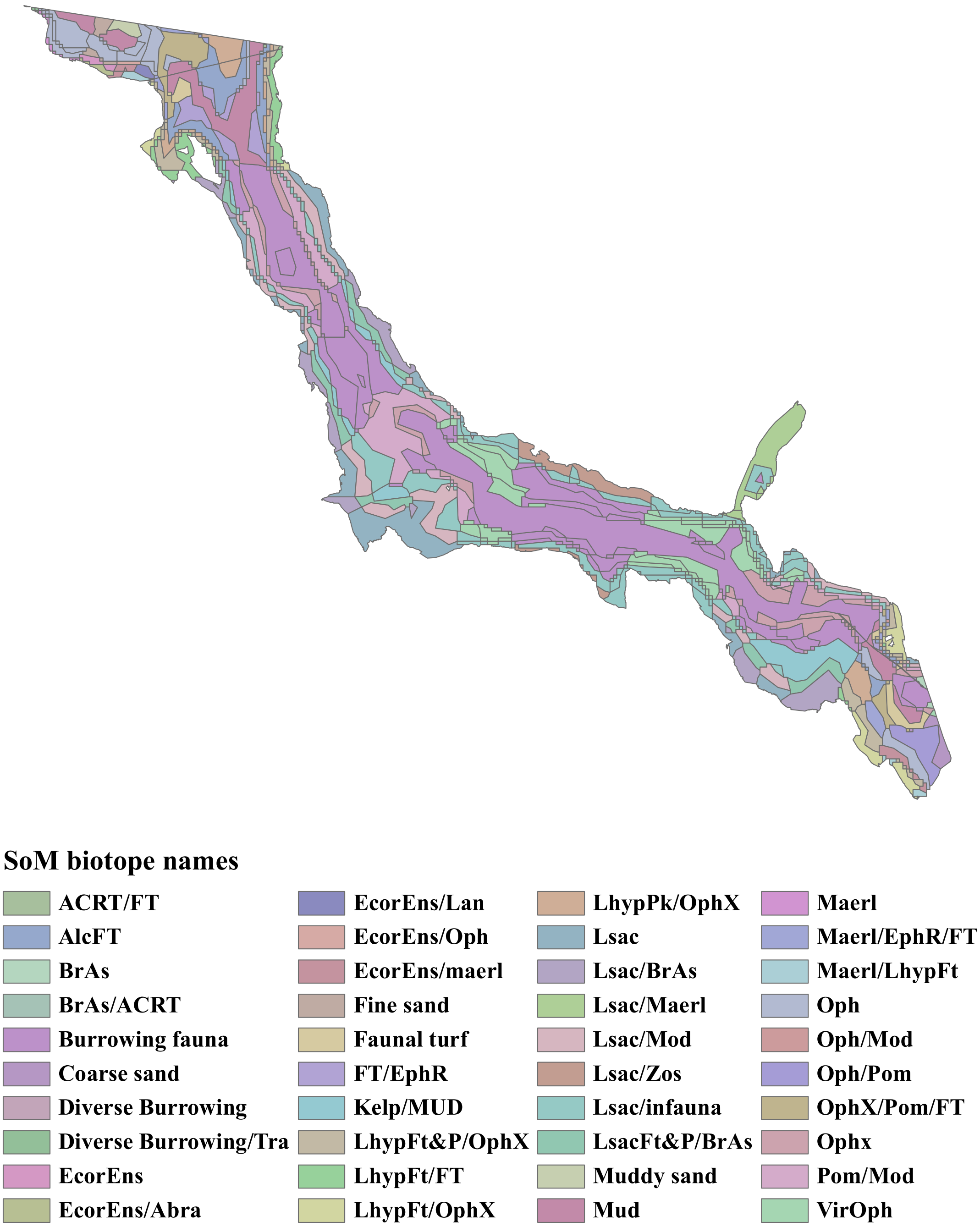


Figure 4.10: Biotopes found within the Sound of Mull study area from data published in Foster-Smith (2010)

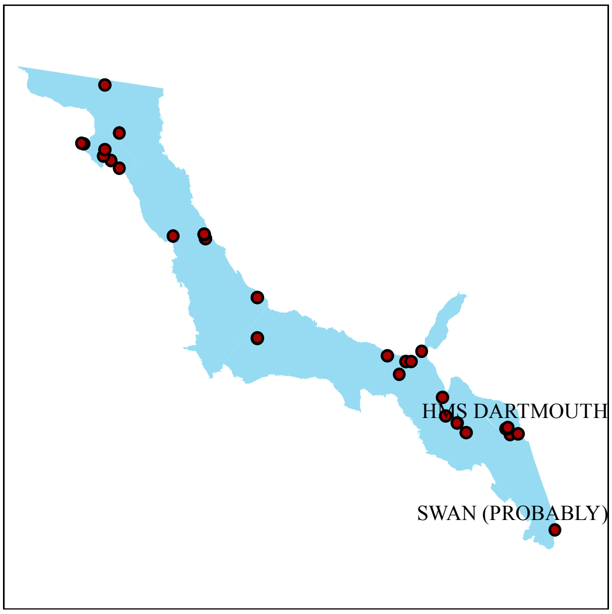


Figure 4.11: Position of the 44 wrecks within the Sound of Mull with the two protected wrecks highlighted

Socioeconomic and cultural data

Wreck position data

The Sound of Mull area has 44 known wrecks within it. Two wrecks, HMS Dartmouth and Swan, are protected by the Designation of Wrecks Act. The HMS Dartmouth is an English warship wrecked in 1690 and the Swan was wrecked with two companion ships in 1653. These wrecks are highlighted in Figure 4.11. Many of the wrecks within the Sound of Mull are popular dive sites, although the two protected wrecks require a license to dive on them.

Dive sites

The Sound of Mull is popular with divers because of its sheltered waters and many wrecks (Figure 4.12). Dive site data were digitised from advertised dive sites and from a popular dive site book Ridley (1998) by Sound of Mull marine spatial plan project staff. A study estimated that around 8000 dive days were taken within the SoM in 2007 (Magill et al. 2009). Magill et al. (2009) estimate that divers spend approximately £69 per person per day and that in 2007 the total value was £550,000. The estimated number of dive days was obtained by discussions with local dive and boat operators. It was not possible to get exact numbers of dive days because

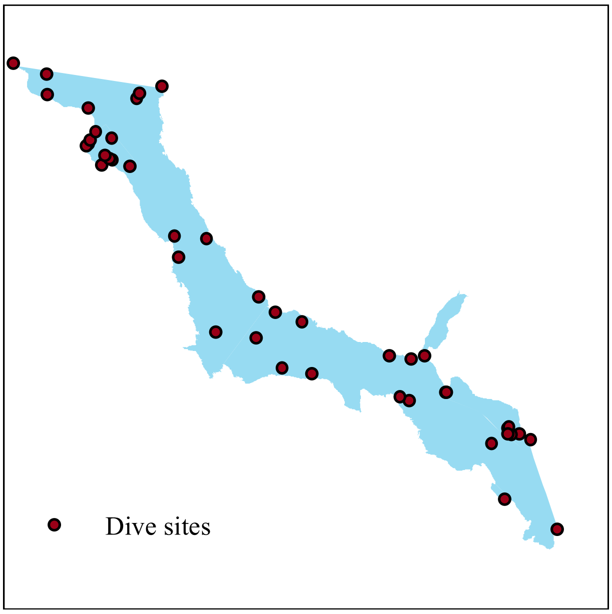


Figure 4.12: The location of the most popular dive sites within the Sound of Mull study area

not all divers use local charter boats or facilities but come from a wide area and may bring their own boats.

Skate angling areas

The common skate, *Dipturus batis*, is the main target species for sea angling within the SoM (Figure 4.13). A recent study estimated (Thorburn 2008) the economic value of the common skate fishery around the SoM and the Firth of Lorn was £292,500 annually to the local economy brought in by approximately 2000 anglers (Magill et al. 2009).

Fish farms and net washing

Approximately 7% of the working population of the SoM is employed by the aquaculture industry (Magill et al. 2009). In the SoM marine spatial plan three of the six areas have key policies that encourage the development of further finfish and shellfish aquaculture.

Atlantic Salmon is farmed within the SoM (Figure 4.13) which started in the 1980s. The are two finfish farm leases not currently in use. There is one small commercial mussel farm operating in Tobermory Bay. There is one net washing station in the SoM. The nets used in aquaculture can be covered in biofouling organisms and these need to be removed by using power washers

Figure 4.13: Areas where skate fishing occurs within the Sound of Mull study area and locations of fishfarms and areas where fish nets are washed

in situ or *ex situ*.

Fishing

Fishing is an important part of the SoM economy and is estimated to be about 7% of its value (Magill et al. 2009). Figure 4.14 shows that much of the Sound is used for fishing. The fishing data here were gathered through the Mull Aquaculture and Fisheries Association, because the Sound is a relatively small area most of the local fishermen were contacted and any non-local fishermen were noted. This dataset does not give frequency of use for the areas fished as was the case for the Lyme Bay case study.

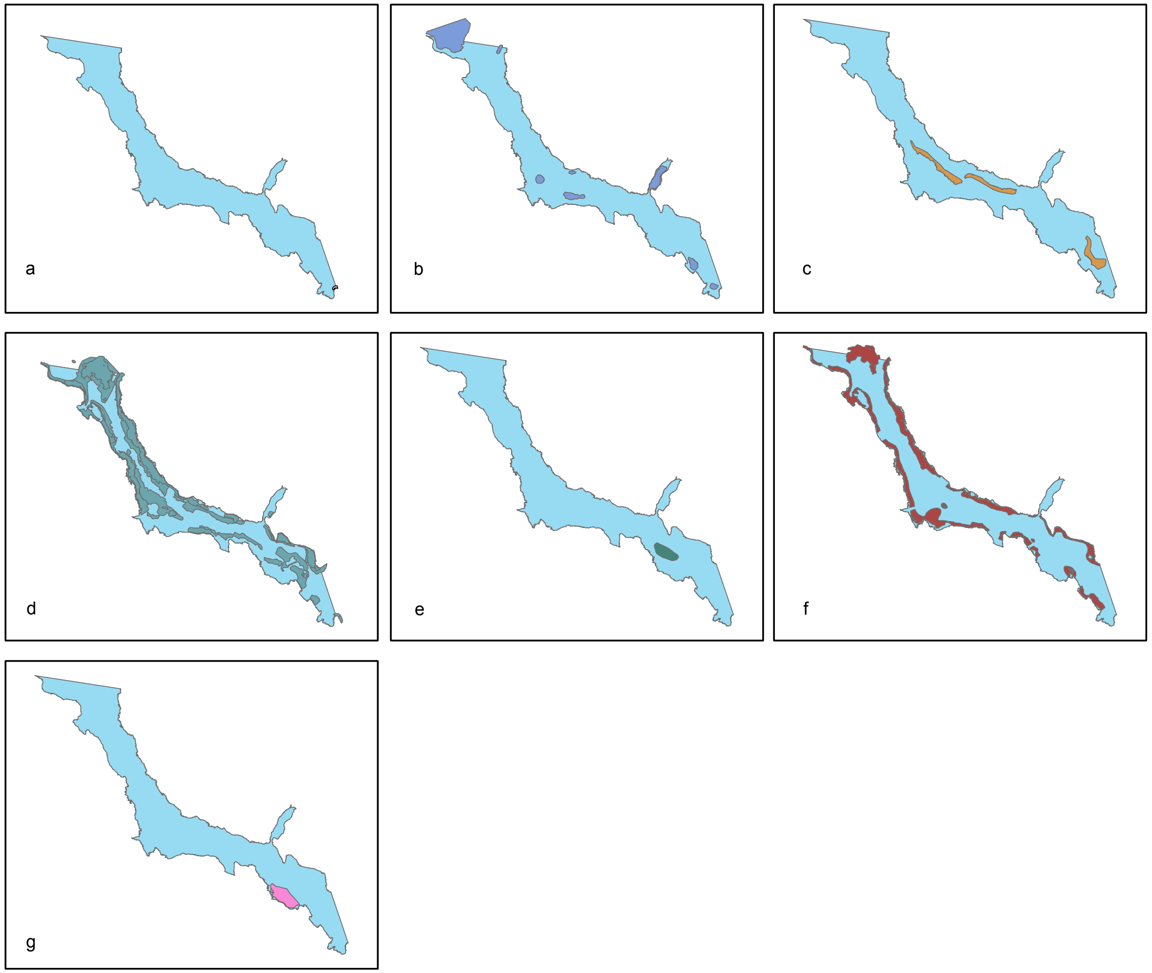


Figure 4.14: Areas of fishing (shaded) in Sound of Mull study area by species. a = lobster, b = prawn, c = queen scallop, d = scallop, e = scallop and prawn, f = velvet crab and lobster and g = velvet crab and prawn

4.5 East Channel

The East Channel study region is from west of the Isle of Wight to Dungeness in the east and out to the mid-line of the English Channel (Figure 4.15). The case study area and data described in this section will be used in chapter 7 to evaluate the impacts of using confidence levels in habitat data on marine biodiversity protection. The area of the case study site is approximately 12620km^2. The study area is shallow near the coast, sloping towards an average depth of 50 metres with a deeper channel (50-100 metres) running west to east from south of the Isle of Wight (Figure 4.16). The case study site contains a variety of habitats including gravel, reef, sandbanks and mud (Balanced Seas 2011*b*). Portsmouth is an important estuarine habitat which is a Specially Protected Area (SPA) for feeding birds on mudflats, RAMSAR site and an SSSI. There are 4 SACs and three suggested MCZs.

This area has many sectors competing for space; it contains several military practice areas, three licensed windfarm areas and 20 areas licensed for aggregate dredging. Fishing in this area is primarily carried out on inshore fishing boats (under 10 metres) with some larger vessels fishing in offshore waters. Recreational sectors are important to the local economy with many anglers using the area. The area around the Solent, in particular, is a very popular place for recreational yachting.

The English Channel is a busy shipping area with a traffic separation line and up to 400 ships passing though each day. Two important ports are within the study area (Southampton and Portsmouth) and three ferry ports Portsmouth, Poole and Southampton.

4.5.1 Data layers

UKSeaMap 2010 data

The UKSeaMap 2010 data layer covers the whole of UK waters, the data relevant to this study can be seen in Figure 4.17. Seven data types were used to model this data: substrate, salinity, major topographic features of the seabed, coastal features, biological zones, energy regimes (wave energy and tidal current energy) and depth to define Arctic and Atlantic biogeographic zones. It is more fine-scale and detailed than the UKSeaMap 2006 data layer (McBreen et al.

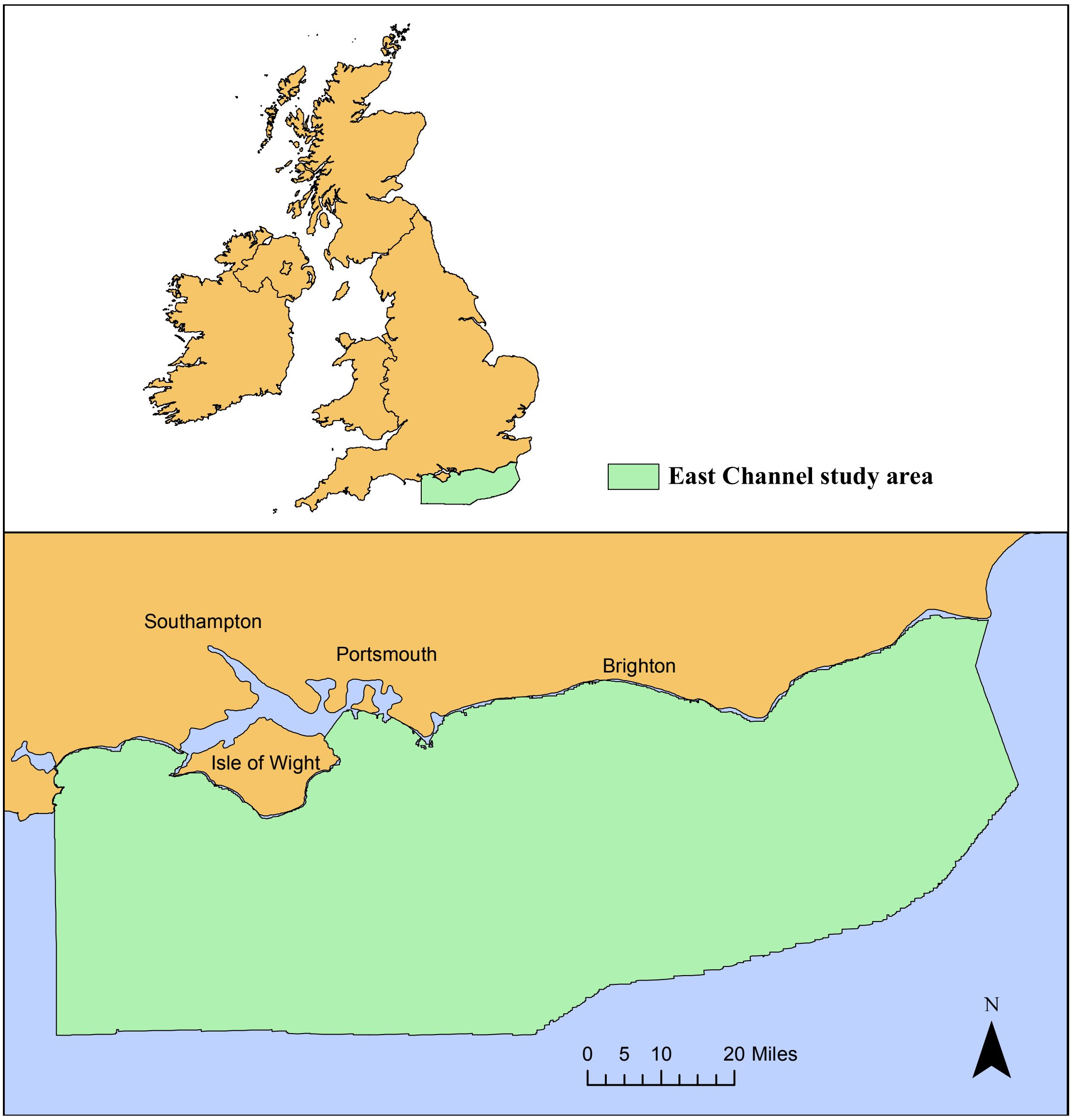
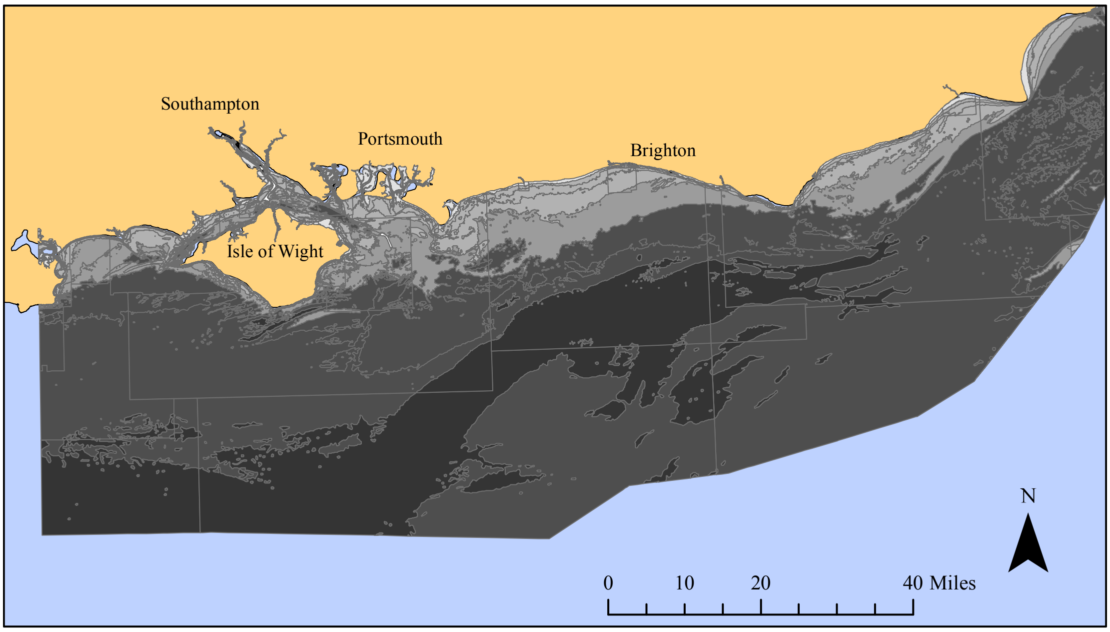


Figure 4.15: The East Channel study area.



Depth contours

Depth area (<= 0m)

Depth area (<= 10m)

Depth area (<= 20m)

Depth area (<= 50m)

Depth area (<= 100m)

Depth area (Undefined)

Figure 4.16: The bathymetry of the East Channel study area within the English Channel in metres.

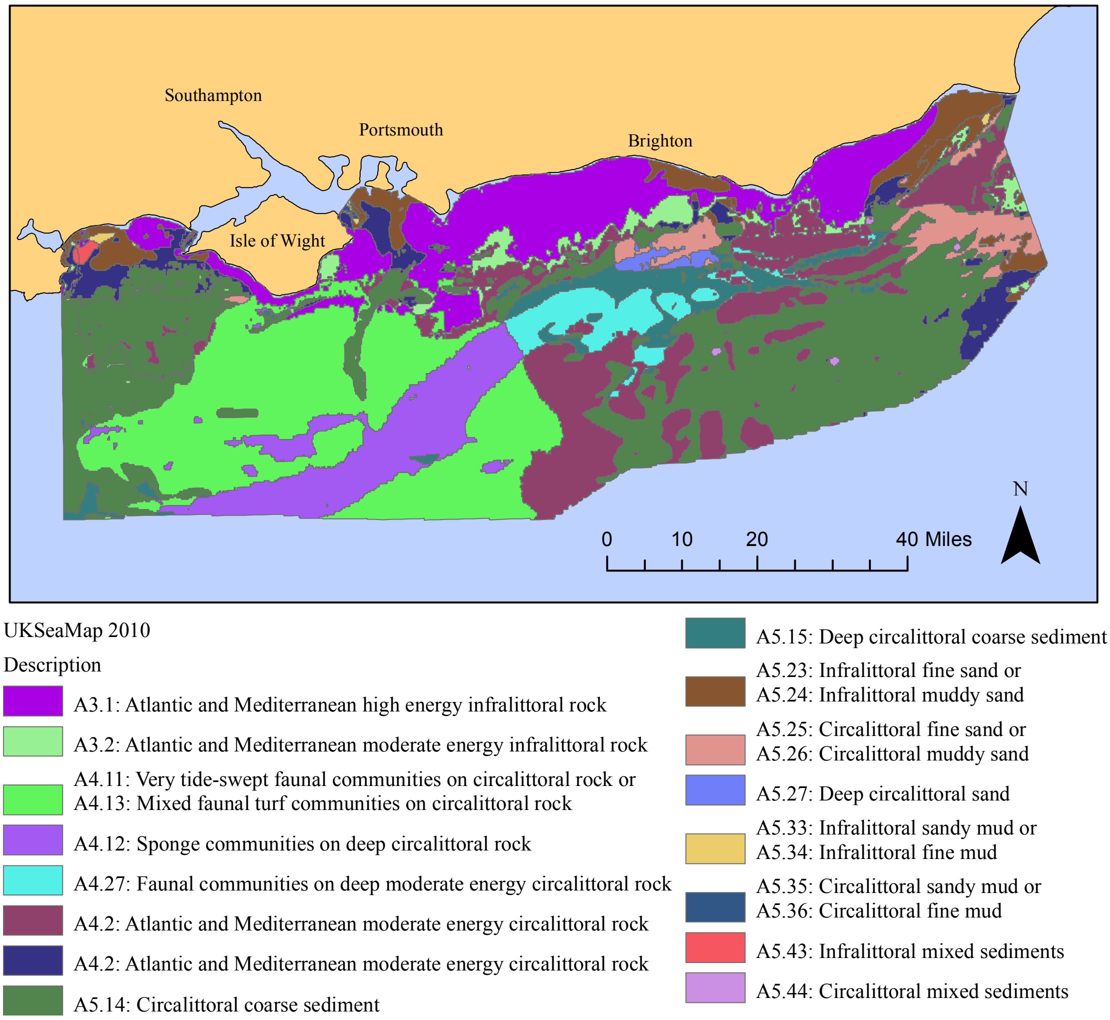


Figure 4.17: The UKSeaMap 2010 data used in the East Channel study

2011).

Each data layer was subject to a confidence assessment with the overall predictive seabed habitat map being created by multiplying confidence scores for the main input layers: biological zones; seabed substrata; wave energy and tidal current energy. The confidence scores that were applied in each area depended on the habitat type, if the predicted habitat did not depend on one of the data layers this was not applied.

East Channel EUNIS data

The data layer covers the study area (Figure 4.18). The European Nature Information System (EUNIS) data layer was created using sediment data, tidal current velocity and depth, which

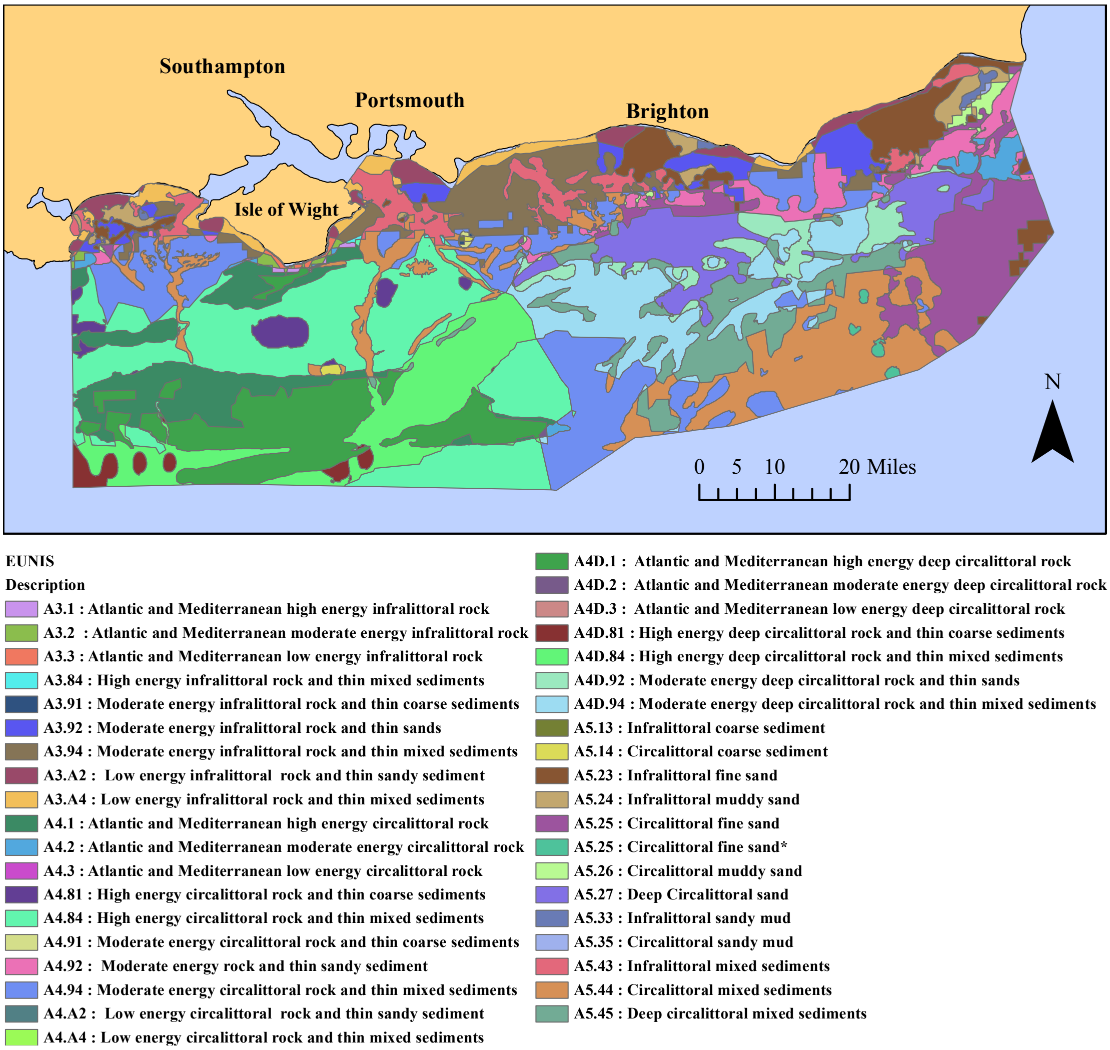


Figure 4.18: The European Nature Information System (EUNIS) data used in the East Channel study

included photic/aphotic zones. A study re-analysed grab and video data collected from 429 ground-truth sample stations in the study area, of which 374 were grab samples. For stations on hard ground, where no grab samples were obtained (55 stations), a biotope assessment has been made on the basis of the analysis of sea bed videos and photographs (James et al. 2011). A high degree of accuracy was found with the EUNIS level 4 modelled map when assessed with ground-truthed data.

This chapter has demonstrated the rationale for each of the case studies and described the data used in the data analysis chapters. In the following chapter the methodology for Marxan will be applied to assess the resolution and complexity of data required to protect marine biodiversity using currently available data, using the Lyme Bay case study area.

Chapter 5

Assessing the quality of data required to identify effective protected areas

The analysis in this chapter has been published as: Peckett, F.J., Glegg, G.A and Rodwell, L.D (2014), Assessing the quality of data required to identify effective protected areas, Marine Policy (45), 333-341.

I, Frances Peckett, undertook the analysis published in the above article, with helpful comments from my supervisors, Gillian Glegg and Lynda Rodwell.

5.1 Introduction

To create a marine protected area network using systematic conservation planning requires biological data such as detailed habitat maps or presence/absence species data. An issue facing marine planners in the UK, and globally, is that these data are not available for the majority of the marine and coastal environment. Obtaining such data is very expensive and requires considerable time and expertise and so surrogates, such as substrate or other environmental characteristics, are sometimes used to represent marine biodiversity. However, gathering even surrogate information, such as sidescan data, can be resource intensive and may not represent biotopes very effectively (Stevens et al. 2007). Rodrigues and Brooks (2007) reviewed the effectiveness of surrogates for biodiversity conservation planning and concluded that surrogates derived from abiotic data did not adequately represent marine biological diversity. A study by Grantham et al. (2010) found that the effectiveness of surrogates for the taxa they evaluated (mammals, birds, reptiles, frogs and plants) was low. They concluded that the effectiveness of surrogates was sensitive to the study area, the choice of surrogate and the type of species (eg

Table 5.1: Benthic, biological data used in marine planning.

Marine plan or marine protected area	Resolution
Plymouth and Estuaries SAC, UK	Between 100m and 2km for benthic biotope data (Moore et al, 1999)
Marine Spatial Plan, Belgium	250x250m modelled benthic data (Derous et al, 2005)
New Zealand	EEZ mapped to 1km scale (Snelder et al, 2001)
England MCZ project	Data ranges from 1-2 to 9km grid with the data interpolated to a 1.85km grid, with some finer scale habitat species data used where available (Vina-Herbon and Davies, 2011)

mammal or plant) that the surrogates are intended to represent.

Information on the scale and resolution of ecological data used to plan MPAs or in marine planning is not widely reported in the literature. For example in the Great Barrier Reef Marine Park it was stated that the ecological data was in the range 10km to 100km (Day et al. 2000) with no specific resolution given. Table 5.1 shows the wide range of resolutions of data used in marine planning and different ways of interpreting the base survey data (modelling and interpolating). There is no general consensus of what resolution of ecological data should be used when planning to protect marine biodiversity as this is driven by both the spatial variability of the biodiversity and the scale of the management envisaged (Stevens 2002). In reality the data used is often simply that which is available as there are seldom funds to gather new data.

In the light of the limited data availability, it is necessary to use what is available as effectively as possible in the creation of spatial plans and decision support tools have been developed to aid in this task such as Marxan and Marxan with Zones (Ball et al. 2009; Possingham et al. 2000).

5.1.1 Chapter aims and objectives

This study aimed to evaluate the effectiveness of currently available surrogate data (substrate) to designate marine reserves to meet defined conservation objectives. In the case study area high quality biotope data is available to contrast with the Marxan outputs and hence assess the extent of protection afforded. An effective MPA is defined here as one which has the least area and boundary possible to represent all biotopes by a stipulated amount.

The objectives of this study were to analyse scenarios in Marxan to investigate the implications of:

- using different resolutions and complexity of substrate data,
- incorporating a predefined closed area and
- using no data at all.

The case study used in the chapter is Lyme Bay. The data used in the analysis of this chapter are discussed in Chapter 4. The methods used to manipulate the data and create the plans are described in Chapter 3.

This chapter will be fulfilling one of the overall objectives for this PhD:
Objective 4. To assess the resolution and complexity of data required to protect marine biodiversity using currently available data.

5.2 Methods

5.2.1 Study area

This study uses the Lyme Bay case study area. Four of the data layers used in this analysis are discussed in the case study chapter. The spatial decision support tool Marxan is used in this analysis. The methodology used in this study is described in the methods chapter.

5.2.2 Description of Data

Three different substrate datasets (high, medium and low resolution, see Table 5.2) were identified as examples of differing complexities to be applied alongside the high resolution (average 3.5km) biotope data. A biotope is defined as a combination of the abiotic habitat, which includes the substrate, topography, wave exposure, salinity and tidal currents that affect the shore or seabed, and the species associated with that habitat (Connor et al. 2004).

The no data layer scenario had neither substrate or biotope data but the area for protection was chosen at random (Table 5.2). In this case all parts of Lyme Bay are equally likely to be chosen and because there are no substrate or biotope data for the program to select against, any 20%

Table 5.2: The type, range and source of the five data layers

Layer name	Data type	Range	Source
High resolution biotope	JNCC biotopes	0.4km to 4.7km with an average resolution of 3.5km.	Devon Biodiversity Records Centre (DBRC)
High resolution substrate	JNCC substrate	0.4km to 4.7km with an average resolution of 3.5km.	Devon Biodiversity Records Centre (DBRC)
Medium resolution substrate	European Nature Information System (EUNIS) substrate Level 3	Data used ranges from 1-2km to 9km grid, some modelled. The data is interpolated to a 1.85km grid	JNCC MESH project. EUNIS data
Low resolution substrate	UKSeaMap substrate	Basic grid 2km but some of the underlying data on grids of 7 or 12km.	Joint Nature Conservation Committee website (accessed 5 November 2009) UKSeaMap data
No data	None	N/A	

of Lyme Bay will fulfil the objective. The 20% target was chosen in agreement with the IUCN recommendation of including 20-30% of habitats within a protected area (IUCN 2003). There will be constraints such as the length of boundary of the selected area.

5.2.3 Analytical calibration and design

Before the analysis was run in Marxan the parameters were calibrated to ensure that efficient solutions were created. This included checking that all the features met their targets, that a wide variety of solutions were created and there was an appropriate degree of clustering.

The value chosen for the BLM was calibrated. Marxan analyses were run using BLMs of 0, 10, 100, 1000, 10 000 and 100 000 to evaluate the affects of these BLMs on the objective function value and the boundary length. A BLM of 10,000 was chosen because this produced outputs with a reasonable degree of fragmentation. Also using a higher BLM resulted in a increase of approximately 70% of the objective function and only reduced the size of the boundary by a small amount (approximately 5%).

The replication, size and placement of the features were examined in ArcGIS. Features that occurred in fewer than ten planning units were identified. Smaller habitats, spread over a few planning units need to have their targets calibrated to ensure they are met. They often need their targets increasing to ensure they are protected by at least 20%.

The penalty feature was calibrated so that all features were protected at the targets set for them. The penalty factor used was 1000,000.

For this analysis the shapes of square, hexagon or the boundaries of the habitats were considered for the planning unit shape. Hexagons were chosen as the planning unit shape because they help create reserves with low edge to area ratio (Ardron et al. 2008). Various sizes of planning units were considered. The size chosen, approximately 4.4km^2, was selected as a balance between the flexibility of the network, the requirement for analytical time and the resolution of the biotope data available. The edges of the bay have smaller planning units due to the bay's irregular outline. For this study, the cost of each planning unit was set as its area, assuming a proportional relationship between cost and area.

The number of runs and iterations were calibrated so that a reasonable spread of solutions (using different planning units) were produced. If the number of iterations was set too low then only local minima would be reached. A cluster analysis was performed to test this. The number of runs chosen was 200 and the number of iterations were set at 2 million.

5.2.4 Scenarios investigated

Ten different scenarios were analysed in Marxan (Table 5.3) to determine how effective each one was at representing 20% of biotopes. This setting was consistent with IUCN recommendations 'to include 20-30% of each habitat within strictly protected areas' (IUCN 2003; OSPAR 2006; Bohnsack 1996). The scenarios considered the implications of:

- three different substrate layers (i.e. high, medium and low; see Table 5.2);
- data of differing complexity (biotope versus substrate);
- randomly generated closed areas (no data used) and
- locking in' the closed area (which currently excludes all bottom dredging)

on the size and shape of the resulting protected areas. Each of the five data layers were used in two runs with the same variables and parameters. In the first run the closed area was not 'locked in' and in the second run the closed area was 'locked in'. Marxan can be set to always include a set of planning units within the protected areas, this is referred to as locking in. Sets of planning units may also be excluded from the protected areas, making them locked out of a Marxan analysis.

5.3 Results

The scenario which represented all the biotopes by at least 20% for the smallest total area (531km^2) was produced using the high resolution biotope data, without the closed area locked in (Tables 5.3 and 5.4; Figure 5.1. A1). This was because it contained the most detailed information on biotopes and was not constrained by the closed area. The no data layer scenario had the least area but this had very limited species protection (Tables 5.3 and 5.4; Figure 5.1. A5) and the scenario which resulted in the largest area was high resolution biotope with closed area locked in (Figure 5.1 B1 and Table 5.3).

5.3.1 Biotope representation

When comparing the scenario outputs using high resolution substrate data to the high resolution biotope scenarios (Figure 5.1A and Table 5.4), the main differences identified were that the high resolution substrate scenarios contained fewer planning units, had less fragmentation, smaller areas and had reduced inclusion of biotopes. The scenarios including the three substrate layers represented, by at least 20%, only between 7 and 9 biotopes, out of the possible 22 (Table 5.4).

Table 5.3: Scenarios with Marxan using different data layers in the inputs, each scenario was run with the closed area locked in and without it locked in. See Figure 5.1 for best output (out of 200 runs) for each of the ten scenarios tested (A1 to B5). Columns 5-6 show the number of planning units (PU) in the best solution for each scenario with the percentage difference between scenarios A and B given in column 7. Columns 8-9 show the area in km^2 for each of the scenarios with the percentage difference in area shown in column 10.

		Scenario		No. of planning units			Area (km^2)		
Main data layer	Level of representation required	Closed area not locked in	Closed area locked in	Closed area not locked in	Closed area locked in	Percentage difference	Closed area not locked in	Closed area locked in	Percentage difference
High resolution biotopes	20% of each biotope	A1	B1	126	167	33%	531	641	17%
High resolution substrate	20% of each substrate	A2	B2	119	139	17%	493	556	11%
Medium resolution substrate	20% of each substrate	A3	B3	124	155	25%	484	628	23%
Low resolution substrate	20% of each substrate	A4	B4	118	147	25%	475	594	20%
No data	20% of Lyme Bay	A5	B5	113	117	4%	472	475	1%

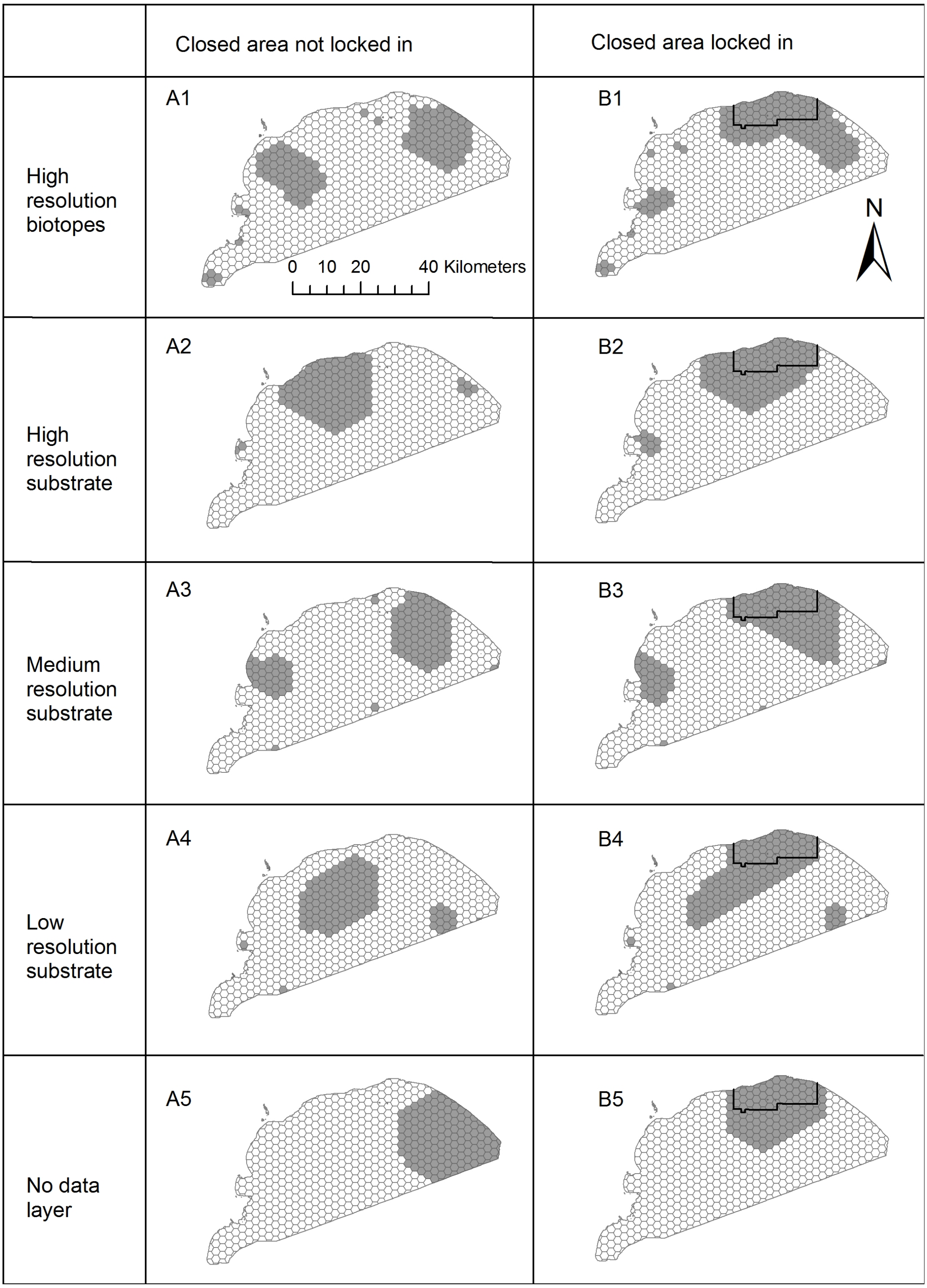


Figure 5.1: Lyme Bay best solution (out of 200 runs) for each of the ten scenarios, with the existing closed area outlined in black, the filled in areas indicating selected planning units for protection. Scenario A5 produced solutions that clustered around all parts of the Lyme Bay coast i.e. outputs were not clustered around the eastern end.

The scenario using the high resolution biotope data (A1), represented all of the biotopes by at least 20% as would be expected. For 13 out of the 22 biotopes the percentage protected was within 5% of the 20% required, indicating that Marxan can select solutions efficiently (Table 5.4). If the constraint of the boundary length (BLM) had not been used, all of the biotopes would have been protected at a level closer to 20% but because Marxan was reducing the overall reserve boundary some biotopes were protected at a higher proportion.

The high resolution substrate scenario (A2) had an area of 493km^2 and protected (to over 20%) 8 biotopes out of 22. The medium resolution substrate scenario (A3) had an area of 484km^2 and protected (to over 20%) 9 biotopes out of 22, the highest out of the three substrate layers. The low resolution substrate scenario (A4) protected 5 biotopes (over 20%) out of 22, the least amount of biotopes from any of the scenarios. The no data layer scenario (A5) had the smallest area compared to the other scenarios and protected 7 biotopes (over 20%). More of the biotopes were represented in the no data scenario than when using the low resolution substrate data.

Therefore, in contrast to the biotope data scenarios, the solutions produced using the three substrate layers (high, medium and low resolution) or the no data layer as the base layer, did not protect all of the biotopes. The high resolution substrate layer protected 8 biotopes by over 20% and a further 3 were included in the protected area by less than 20%. Proportionally, the biotopes with a smaller area were less likely to be protected than the larger biotopes. One of the key biotopes that contained seagrass (SS.SMp.SSgr.Zmar, Table 5.4) had an area of less than 1% of Lyme Bay and was not included, and therefore not protected, in any of the runs using the substrate data layers. Further to this, seven biotopes were never included above 20%, in the three substrate scenarios (5.4) and a further two are only protected well below the 20% threshold. In each of these scenarios, 13 or 14 biotopes are not protected above the 20% level and only seven biotopes are always protected. When the closed area was locked in, the number of biotopes protected using substrate data did not increase.

5.3.2 Effects of 'locking in' the closed area

In the scenario using high resolution substrate as the base layer and with the closed area locked in, there were 21 planning units selected in every solution as well as the locked in planning units.

Table 5.4: Percentage of each biotope protected; the highlighted cells are those where the protection is less than 20%, when biotopes are used, the amount of each biotope is at least 20%. Scenarios B3, B4 and B5 are not included because they follow the trend shown by scenarios B1 and B2. For further information about the biotope codes see Table 4.2 and (Connor et al. 2004).

		Scenario						
Biotopes	Percentage of biotope area in Lyme Bay	A1	B1	A2	B2	A3	A4	A5
SS.SMx.CMx.OphMx	0.003	100	100	100	100	0	0	0
CR.HCR.XFa.ByErSp.Eun	0.032	33.7	100	0	100	0	0	0
IR.HIR.KFaR.LhypR	0.037	23.7	23.7	0	0	33.3	0	60.1
LS.LMp.LSgr.Znol	0.066	21.2	21.2	0	0	0	41.9	0
SS.SCS.CCS.Pkef	0.097	20.7	20.7	0	0	0	0	0
SS.SCS.CCS.Blan	0.1	79.5	79.5	0	0	0	7.7	0
CR.HCR.Xfa	0.2	21.1	22.1	0	0	0	2.1	0
SS.SMp.SSgr.Zmar	0.42	26.5	26.5	0	0.4	0	0	0
CR.HCR.XFa.ByErSp.Eun and SS.SMx.CMx	0.45	49.6	100	64.1	70.5	35.9	50.4	0
SS.SCS.CCS	0.69	100	100	0	2.9	100.0	30.8	53.0
SS.SMp.Mrl.Pcal	1.16	39.6	20.2	90.0	90.0	0	0	0
SS.SMu.CsaMu	1.19	27.2	20.2	23.9	19.6	0	17.9	0
SS.SSa	1.5	55.8	67.1	0	13.8	66.2	0	52.5
SS.SSa.IFiSa.IMoSa	1.6	21.3	21.3	0	0	0	0	0
SS.SCS.CCS.PomB	2.2	20.2	72.6	48.2	84.3	29.1	6.2	0
CR.HCR.Xfa and SS.SMx.CMx	6.8	23.0	76.2	20.4	64.6	26.5	7.5	28.6
SS.SMx.CMx	7.3	20.0	20.1	11.6	0.4	15.0	28	93.2
SS.SMu.CSaMu.TcomSinf	10.5	21.3	20.4	0.0	0	27.3	0.2	0
SS.SMx.CMx.ClloMx	11.6	20.8	20.2	38.5	37.8	23.2	16.4	0
SS.SCS.CCS.MedLumVen	12.3	21.1	20.1	18.5	18.2	11.3	13	34.3
SS.SSa and SS.SMu.CSaMu	14.6	20.1	20.1	60.5	52.4	0	83.2	0
SS.SSa.CMuSa.AalbNuc	25.7	20.7	20.8	0.3	4.6	30.5	3.9	21.4

This is because the BLM was used, which would lead to it being ’cheaper’ to add planning units around the already selected planning units of the locked in closed area. Including the closed area in the analysis increased the area significantly (between 11-23% - Table 5.3) in all of the scenarios except the no data layer.

5.3.3 Selection frequency

Two planning units in the high resolution biotope scenarios are always selected and therefore are essential to the stated objectives (Figure 5.2). One of the selected planning units is not in the closed area and contains a biotope that is only found across three planning units in the south west part of Lyme Bay; it contains the largest amount of the biotope SS.SCS.CCS.Blan (*Branchiostoma lanceolatum* in circalittoral coarse sand with shell gravel) within the planning area. The other ’always selected planning unit’ was within the closed area and contains a mix of the biotopes that are only present in small areas within Lyme Bay. In the remaining area, 81 planning units are 50% selected and therefore can be considered important to meeting the objectives.

The high resolution substrate scenarios (Figure 5.1:A2 and B2) did not include the planning unit outside the closed area, therefore these solutions are not able to protect 20% of each biotope. In the high resolution substrate scenario, without the closed area, the wider range of options for solutions meant that while there were some highly selected planning units (>90%) none were always selected. The medium resolution substrate scenario had three planning units at 100% and 45 selected over 50%. The 100% selected planning units occur on substrate types that only occur around the edges of the study area. The low resolution substrate scenario contained one 100% selected planning unit and 20 planning units that were selected by over 50%. The 100% selected planning unit has a substrate type found in only one place in Lyme Bay. The no data layer scenario had no planning units selected in over 50% of runs.

5.4 Discussion

There is no consensus on the resolution and complexity of data necessary to identify areas of the marine environment for protection. Data requirements will depend on features such as the

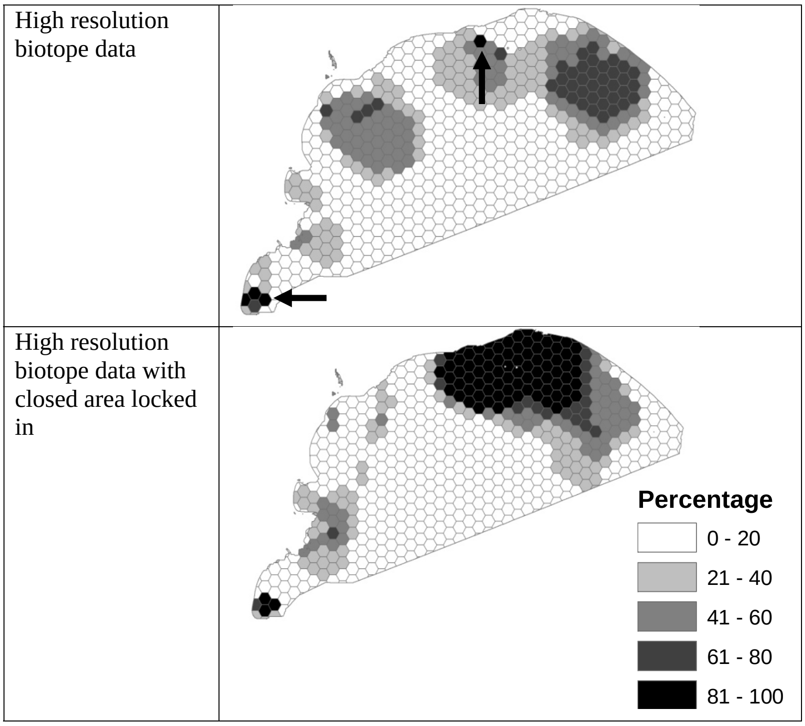


Figure 5.2: Selection frequency produced using high resolution biotope as the main layer; the arrows indicate the two most frequently selected planning units when run without the closed area.

reserve objectives and the scale of management as well as the availability of data. This study demonstrates the implications of using data of different resolution and type for marine biodiversity conservation. Using any one of the three types of substrate data tested did not enable marine biodiversity to be adequately represented. This finding is supported by other recent studies (Stevens et al. 2007; Ban 2009). Ban (2009) investigated the minimum data requirements for designing a theoretical network of marine protected areas in two regions of British Columbia, Canada and concluded that abiotic datasets such as depth, exposure, substrate and salinity, alone do not adequately represent biological diversity. Rodrigues and Brooks (2007) reviewed the effectiveness of biodiversity surrogates, such as abiotic data and cross-taxon surrogacy, in marine and terrestrial studies and found that the use of surrogates based on environmental (abiotic) data, did not represent biodiversity well. They also highlight that the type of data (high resolution biological data) required for marine conservation planning is not widely available.

In this study our findings suggest that biotope data (average resolution of 3.5km) can be used to design relatively efficient and effective MPAs and that substrate data alone is not a suitable alternative. However, biotope data of the resolution and complexity used in this study are not currently available for the entire UK marine environment and in many other countries the data situation is far worse. There is some evidence to show that using substrate data as a proxy for community and species distribution is acceptable if the data are at the scale of the zones of both the habitat patches and the marine plan (Stevens and Connolly 2004). However, if too coarse data are used there is the potential for plans to be unrepresentative of the biological habitats contained with the area to be planned (Stevens et al. 2007).

The key problem identified in this study is the poor representation of the range of biotopes in a complex marine area if the data used in the planning process is insufficiently detailed. In particular, using substrate data, regardless of resolution, led to 64-82% of the 22 biotopes in the area not being protected, with the smaller biotopes being particularly affected. Given that good quality biotope data is seldom available, planners are likely to consider using substrate data, on the basis that this would be 'better than nothing'. However, the findings here suggest that this is a risky strategy and that if substrate data alone are used, many of the biotopes, in particular the smaller biotopes may be excluded. Even using the high resolution substrate data the solution represented only eight biotopes by at least 20% with 8 out of the 10 smaller biotopes (those which cover <1% of Lyme Bay) not represented at all, while selecting an area at random included 20% of the area of seven biotopes in the solution. Such poor representation when using substrate data points to a need for more information before appropriate reserves can be identified. Or these reserves will not be representative of the substrates and biological communities they are set up to protect and will not be able to ensure that ecosystems are maintained (Margules and Pressey 2000).

The lack of adequate data has serious implications for the UK Government and its ability to meet its international legal obligations (OSPAR 1992; European Union 1992; Marine and Coastal Access Act 2009). For example, in the substrate scenarios three of the biotopes not included contain species that require protection at a high level; while the two biotopes containing seagrass, which is a declining/threatened OSPAR habitat, were not protected in any of the substrate scenarios (5.4). In the high resolution substrate scenario, one of the biotopes containing the pink sea fan, which is a UK Biodiversity Action Plan priority species, was not protected. Another biotope not represented contains *Saballaria spinulosa*, an OSPAR declining threatened habitat. It is essential that policy makers are aware of the significance of the problems encountered with inadequate data so they can consider alternative approaches.

The biotope distribution in Lyme Bay has been studied over many years. However, the distribution of marine biotopes throughout UK waters is less well known and in many places unknown (MSPP Consortium 2005; Natural England and Joint Nature Conservation Committee 2010). The results suggest that until such data are available, the UK will be unable to determine whether or not it will meet its international obligations of designating a network of representative MPAs. Therefore alternative approaches may be necessary to guide the designation of MPAs and overcome some of the issues associated with lack of good quality biological data. For example, using data gathered from stakeholders, including expert opinion from scientists, managers and users of the area may need to be considered and used within a precautionary framework. Expert opinion was used as an input, in addition to the available environmental data, when the Great Barrier Reef Marine Park was rezoned in 2003 (Fernandes et al. 2005). Stakeholder knowledge has been gathered and used extensively in the planning of a state-wide marine reserve off the Californian coast to ensure that local knowledge was captured and available for use in the designation of the marine reserves (Gleason et al. 2010; Scholz et al. 2004).

In the case of Lyme Bay much of the data have been gathered by stakeholders, in this case the Devon Wildlife Trust (Stevens et al. 2007; Devon Wildlife Trust 1998; Homarus Ltd 2007), not by government authorities and this is an approach which could be encouraged. Ongoing studies in Lyme Bay are continuing to produce new data on the impacts which the closed area has had on the recovery of the site and on local communities (Attrill et al. 2011; Stevens and Attrill 2013; Mangi et al. 2011). This emphasises the need for an adaptive approach to management which can respond to improving information as it is obtained.

The results from this study show that the scenario which best met the objective of 20% protection of each biotope, with the least area and least boundary (and so lowest cost), was produced with the high resolution biotope data, but with the constraint of the closed area being removed. Both scenarios which used the biotope data gave equal protection but when the closed area was locked in 17% greater area was required (Figure 5.1, A1 and B1). If current MPAs are used as a basis for this network it could lead to the UK needing to designate more of its marine environment than strictly necessary to ensure it meets its marine conservation goals. The creation of marine reserves, to ensure that marine habitats and species are adequately represented, may lead to conflict between governments, which create and enforce reserves, and stakeholders. If the reserves are larger than needed to meet agreed conservation goals, stakeholder objections are likely to increase. Therefore, it is essential that great care is taken to select appropriate sites for these protected areas to ensure they cover the key habitats without unnecessarily excluding other legitimate users of the marine environment.

This study has explored the use of different data types for the identification of suitable sites for protection of marine biodiversity within a small coastal bay. Using Lyme Bay as a case study, it has found the nature of the data used has significant implications on the distribution and total area of sites selected and on the proportion of the selected biotopes they represent.

If the UK government were to designate a marine reserve network starting from its current MPAs, it is highly likely that a greater area will need to be designated to enable conservation goals to be met than required. This study shows that using inadequate data can produce a deceptive result and could lead to a false sense of security about the protection of marine biodiversity.

This chapter assessed the effect of using data of different resolutions and complexity on marine biodiversity protection. The next chapter will determine how to integrate conservation and socioeconomic data and objectives in a marine plan.

Chapter 6

Balancing conservation and socioeconomic objectives in marine plans

6.1 Introduction

The UK is committed to using the marine environment sustainably (UKMMAS 2010). To deliver this the UK government has enacted the Marine and Coastal Access Act (2009), the Marine (Scotland) Act and the Marine Act (Northern Ireland), written the Marine Policy Statement as a framework for preparing marine plans, and is designating Marine Conservation Zones (England, Wales and Northern Ireland) and Nature Conservation MPAs (Scotland) in its waters. For both the preparation of marine plans and the designation of MPAs it is essential to balance the needs of the various sectors that use the marine environment.

Fishing, conservation, recreation and other uses of the marine environment often compete for the same resource. Consequently, there is a need to determine what is an acceptable allocation of marine resource to each sector. A common starting point in the marine planning process is to find out what the marine environment is currently used for (MMO and Marine Scotland 2012*b*; des Clers et al. 2008). It is important that the planning process happens in a transparent manner and it can be said that the process is as important as the outcome (Rutherford et al. 2005).

To enable a sector's needs to be recognised during the planning process, data are required of which areas are used, for what and how often. Studies have compared how using different types of marine activity data can influence how much a sector is impacted by a marine planning process. Klein et al (2008) compared stakeholder designed marine protected areas with those identified using the computer based programme Marxan. In the Marxan analysis commercial fishing data not directly available to the stakeholders were included. The study found that the Marxan designed network had less of an estimated impact on commercial and recreational fisheries than networks designed by the stakeholders. This suggests that using additional activity data, such as commercial fishing data, can minimise socioeconomic impacts. It also indicates that stakeholders are not as effective as Marxan at complex optimisation tasks.

A study by Carwardine et al (2008) highlights the importance of using the correct socioeconomic data during the planning process to minimise costs. This terrestrial study compared three cost surrogates, area, land acquisition, and stewardship on the cost of conservation. The study found that without cost data that was related to a specific conservation action there was an increase in cost for the action. For example, when planning a network of protected areas, if area is used as a cost surrogate rather than the cost of land acquisition the resulting cost of the network was approximately 1.4 times greater.

When using spatial decision support software to create marine plans it is considered best practice not to accept the first potential plan the program produces which fulfils the targets set (Ardron et al. 2008). This plan may have potential problems such as a high degree of fragmentation, which will make the plan confusing and unenforceable or the plan may impact more highly one sector. It is likely that calibrating the plan and analysing its impacts on each sector will create a plan that more closely fits the needs of all sectors.

6.1.1 Chapter aims and objectives

This study builds on the work of Chapter 5, which demonstrated the importance of using the correct type of data for biodiversity conservation when creating marine spatial plans, i.e. data which most closely describes the ecosystem being planned. This study will:

- incorporate socioeconomic costs for three sectors: fishing, aquaculture and recreation, into marine planning and

- explore the compromises required to integrate conservation (both environmental and cultural), recreation and fishing targets into a marine spatial plan.

The aim of this study is to determine how to minimise the impact of a marine plan on human activities and protect marine biodiversity and wrecks.

This chapter aims to fulfil one of the overall objectives for this PhD:
Objective 5. to assess how to integrate biodiversity and cultural conservation and socioeconomic data, and objectives, focusing on recreation and fishing, in a marine plan using Marxan with Zones.

6.1.2 Chapter methods

The case studies used in the chapter are Lyme Bay and the Sound of Mull. The data used in the analysis of this chapter are discussed in Chapter 4. The methods used to manipulate the data are described in Chapter 3. Marxan with Zones and Zonae Cogito were used to create each of the marine plans.

The case study areas were each broken into planning units. For the Lyme Bay case study the same hexagons were used as in the previous chapter. The planning unit size for the Sound of Mull case study site was 0.45km^2. This size was selected because it reflected both the resolution of the biotope data and the size of the planning area. Larger planning units would have restricted the flexibility of the solutions that Marxan with Zones could produce.

For both case study sites the spatial distribution of the features (habitats) was mapped. Their extent within each of the planning units was calculated. Targets were chosen for each of the habitats, depending on their sensitivity and likely impacts. Targets were set for overall protection within protected zones and for specific zones.

The costs for each case study site were determined and mapped and a file listing each of the costs was prepared. The costs were set to be applied in the different zones depending on the activities that could occur in them.

The contribution to protection of features for each of the zones was chosen. When a feature was included in the highly protected zone in each case study 100% of its area contributed towards the target. In the medium protected zones 50% was contributed and 0% in the zone without protection.

The boundaries between the planning units in each case study were calculated using ArcGIS and the BLM was calibrated so that the solutions produced by Marxan with Zones were not highly fragmented. For each case study analysis a zone boundary cost file was included. This file was set up so that Marxan would attempt to create a buffer of medium protection zone between the highly protected and no protection zones. This file was weighted as less important than meeting the feature targets, so if Marxan had a choice between meeting the targets or creating the buffer it would choose to protect the features.

6.2 Lyme Bay

6.2.1 Methods

Nine scenarios (Table 6.3) were run to test the effects of different levels of protection and using different data types on:

- the area assigned to each zone;
- recreation and fishing activities when they were excluded from certain zones, and
- marine biodiversity protection.

Three data layers were selected to assess how to balance the objectives of the fisheries and recreation sectors with conservation in Lyme Bay. Four main steps were required to fulfil the purpose of the Lyme Bay part of this study (Figure 6.1).

Four zones were used in the Lyme Bay analysis, with different activities allowed or encouraged in each (Table 6.1).

1. Multiple-use zone (MUZ) - All activities except bottom fishing (trawling and scallop dredging) allowed.
2. Partial-use zone (PUZ) - this zone is only included in the conservation and recreation scenarios and recreational activities would be encouraged here.
3. No-take zone (NTZ) - all extractive and highly damaging activities banned.
4. Fishing zone (FZ) - this area will be restricted to fishing and recreation.

Table 6.1: The zones used in the Lyme Bay marine plan. The crosses indicate which activities are allowed in each zone with any exclusions. *All fishing except scalloping and bottom trawling. The partial-use zone was used in the conservation and recreation scenarios, and not included in the fishing and marine plan scenarios.

	Activity		
	Diving	Fishing*	Scalloping/Trawling
Multiple-use zone (MUZ)		x	
No-take zone (NTZ)	x		
Fishing Zone (FZ)	x	x	x

The PUZ was used in two of the scenarios (Conservation and Recreation). It was designed to be an area where recreational activities would be encouraged. This is because recreational activities are an important part of the Lyme Bay economy.

The NTZ was used in all the scenarios and was used to protect both sensitive species and to protect some of each habitat. When all the scenarios were run initially, all recreational activities were banned, but many of the recreational activities occurred in areas the NTZ was often placed. Therefore apart from the conservation and recreation scenarios the recreation costs were not applied in any zone. As recreation is a significant part of the Lyme Bay economy, it was felt that any attempt to ban recreation activities from areas used frequently was not feasible. Therefore only extractive and highly damaging activities were banned from this zone. In this zone the targets were higher for the more sensitive species.

Significant areas of Lyme Bay are used for fishing and recreation, so two zones were created where they could occur. In the MUZ all activities except trawled bottom fishing were allowed. After the biotope sensitivity analysis had been performed, this activity had the greatest impact on the greatest number of habitats. Using the zone meant that some activities that conflicted, such as, diving and scallop dredging could be separated. The FZ was 'business as usual' with all activities allowed to continue as they do currently with no extra restrictions.

Step 1 of Figure 6.1

Three conservation scenarios were run using only the biotope data. The zones included in the resulting configuration were the MUZ, PUZ and the NTZ. The percentage of each biotope included in the protected zones in scenario Conservation 20 was 20%, with 10% each in the

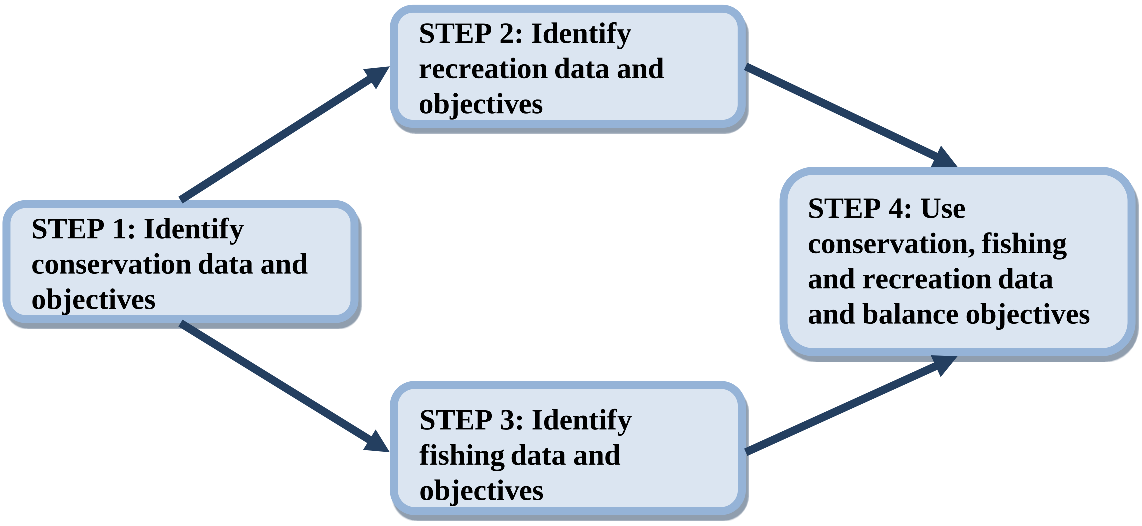


Figure 6.1: The steps completed in the Lyme Bay section of this study, using Marxan with Zones. Scenarios were run to assess the targets to set in Marxan with Zones. For example what percentage of each conservation feature is to be included in a protected zone. The recreation and fishing data sets were added separately to the conservation data to investigate the addition of a dataset and objectives. The right-hand side box indicates that the three sectors objectives were balanced in a single Marxan with Zones scenario.

PUZ and NTZ zones. In the scenarios Conservation 30 and Conservation 40 the overall biotope inclusions were increased to 30% and 40% with the biotope protection split evenly between the PUZ and NTZ (Table 6.3). The three conservation scenarios had different targets of protection to assess the proportion of Lyme Bay that would be required to be in a protected zone for Marxan with Zones to ensure that the targets for habitat protection were met. When this had been assessed a target for biotope protection was chosen for use in the following steps of preparation for the marine plan and in the marine plan.

Step 2 of Figure 6.1

Recreation scenarios were run using the biotope and recreation data layers to:

- investigate how using recreational data in a marine plan could reduce the impact of pursuing conservation targets on recreational activities and

- assess whether both conservation and recreational objectives can be met in a marine plan.

Table 6.2: How the costs were applied in the Lyme Bay Marxan with Zones analysis. *x = cost applied. ** The recreation costs were applied in the recreation scenarios but not applied in the final marine plan. The partial-use zone was used in the conservation and recreation scenarios, and not included in the fishing and marine plan scenarios.

		Zone type*			
Cost	**Data used as cost**	MUZ	PUZ	NTZ	FZ
Recreation	Frequency of use			x**	
Fishing	Frequency of fishing activity	x	x	x	

Recreation activity frequencies were added as a cost to the analysis, i.e., if a planning unit were to be added to a zone where recreation activities were not permitted this additional factor would be included (Table 6.2). Marxan with Zones would therefore be less likely to add planning units that contain recreational activity into zones where recreational activities are not allowed. The zones used were: MUZ, PUZ and NTZ. The amount of biotopes included in the PUZ and NTZ was varied in the three recreation and conservation scenarios to examine the impact of weighting: conservation over recreation (Recreation and conservation 1:3), them both equally (Recreation and conservation equal) and recreation over conservation (Recreation and conservation 3:1). The zones in the recreation scenarios were distributed as 1:3, 1:1 and 3:1 to explore a broad range of potential impacts on the conservation and recreation targets. This would indicate the flexibility of a marine plan fulfilling conservation targets with a reduced impact on recreation activities.

Step 3 of Figure 6.1

Three scenarios were run using the biotope data and Fishermap data. The fishing data are used in this part of the analysis to investigate whether: (i) using fishing activity data in Marxan with Zones can reduce the potential loss of fishing grounds and lost fishing revenue by choosing areas for protection that are less important to the fishing industry; (ii) if fishing and conservation objectives can both be met in a single marine plan and (iii) using different weightings for fishing and conservation sectors changes the potential impacts of a marine plan on fishing activity.

The frequency of fishing activity use data was applied in Marxan with Zones as a cost (Table 6.2). Therefore if a planning unit is selected that contains fishing activity the potential loss of fishing activity is added to the objective function. This means that if two planning units with

Table 6.3: The Lyme Bay marine plan scenarios, showing the target percentage of biotopes in the multiple-use zone, the partial-use zone and no take zone. The partial-use zone was not included in the Fishermap scenarios

Scenarios		**Multiple-use zone**	**Partial-use zone**	**No-take zone**
Conservation scenarios	Biotope protection			
Conservation 20	20		10	10
Conservation 30	30		15	15
Conservation 40	40		20	20
Recreation scenarios				
Recreation and conservation 1:3			5	15
Recreation and conservation equal			10	10
Recreation and conservation 3:1			15	5
Fishermap data scenarios	Penalty factor applied			
Fishermap and conservation low	100%	10	N/A	10
Fishermap and conservation mid	50%	10	N/A	10
Fishermap and conservation high	33%	10	N/A	10

identical amounts of habitat are available and one is fished and one is not, Marxan with Zones will be more likely to choose the one without fishing activity. In these scenarios the weighting given to conservation and fishing is varied, from conservation being weighted more highly (Fishermap and conservation low) to fishing more highly weighted (Fishermap and conservation high). In the first fishing scenario (Fishermap and conservation low) the full penalty factor (100%) was applied. In the second scenario (Fishermap and conservation mid) only half the penalty factor (50%) was applied increasing the weighting of fishing activity. For the third scenario (Fishermap and conservation high) a third of the penalty (33%) was applied further reducing the weighting for conservation targets. In these scenarios the zones used were: MUZ, NTZ and FZ, with a 10% target for each biotope in the MUZ and NTZ and no fixed amount in the fishing zone.

To investigate the potential impacts on the fishing industry in Lyme Bay, the amount of fishing activity taking place within the fishing zone was analysed in the Fishermap and conservation scenarios.

Step 4 of Figure 6.1

The data used in the marine plan were the biotope and Fishermap data layers. After preliminary analysis, exclusion of the recreation activities from the NTZ led to a potential reduction in value to the recreation sector of 80%. Therefore all recreation activities were allowed in all zones and so not applied as a cost. In the marine plan scenario for some of the biotopes (Table 6.4) the target for protection was reduced to 12-15% with at least 10% of every biotope protected in the no take zone. This was done to ensure that an acceptable amount of clumping occurred for each zone and to ensure that the larger and less sensitive habitats were not driving the analysis at the expense of the fishing and recreation sectors. The Fishermap data were used as costs as described above when these layers were used separately (Table 6.2). The full penalty factor was applied as changing it did not have a significant impact on the amount of fishing activity taking place in the FZ. The zones used in the marine plan were the MUZ, NTZ and FZ.

The Marxan with Zones process flowchart (Figure 3.1) was followed to ensure that the program was producing good quality configurations. The potential financial consequences of the marine plan where recreation or fishing activity is excluded from certain areas, where they previously had taken place, were evaluated.

Impact of recreation and fisheries activities on biotopes in Lyme Bay

An analysis of the likely effects of the recreational and fishing activities on each of the biotopes was carried out. This was completed to ensure that the activities that were damaging to habitats did not take place in the NTZ and the very sensitive habitats had a target of 20% within the NTZ and were therefore not impacted by the activities permitted in the other zones (Table 6.4). This information was applied to the marine plan to show how much (by percentage) each biotope was exposed to the potential impacts of the activities that occur within in each zone. Each biotope was scored from very high to no impact to show how it would be effected by being present in a certain zone and thus exposed to certain activities.

The estimates of likely impacts on biotopes as a result of them being present in zone and potentially affected by an activity is based on the results presented in table 6.5 (Tyler-Walters et al. 2009; Jones et al. 2000; Hiscock et al. 2005; Tyler-Walters and Hiscock 2005).

Table 6.4: The minimum percentage of each of the biotopes target of protection for Marxan with Zones in the Lyme Bay marine plan. The biotopes associated with the highlighted cells are more sensitive and their 20% protection is entirely within the no take zone.

		Percentage protected (%)	
Biotope	**Description**	**No take zone**	**Multiple use zone**
CR.HCR.Xfa	Mixed faunal turf communities	10	10
CR.HCR.Xfa and SS.SMx.CMx	Mosaic of mixed faunal turf communities and sublittoral mixed sediment	10	10
CR.HCR.XFa.ByErSp.Eun	*Eunicella verrucosa* and *Pentapora foliacea* on wave-exposed circalittoral rock	20	0
CR.HCR.XFa.ByErSp.Eun and SS.SMx.CMx	Mosaic of pink sea fans on rock and sublittoral mixed sediment	20	0
IR.HIR.KFaR.LhypR	*Laminaria hyperborea* with dense foliose red seaweeds on exposed infralittoral rock	20	0
SS.SCS.CCS	Circalittoral coarse sediment	10	10
SS.SCS.CCS.Blan	*Branchiostoma lanceolatum* in circalittoral coarse sand with shell gravel	20	0
SS.SCS.CCS.MedLumVen	*Mediomastus fragilis*, *Lumbrineris* spp. and venerid bivalves in circalittoral coarse sand or gravel	10	2
SS.SCS.CCS.Pkef	*Protodorvillea kefersteini* and other polychaetes in impoverished circalittoral mixed gravelly sand	20	0
SS.SCS.CCS.PomB	*Pomatoceros triqueter* with barnacles and bryozoan crusts on unstable circalittoral cobbles and pebbles	10	10
SS.SMp.Mrl.Pcal	*Phymatolithon calcareum* maerl beds in infralittoral clean gravel or coarse sand	20	0
LS.LMp.LSgr.Znol	*Zostera noltii* beds in littoral muddy sand	20	0
SS.SMp.SSgr.Zmar	*Zostera marina/angustifolia* beds on lower shore or infralittoral clean or muddy sand	20	0
SS.SMu.CsaMu	Circalittoral sandy mud	10	10
SS.SMu.CSaMu.TcomSinf	*Turritella communis* and *Scalibregma inflatum* in circalittoral sandy mud. New biotope proposed by Aquatonics.	10	5
SS.SMx.CMx	Circalittoral mixed sediment	10	10
SS.SMx.CMx.ClloMx	*Cerianthus lloydii* and other burrowing anemones in circalittoral muddy mixed sediment	10	5
SS.SMx.CMx.OphMx	Brittlestar bed. *Ophiothrix fragilis* and/or *Ophiocomina nigra* brittlestar beds on sublittoral mixed sediment	20	0
SS.SSa	Sublittoral sands and muddy sands	10	5
SS.SSa and SS.SMu.CSaMu	Mosaic of sublittoral sands and muddy sands	10	5
SS.SSa.CMuSa.AalbNuc	*Abra alba* and *Nucula nitidosa* in circalittoral muddy sand or slightly mixed sediment	10	5
SS.SSa.IFiSa.IMoSa	Infralittoral mobile clean sand with sparse fauna	10	5

Table 6.5: The sensitivity of each of the Lyme Bay biotopes to each activity. Key: Green - from MarLIN Sensitivity survey (online) available at <www.marlin.ac.uk/human-activity.php> (accessed 25/07/11), with data analysis published in Tyler-Walters and Hiscock (2005) and Hiscock et al. (2005); Yellow from Tyler-Walters et al. (2009)); Blue from Jones et al. (2000); Pink = no data

Biotope	Protected by 20% in the NTZ	Pots	Nets	Lines (same effects as angling)	Dredging	Bottom trawling	Angling	Diving
CR.HCR.Xfa		low		low	intermediate	intermediate	low	
CR.HCR.Xfa and SS.SMx.CMx		low		low	intermediate	intermediate	low	
CR.HCR.XFa.ByErSp.Eun	yes	moderate	very high	very high	very high	very high	very high	very high
CR.HCR.XFa.ByErSp.Eun and SS.SMx.CMx	yes	moderate	very high	very high	very high	very high	very high	very high
IR.HIR.KFaR.LhypR	yes	moderate	moderate	Moderate	moderate	moderate	moderate	moderate
SS.SCS.CCS					very low	very low		
SS.SCS.CCS.Blan		none	none	none	very low	very low	none	none
SS.SCS.CCS.MedLumVen		none	none	none	very low	very low	none	none
SS.SCS.CCS.Pkef					very low	very low		
SS.SCS.CCS.PomB		none	none	none	none	none	none	none
SS.SMp.Mrl.Pcal	yes	very high	very high	very high	very high	very high	very high	very high
LS.LMp.LSgr.Znol	yes	very high	very high	very high	very high	very high	very high	very high
SS.SMp.SSgr.Zmar	yes	very high	high	moderate	very high	very high	moderate	high
SS.SMu.CsaMu					moderate	moderate		
SS.SMu.CSaMu.TcomSinf					moderate	moderate		
SS.SMx.CMx					high	high		
SS.SMx.CMx.ClloMx					high	high		
SS.SMx.CMx.OphMx					high	high		
SS.Ssa					moderate	moderate		
SS.SSa and SS.SMu.CSaMu					moderate	moderate		
SS.SSa.CMuSa.AalbNuc		none	none	none	moderate	moderate	none	none
SS.SSa.IFiSa.IMoSa					very low	very low		

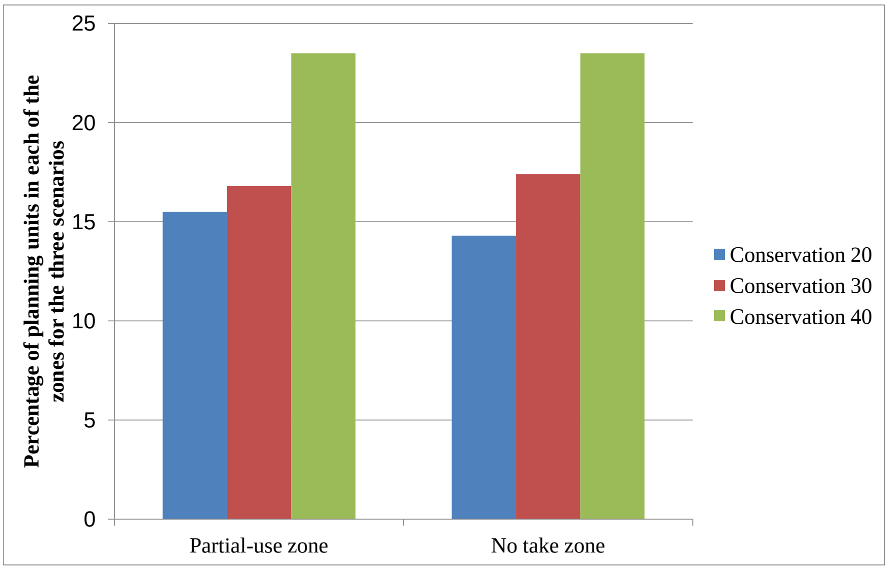


Figure 6.2: Percentage of planning units in each of the zones for the three Lyme Bay conservation scenarios.

6.2.2 Results

The nine scenarios with the three data layers (biotope, biotope and recreation and biotope and Fishermap) were used to explore the effects of using the data layers on the Marxan with Zones outputs and to investigate the calibration required to ensure that the parameters for the marine plan were optimal.

Step 1 (Figure 6.1) was producing the 20, 30 and 40 conservation scenarios. Increasing the target percentage for each of the biotopes in the PUZ and NTZ led to an increase in the amount of Lyme Bay being assigned to the partial-use and no take zones (Table 6.6) and to the increased clumping of selected areas. To protect 20% of each of the biotopes approximately 30% of Lyme Bay had to be included in one of the protected zones (Figure 6.3). Increasing the amount of each biotope by 10% (as occurred between each of the three conservation scenarios) required did not lead to a 10% increase in the number of planning units in one of the protected zones (Figure 6.2). This suggests that the initial 20% target captures many of the complexities of protecting a variety of habitats and that increasing conservation targets may not lead to comparable increase in the amount of area requiring protection.

The original conservation target was set at 20% because the configuration produced in scenario

Table 6.6: The number and percentage of planning units contained in the protected zones (partial-use and no take zones) for the Lyme Bay low, medium and high conservation scenarios.

Scenario	Number of planning units and percentage of planning units (out of 612)				Total number of planning units in protected zones and percentage of planning units (out of 612)	
	Partial-use zone		No take Zone		Combined results from partial-use zone and no take zone	
Conservation 20	95	15.5%	88	14.3%	183	29.8%
Conservation 30	103	16.8%	107	17.4%	210	34.2%
Conservation 40	144	23.5%	144	23.5%	288	47%

Conservation 20 had a high degree of clumping of the planning units within the zones (Figure 6.3) and this target allowed flexibility in the shape of the zones when additional socioeconomic data were added to the analysis. Also using this target led to approximately 30% of Lyme Bay being within a protected zone, agreeing with IUCN recommendations (IUCN 2003). Increasing the conservation target would reduce the amount of Lyme Bay available for recreational and fishing activities and reduce the potential flexibility of marine plan configurations.

Step 2 (Figure 6.1) was to include the recreation data. Including the recreation data in the scenarios changed the areas being chosen for the NTZ. Areas that had a high frequency of recreational activity were chosen less often for this zone. In the recreation scenarios, increasing the amount of habitat required to be in the partial-use zone led to there being more of Lyme Bay being included in the partial-use zone (55 planning units in Recreation and conservation 1:3, 78 in Recreation and conservation equal and 40 in Recreation and conservation 3:1) and also led to increased clumping of the outputs. Reducing the conservation target for the NTZ led to a reduction in the number of planning units in this zone (Figure 6.3). More activities can occur in the PUZ, with increased impacts on biotopes, this indicates that if recreation activities are prioritised over conservation objectives there would be a reduction in marine biodiversity protection.

Step 3 (Figure 6.1) was to include the fishing data. In the fishing scenarios, reducing the penalty applied when the biotopes were not protected by the required amount increased the weighting

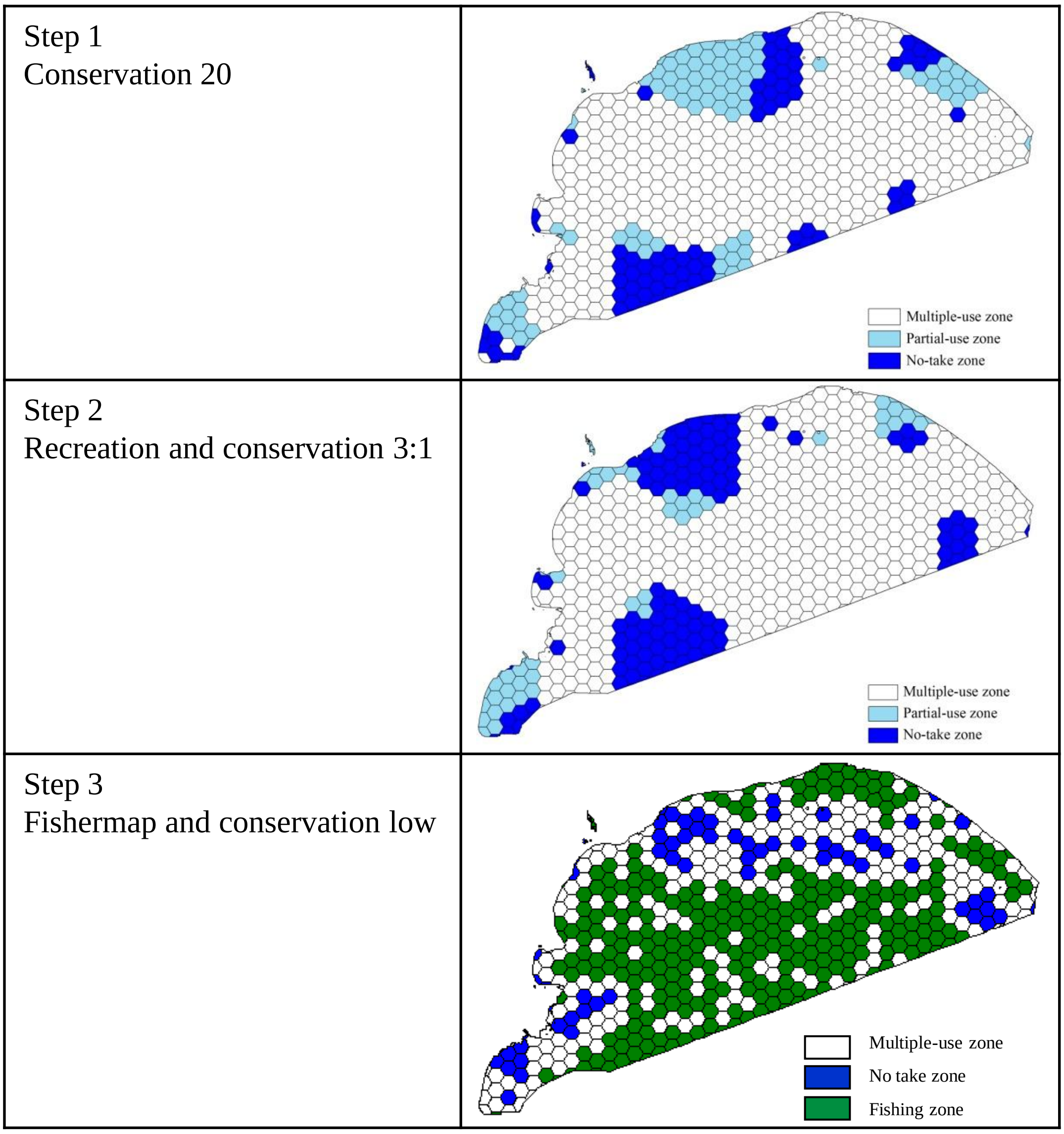
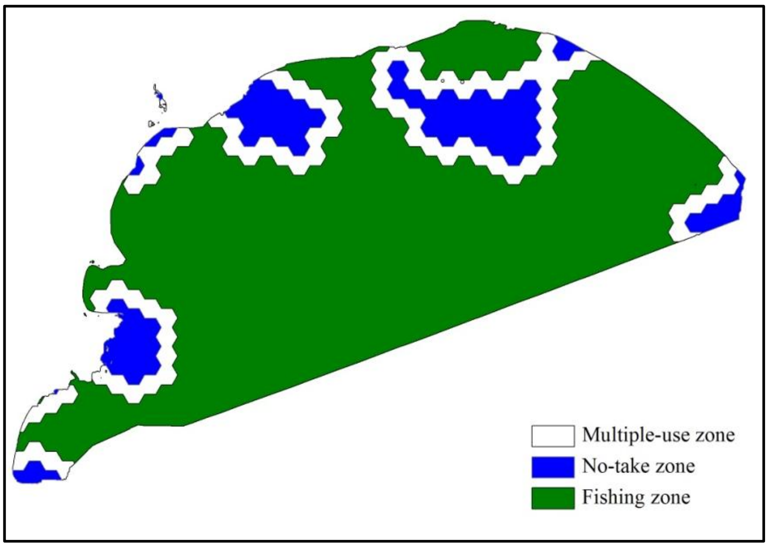


Figure 6.3: The best solution outputs with 20% biotope protection from the Lyme Bay Conservation 20, Recreation and Conservation 3:1 and Fishing and conservation low scenarios



Activity	Reduction in activity
Pots	13%
Nets	21%
Lines	17%
Scallop dredging	22%
Bottom trawling	13%
Recreation	12%

Figure 6.4: The best solution from the Lyme Bay marine plan scenario. The table on the right shows the percentage reduction on each activity of the plan.

of the fishing costs and reduced the importance of the conservation targets. In the Fishermap Scenarios approximately 55% of fishing was included in the fishing zone regardless of how conservation and fishing objectives were weighted. This is because most of Lyme Bay is used for fishing and therefore it is harder to avoid conflict between fishing and conservation targets. There was increased fragmentation of zones in all of the Fishermap and conservation scenarios compared to the conservation and recreation & conservation scenarios (Figure 6.3).

Lyme Bay Marine Plan

Step 4 (Figure 6.1) was to include objectives for conservation, recreation and fishing. The biotope and Fishermap data layers were used in the marine plan. The biotope sensitivity analysis (Table 6.5) was applied to the analysis to ensure that biotopes which were impacted by the various activities could be partially protected in zones where that activity did not take place. Not all of the biotopes were protected by 20% (Table 6.4). The biotopes that were found to be more robust in the analysis or had an area of over 10% of Lyme Bay had their target reduced so that the resulting output did not adversely affect the amount of fishing activity that took place and to ensure that the resulting output had clear, well-defined and buffered zones (Figure 6.4).

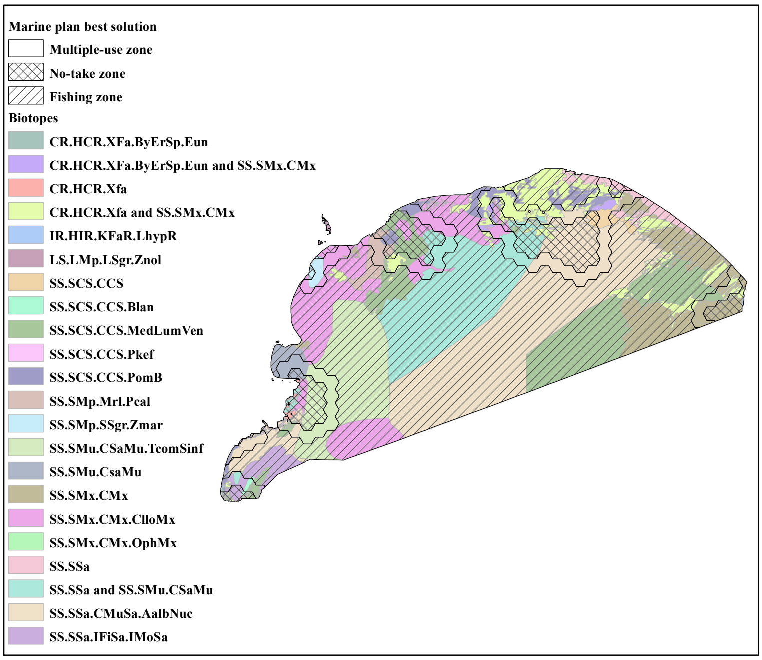


Figure 6.5: The best solution from the Lyme Bay marine plan scenario with the biotopes overlaid.

An analysis of the potential impacts of the plan on marine biodiversity was carried out (Table 6.7). The majority of Lyme Bay in this plan is not a protected zone and could potentially be impacted by fishing or recreation activities. Approximately 25% of Lyme Bay is within a protected zone and therefore not affected by the fishing activities which have the highest impact. Of the biotopes containing sensitive species one is entirely within the NTZ. The biotopes containing sensitive species are 20-30% within a protected zone and therefore 70-80% potentially impacted (Figure 6.5).

If recreational activities were excluded from the no take zone there would be a reduction in the recreation sector (Figure 6.4) with the potential monetary value reduction for recreation of approximately £2.2 million (Rees et al. 2010). The fisheries reduction in activity is between 13-22% with a potential monetary value reduction for all fisheries (17%) approximately £1.7 million (Stevens et al. 2007).

Table 6.7: Potential impacts of the permitted activities (within each zone) on each of the biotopes in Lyme Bay for the Fishing scenarios and the marine plan scenario. In the second, third and fourth columns: green no impact, amber medium impact, red high impact, white no information. The final two columns show how much each biotope could be impacted (high, medium or low/no impact) as a result of the activities that occur in each zone. In the final two columns a blank field indicates that no data were found on the impacts on the biotopes from the activities occurring within the plan area.

	The percentage of the biotope in each zone			**Potential impact on biotope**	
Biotope name	**In Multiple-use zone**	**In No Take zone**	**In Fishing zone**	**High (%)**	**Medium (%)**
CR.HCR.Xfa	55	20	25	0	80
CR.HCR.Xfa and SS.SMx.CMx	28	11	60	0	89
CR.HCR.XFa.ByErSp.Eun	37	29	34	71	0
CR.HCR.XFa.ByErSp.Eun and SS.SMx.CMx	43	30	27	70	0
IR.HIR.KFaR.LhypR	52	43	5	0	57
SS.SCS.CCS	54	42	4		
SS.SCS.CCS.Blan	71	19	10	0	0
SS.SCS.CCS.MedLumVen	10	14	76	0	0
SS.SCS.CCS.Pkef	56	25	19		
SS.SCS.CCS.PomB	33	12	55	0	0
SS.SMp.Mrl.Pcal	65	22	13	78	0
LS.LMp.LSgr.Znol	64	22	14	78	0
SS.SMp.SSgr.Zmar	46	42	12	58	0
SS.SMu.CsaMu	38	13	49		≥49
SS.SMu.CSaMu.TcomSinf	11	10	79		≥79
SS.SMx.CMx	11	10	79	≥79	
SS.SMx.CMx.ClloMx	18	10	71	≥71	
SS.SMx.CMx.OphMx	0	100	0	0	0
SS.SSa	20	12	68		≥68
SS.SSa and SS.SMu.CSaMu	15	10	75		≥75
SS.SSa.CMuSa.AalbNuc	13	10	77	0	77
SS.SSa.IFiSa.IMoSa	14	12	74		

6.3 Sound of Mull (SoM)

6.3.1 Methods

Two plans were created, with Marxan with Zones, using the data layers described in Chapter 4: biotope data, wreck frequency data, fishing species data, diving point data, skate angling areas and fish farm frequency using methods described in Chapter 3. A third plan, taken from the SoM MSP project was also used as a comparison and is described in Chapter 4.

The Zones used in the SoM Marxan with Zones analysis were:

- Multiple-use zone (MUZ)
- No-take zone (NTZ)
- Mobile gear zone (MGZ)

Some activities were allowed or excluded from occurring in each of the zones. This is to ensure that conservation objectives are met and that the most damaging activities have limited impact (Table 6.8). Low impact activities can take place in the no-take zone with the high impact activities occurring in the mobile gear zone (Figure 6.6).

The zones chosen for the SoM plans were partly a continuation of the Lyme Bay zones and chosen for the same reasons, although they covered a wider range of activities which was accounted for and tailored to the SoM area. More activity data were available for the SoM plan area so more activities could be assigned to zones.

In this case study a smaller amount of area compared to the previous case study, although still a large proportion (approximately 38%), is used for highly damaging activities. Also, the plans were designed to protect a wider variety of habitats than in the Lyme Bay case study and also included the protection of cultural assets. Therefore it was decided that the NTZ should have all activities except research and sailing through restricted. Also the more highly sensitive species had slightly higher targets in the NTZ.

In the MUZ all activities except highly damaging bottom trawling and dredging were allowed.

There are a variety of sensitive species in the SoM area and it was decided they required protection from these activities.

The MGZ was the business as usual zone with no new restrictions. Fishing is an important part of the SoM economy and culture, therefore it was considered important to have a zone with no restrictions so this and other potentially damaging activities could occur.

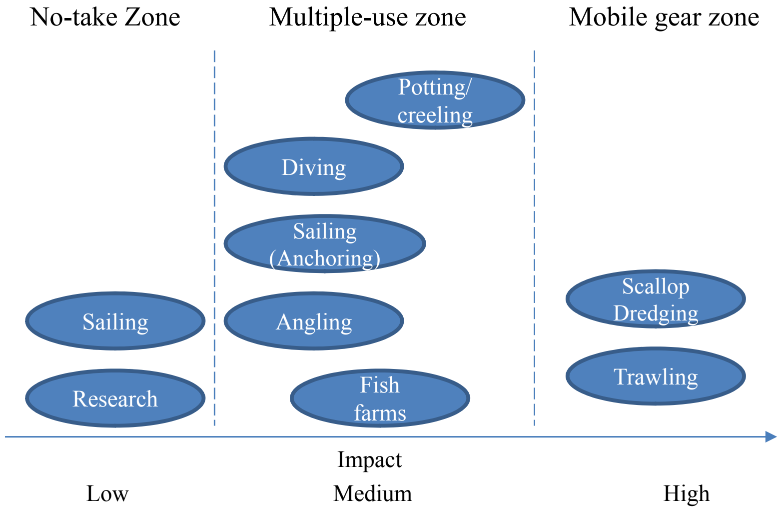


Figure 6.6: The scale of environmental impacts caused by human activities in each of the SoM zones.

Unmodified Plan

In this unmodified plan the settings in Marxan with Zones were applied in the standard way with no calibration or alteration to make the plan easier to implement and use. All the costs were applied as shown in Table 6.9 and the biotope protection target within the no-take zone and multiple-use zone was set at 10% for each zone.

Modified Plan

The costs, in this plan, were applied in the same way as the unmodified plan. The settings were calibrated to ensure increased clumping, a buffer of MUZ was encouraged around NTZ and parts of the SoM were locked into certain zones. The biotope protection target was varied between 15% and 20% target for the no-take zone.

An analysis was performed on the unmodified and the modified plans to evaluate how much

Table 6.8: The zones used in the Sound of Mull analysis for the unmodified plan and the modified plan. The crosses indicate which activities are allowed in each zone with any exclusions.

	Activity							
Zone	**Research**	**Angling**	**Diving**	**Sailing**	**Fish farms**	**Creel/potting**	**Scallop dredging**	**Trawling**
No take zone	x			x (no anchoring)				
Multiple use zone	x	x	x	x	x	x		
Mobile gear zone	x	x	x	x	x	x	x	x

of each activity or biotope was in each of the zones, to demonstrate potential impacts on the historic, environmental and socioeconomic sectors in the SoM.

There were seven main categories of costs applied within Marxan with Zones for the unmodified plan and the modified plan. Six of these were applied as costs in the zones (Table 6.9). The seventh cost is the feature penalty factor which is applied when the target for level of protection is not met in a feature, which in this case are biotopes. The amount a biotope contributes to meeting the feature target is different is in each of the zones. In the mobile gear zone there is no contribution to the target amount. The contribution is 1 in the no-take zone, that is each area of biotope contributes its entire area to fulfilling the target. In the multiple-use zone the contribution is 0.5 to reflect the reduction in protection in this zone. The costs were applied depending on if an activity is allowed to occur in a zone or if, in the case of wrecks, it will be protected within a zone (Table 6.9). For example, skate angling can occur in the MUZ and the MGZ so it is not applied as a cost within these zones.

Various levels of weightings were used within the plans. One of the most important, and overriding, cost was that the targets set for the features in each zone were met. The more sensitive species had higher targets in the NTZ. These targets had been calibrated to ensure that they could be met without significantly reducing the flexibility of the plans. A lesser weighted cost was the creation of a buffer between the NTZ and the MGZ. This was required to reduce edge effects but was weighted as less important than meeting the feature targets to maintain flexibility in the plans. It was assumed that the less robust habitats were only protected with the NTZ, although some protection would be given in the MUZ.

Table 6.9: How the costs were applied in the SoM Marxan with Zones analysis for the unmodified and modified plan. *x = cost applied. **Lobster or velvet crab costs were not applied in the MUZ. MUZ = multiple-use zone; NTZ = no-take zone; MGZ = mobile gear zone. ***Edge planning units are smaller.

		Zone type*		
Cost	**Data used as cost**	**MUZ**	**NTZ**	**MGZ**
Wrecks	Frequency in planning unit with 50 metre buffer	x		x
Diving	Frequency in planning unit		x	x
Skate angling	Percentage of PU where skate angling occurs		x	
Fish farm	Frequency		x	x
Fishing	Percentage of planning unit where fishing of species occurs	x**	x	
Area	Relative size of planning unit (PU) to full size PU***	x	x	x

The wrecks were not included in as features so targets for protection could not be explicitly set, but their protection was highly weighted and of similar importance to the protection of habitats. The wrecks are widely distributed and protecting them reduced the flexibility of solutions that Marxan with Zones could produce. It was assumed that the wrecks would not be protected in any zone except the NTZ, although it is likely that they would be more protected in the MUZ than they are at present and the officially designated wrecks should be protected in all zones.

Using the human activity data as costs reduced the flexibility of solutions that Marxan with Zones could produce, but were vital to produce solutions that would be acceptable to stakeholders in a non-theoretical situation. If this study were to be run to produce a MSP that were to be implemented within the SoM, stakeholder-based weightings would be used as costs within Marxan with Zones.

Impact of recreation and fisheries activities on biotopes in the Sound of Mull

An analysis of the likely effects of the recreational and fishing activities was carried out on each of the biotopes. The estimates of likely impacts from a biotope being in a specific zone or in the same location as an activity are based on the results presented in table 6.10 ((Tyler-Walters et al. 2009; Jones et al. 2000; Hiscock et al. 2005; Tyler-Walters and Hiscock 2005)). This information was applied to each of the three marine plans to explore by how much each of the biotopes was exposed to potential impacts. For the SoM marine spatial the extent of each of the activities occurring in the SoM was mapped on to the biotopes, to show the impact of current activities on each biotope.

An evaluation of the potential future effects of the key development objectives and policy guidance for each area of the SoM marine spatial plan was performed.

6.3.2 Results

The results from the analysis of the two plans created in Marxan with Zones were compared to the plan prepared by the marine spatial planning project for the SoM area. This plan is the Sound of Mull marine spatial plan and was developed based on the activities in the SoM. The MSP project investigated the activities that already occur with the SoM and therefore did not alter the current activities directly. The potential impacts of this plan on the wrecks and biotopes were analysed.

Comparison of the three plans

Unmodified plan

Standard settings were applied in this plan. The zones in this plan are widely scattered and this plan would be considered unworkable and would be very confusing to stakeholders (Figure 6.7).

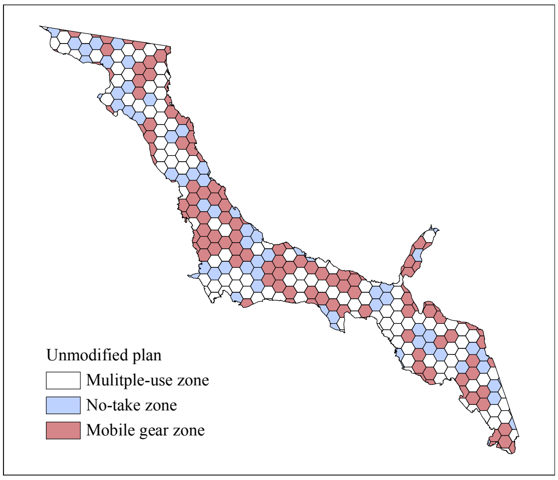


Figure 6.7: This Marxan with Zones output has the lowest objective function score for the Sound of Mull unmodified plan scenario. Low impact activities can occur within the no-take zone, low and medium activities can occur within the multiple-use zone and only mobile-gear fishing (high impact) can occur within the mobile gear zone.

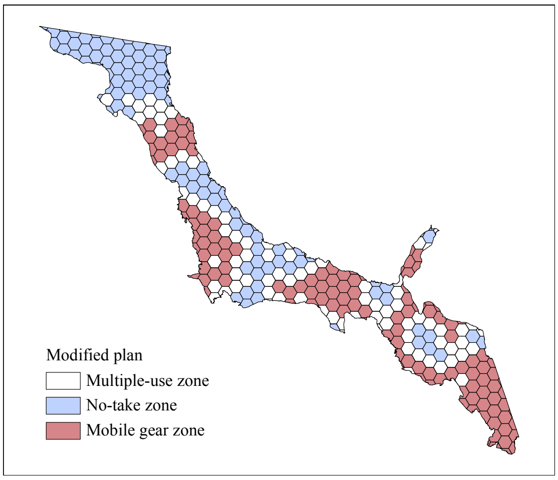


Figure 6.8: This Marxan with Zones output has the lowest objective function score for the Sound of Mull modified plan scenario. Low impact activities can occur within the no-take zone, low and medium activities can occur within the multiple-use zone and only mobile-gear fishing (high impact) can occur within the mobile gear zone.

Modified plan

This plan has been calibrated for clustering of zones and buffering of the NTZ (Figure 6.8).

SoM marine spatial plan

The SoM marine spatial plan, not created in this analysis and used for comparison, does not alter recreational or fisheries activities (Figure 6.9).

The impacts on biotopes of the three SoM Plans

An analysis of the potential impacts of the plan on marine biodiversity was carried out (Table 6.10)

Unmodified plan

A minimum target for all biotopes was set at 20% within the NTZ. To ensure that the socioeconomic activities were not highly impacted, some of the biotopes were not protected at this level but to compensate for this they were included in the MUZ (Table 6.11). Approximately 70% of the SoM is impacted in some way in this plan.

Table 6.10: The sensitivity of the SoM biotopes to each activity. From MarLIN website 2001 Sensitivity survey (http://www.marlin.ac.uk/human-activity.php - accessed 25/07/11, Tyler-Walters and Hiscock (2005), Hiscock et al. (2005)), Tyler-Walters et al. (2009)) and Jones et al. (2000); Pink = no sensitivity data found.* Refers to recreational diving and commercial dive fishing.

		Activity						
Biotope	**Description**	**Creel**	**Dredging**	**Trawling**	**Angling**	**Diving***	**Anchoring**	**Fish farms**
ACRT/FT	Algal crust/faunal turf	moderate	moderate	moderate	moderate	moderate	moderate	moderate
AlcFT	Faunal turf	moderate	moderate	moderate	moderate	moderate	moderate	moderate
BrAs	Faunal turf							
BrAs/ACRT	Algal crust/faunal turf	moderate	moderate	moderate	moderate	moderate	moderate	moderate
Burrowing fauna	Burrowing fauna							
CRS	Coarse sand							
Diverse Burrowing	Burrowing fauna							
Diverse Burrowing/Tra	Burrowing fauna							
EcorEns	Infauna	moderate	moderate	moderate	moderate	moderate	moderate	moderate
EcorEns/Abra	Infauna	none	moderate	moderate	moderate	moderate	moderate	moderate
EcorEns/Lan	Infauna	none	moderate	moderate	moderate	moderate	moderate	moderate
EcorEns/maerl	Maerl & infauna	very high	very high	very high	very high	very high	very high	very high
EcorEns/Oph	Infauna	moderate	high	high	moderate	moderate	moderate	moderate
FS	Muddy sand							
FT	Faunal turf	none	moderate	moderate	none	none	moderate	moderate
FT/EphR	Algal crust/faunal turf	none	moderate	moderate	none	none	moderate	moderate
Kelp/MUD	Kelp & infauna	moderate	moderate	moderate	moderate	moderate	moderate	moderate
LhypFt&P/OphX	Kelp forest & park	moderate	moderate	moderate	moderate	moderate	moderate	moderate
LhypFt/FT	Kelp forest	moderate	moderate	moderate	moderate	moderate	moderate	moderate
LhypFt/OphX	Kelp park	moderate	high	high	moderate	moderate	moderate	moderate
LhypPk/OphX	Kelp park	moderate	high	high	moderate	moderate	moderate	moderate
Lsac	Kelp	moderate	moderate	moderate	moderate	moderate	moderate	moderate
Lsac/BrAs	Kelp & infauna	moderate	moderate	moderate	moderate	moderate	moderate	moderate
Lsac/infauna	Kelp & infauna	moderate	moderate	moderate	moderate	moderate	moderate	moderate
Lsac/Maerl	Maerl & seaweed	very high	very high	very high	very high	very high	very high	very high
Lsac/Mod	Kelp & infauna	high	very high	very high	high	high	high	high
Lsac/Zos	Sea grass, kelp & infauna	very high	very high	very high	very high	high	very high	very high
LsacFt&P/BrAs	Kelp & infauna	moderate	moderate	moderate	moderate	moderate	moderate	moderate
Maerl	Maerl	very high	very high	very high	very high	very high	very high	very high
Maerl/EphR/FT	Maerl & seaweed	very high	very high	very high	very high	very high	very high	very high
Maerl/LhypFt	Maerl & seaweed	very high	very high	very high	very high	very high	very high	very high
Medium sand	Sand							
Mud	Mud							
Oph	Ophiura	moderate	high	high	none	none	moderate	moderate
Oph/Mod	Modiolus & infauna	high	very high	very high	high	high	high	high
Oph/Pom	Keelworm & infauna	moderate	high	high	none	none	moderate	moderate
Ophx	Brittle stars	moderate	high	high	none	none	moderate	moderate
OphX/Pom/FT	Brittle stars	moderate	high	high	none	none	moderate	moderate
Pom/Mod	Keelworm & Modiolus	high	very high	very high	high	high	high	high
VirOph	Infauna	very low	moderate	moderate	very low	very low	very low	moderate

Table 6.11: SoM unmodified plan impact on biotopes. No impact - white; very low - green; moderate - light orange; high - light blue and very high - purple. Pink = no data.

	Percentage of biotope within zone		
BIOTSUITE	**MUZ**	**NTZ**	**MGZ**
ACRT/FT	100	0	0
AlcFT	37	22	40
BrAs	62	31	7
BrAs/ACRT	100	0	0
Burrowing fauna	40	20	40
Coarse sand	80	18	2
Diverse Burrowing	50	19	30
Diverse Burrowing/Tra	100	0	0
EcorEns	73	27	0
EcorEns/Abra	69	31	0
EcorEns/Lan	62	38	0
EcorEns/maerl	40	21	38
EcorEns/Oph	75	25	0
Muddy sand	46	32	21
Faunal turf	52	21	27
FT/EphR	53	23	24
Kelp/MUD	44	22	34
LhypFt&P/OphX	38	21	41
LhypFt/FT	41	29	30
LhypFt/OphX	47	19	34
LhypPk/OphX	41	28	31
Lsac	44	19	37
Lsac/BrAs	40	19	40
Lsac/infauna	40	21	40
Lsac/Maerl	30	19	51
Lsac/Mod	43	22	35
Lsac/Zos	40	19	41
LsacFt&P/BrAs	42	19	39
Maerl	64	30	6
Maerl/EphR/FT	49	20	31
Maerl/LhypFt	58	20	22
Medium sand	50	34	16
Mud	42	26	32
Oph	45	28	27
Oph/Mod	100	0	0
Oph/Pom	41	37	22
Ophx	43	25	32
OphX/Pom/FT	43	31	26
Pom/Mod	39	21	40
VirOph	43	22	35

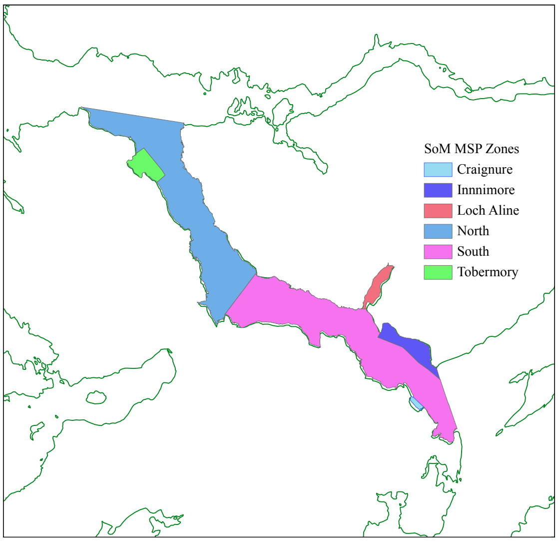


Figure 6.9: Sound of Mull marine spatial plan. This plan was developed during the Scottish Sustainable Marine Environment Initiative. All activities can occur in all zones. Data source Marine Spatial Plan project

Modified plan

Approximately 35% of the SoM is included in the NTZ with higher levels of the more sensitive species within this zone (Table 6.12). To create a simple plan for stakeholders the southern end of the SoM was allocated to the MGZ. Some biotopes only occur within this area and are therefore not protected at all.

SoM marine spatial plan

The results show that much of the SoM is impacted by the activities that occur within it (Table 6.14), in particular the less robust biotopes such as seagrass and maerl. The potential impacts of key development objectives are assessed (Table 6.13).

The impacts on wrecks, recreational and fishing activities of the three SoM Plans

The number of wrecks that are within each of the zones was analysed (Table 6.15). In the unmodified plan all of the wrecks are in the multiple-use zone and the no-take zone. In the modified plan five of the wrecks are within the mobile gear zone and therefore may be damaged by, for example, trawling or anchoring. The protected wreck, the Swan, is also in the mobile gear zone, but would still be protected under the Protection of Wrecks Act (1973).

Table 6.12: SoM modified plan impact on biotopes. No impact - white; very low - green; moderate - light orange; high - light blue and very high - purple. Pink = no data.

	Percentage of biotope within zone		
BIOTSUITE	**MUZ**	**NTZ**	**MGZ**
ACRT/FT	0	100	0
AlcFT	6	86	8
BrAs	0	0	100
BrAs/ACRT	0	100	0
Burrowing fauna	39	20	41
Coarse sand	0	4	96
Diverse Burrowing	81	19	0
Diverse Burrowing/Tra	0	100	0
EcorEns	0	100	0
EcorEns/Abra	0	100	0
EcorEns/Lan	0	100	0
EcorEns/maerl	0	35	65
EcorEns/Oph	0	100	0
Muddy sand	0	100	0
Faunal turf	5	33	62
FT/EphR	18	81	1
Kelp/MUD	56	22	22
LhypFt&P/OphX	28	45	28
LhypFt/FT	18	78	4
LhypFt/OphX	19	21	60
LhypPk/OphX	16	61	23
Lsac	33	21	46
Lsac/BrAs	15	25	61
Lsac/infauna	38	21	41
Lsac/Maerl	32	22	45
Lsac/Mod	28	21	50
Lsac/Zos	33	23	44
LsacFt&P/BrAs	27	23	50
Maerl	0	100	0
Maerl/EphR/FT	9	43	47
Maerl/LhypFt	0	57	43
Medium sand	0	100	0
Mud	12	72	16
Oph	3	78	19
Oph/Mod	0	100	0
Oph/Pom	0	0	100
Ophx	42	28	30
OphX/Pom/FT	1	80	19
Pom/Mod	26	21	53
VirOph	47	29	24

Table 6.13: Potential changes as a result of key recommendations in the SoM marine spatial plan

SoM area	Key recommendation	Effect
North	Development of permanent mooring blocks on on wrecks popular with recreational divers	Decrease impact from anchoring Potential increase in number of divers and their associated impact
	Expand finfish farming	Potential impact on sensitive species
South	Development of permanent mooring blocks on on wrecks popular with recreational divers	Decrease impact from anchoring Potential increase in number of divers and their associated impact
	Expand finfish farming	Potential impact on sensitive species
Loch Aline	Shell fish farming	Potential impact on sensitive species
Inninmore	Development of permanent mooring blocks on on wrecks popular with recreational divers	Decrease impact from anchoring Potential increase in number of divers and their associated impact
Tobermory	Business as usual - no major changes	N/A
Craignure	Business as usual - no major changes	N/A

The SoM marine spatial plan does not have any protective zones so all of the wrecks are potentially at risk. Dangerous or protected wrecks are marked on the UK Hydrographic Office charts. Under the Protection of Wrecks Act (1973) the seabed within a 50 metre area around the wreck is a restricted area.

The potential reduction in recreation activity was analysed (Table 6.16). For the unmodified plan 14% of skate angling and and 37% of diving occur in the no-take zone, in which these activities are excluded. Therefore if this plan were enacted skate angling and diving could have potential losses. In the modified plan the potential reduction was 13% for skate angling and 42% for diving. The SoM marine spatial plan is based on current activities and there are no exclusions therefore no reduction in the recreational activities occured in the SoM marine spatial plan.

In both the unmodified plan and the modified plan the fishfarm bases were present in the MUZ and so were not affected. The net washing areas were, for both plans, in the MGZ and not affected.

Table 6.14: SoM marine spatial plan impact on biotopes. No impact - white; very low - green; moderate - light orange; high - light blue and very high - purple. Pink = no data. Dive fishing refers to commercial scallop diving.

	Percentage of biotope affected by activity							
BIOTSUITE	Creel	Dredge	Trawl	Anchoring	Dive	Dive fishing	Skate	Fish farm
ACRT/FT	79	20	0	0	0	0	0	0
AlcFT	9	59	1	0	<1	15	1	0
BrAs	0	0	0	0	0	0	0	0
BrAs/ACRT		0	0	0	0	0	0	0
Burrowing fauna	4	32	10	0	<1	6	33	0
Coarse sand	0	0	1	0	0	0	4	0
Diverse Burrowing	0	100	0	0	0	55	0	0
Diverse Burrowing/Tra	80	0	0	0	0	82	0	0
EcorEns	38	0	0	0	2	99	0	0
EcorEns/Abra	41	0	0	0	2	61	0	0
EcorEns/Lan	66	34	0	0	0	100	0	0
EcorEns/maerl	91	2	0	0	0	64	0	0
EcorEns/Oph	12	86	0	0	0	80	0	0
Muddy sand	6	2	61	0	0	18	0	0
Faunal turf	0	11	25	0	0	1	5	0
FT/EphR	0	17	0	0	0	0	2	0
Kelp/MUD	33	33	0	0		39	0	0
LhypFt&P/OphX	73	0	0	1	2	67	7	0
LhypFt/FT	68	0	0	5	1	67	1	0
LhypFt/OphX	72	19	0	6	4	50	19	0
LhypPk/OphX	41	41	0	0	1	70	0	0
Lsac	66	0	0	4	<1	28	0	1
Lsac/BrAs	66	0	0	3	<1	33	0	<1
Lsac/infauna	45	20	0	0	1	30	6	1
Lsac/Maerl	60	0	0	0	<1	2	1	2
Lsac/Mod	65	5	0	0	<1	51	2	0
Lsac/Zos	66	0	0	0	<1	39	0	0
LsacFt&P/BrAs	78	9	0	0	<1	58	0	0
Maerl	26	0	0	0	1	27	0	0
Maerl/EphR/FT	65	14	16	0	<1	62	11	0
Maerl/LhypFt	67	0	0	0	0	47	0	0
Medium sand	0	2	98	0	3	0	0	0
Mud	3	25	21	0	<1	1	12	0
Oph	18	29	37	0	0	21	3	0
Oph/Mod	100	0	0	0	0	0	100	0
Oph/Pom	1	0	68	0	0	1	0	0
Ophx	0	44	10	0	0	1	31	0
OphX/Pom/FT	24	54	18	0	0	35	3	0
Pom/Mod	7	67	4	0	<1	15	6	0
VirOph	9	33	4	0	<1	5	41	0

Table 6.15: The zones the wrecks are in for each of the three SoM plans. MUZ = multiple-use zone; NTZ = no-take zone; MGZ = mobile gear zone; SoM MSP = Sound of Mull Marine Spatial Plan.

	All wrecks				Protected wrecks			
	MUZ	NTZ	MGZ	SoM MSP	MUZ	NTZ	MGZ	SoM MSP
Unmodified plan	4	40	0		1	1	0	
Modified plan	10	29	5		1	0	1	
SoM MSP				44				2

Table 6.16: The potential reduction (%) in recreation activities for the Marxan with Zones SoM plans

	Percentage of skate angling taking place in each zone			Percentage of diving taking place in each zone		
	MUZ	NTZ	MGZ	MUZ	NTZ	MGZ
Unmodified plan	59	14	27	58	37	5
Modified plan	44	13	42	47	42	12

Table 6.17: The potential reduction in commercial fishing activities for the SoM plans. SoM MSP = Sound of Mull marine spatial plan (%)

Activity	Reduction in activity for:		
	Unmodified plan	Modified plan	SoM MSP
Lobster	0	0	0
Prawn	53	56	0
Queen scallop	42	42	0
Scallop	48	63	0
Scallop and prawn	69	87	0
Velvet crab and lobster	18	18	0
Velvet crab and prawn	3	0	0

For the unmodified plan and the modified plan the mobile gear fisheries were the most highly impacted (Table 6.17) because these fisheries are excluded from two of the zones. In contrast the creel fisheries were much less affected.

6.4 Discussion

This study (Lyme Bay and SoM) has shown that Marxan with Zones can be used to integrate and weight data from fishing, aquaculture and recreation sectors to produce a marine plan. It has also highlighted the potential compromises required and shown that if marine heritage and biodiversity are to be protected each sector will have to reduce the impact it has on the marine environment. In the Lyme Bay case study three different types of data were integrated and this facilitated the development of a marine plan with a reduced impact on the recreation and fishing sectors. The plan also had protected all of the sensitive habitats over 20% and the more robust habitats over 12%. In the SoM case study six types of data were integrated. The SoM study highlighted that it was not possible to meet conservation objectives and have no effect on recreation, fishing and aquaculture activities, although using Marxan with Zones reduced potential impacts.

Few studies have used Marxan with Zones to integrate data from many sectors. A marine planning exercise carried out in St Kitts and Nevis (Agostini et al. 2010) integrated fisheries, tourism, industrial activities and conservation (species and habitats) data. It found that many compromises were required and that not all goals could be met as highlighted in the research presented here. As the number of activity use data layers increases in a marine plan the flexibility of solutions is reduced. Targets, especially if not set at realistic levels (an issue in the St Kitts and Nevis study) are unlikely to be met. The targets in the St Kitts and Nevis study may be considered to be unrealistic because the levels of protection were set at 100% with little change in activities. In this study using different proportions of protection in the Lyme Bay conservation scenarios highlighted that having a target for protection of over 20% led to over a third of Lyme Bay being included in a protected zone. This suggested that a target of over 20% was unrealistic and that a target below this would lead to the least reduction in activities.

Current policy (Marine and Coastal Access Act 2009) will lead to the creation of a series of marine spatial plans around the UK coast. The area of the first marine plan to be designated in England (Eastern Area onshore and offshore area are being planned together) is used extensively (MMO and Marine Scotland 2012*b*) by potentially impacting activities, for example fishing, aggregate dredging and windfarms (Cefas 2010*a*). A further eight Marine Conservation zones are due to be designated in the planning area. High level objectives have been set for this plan (MMO 2012*b*), specific targets and weightings have not been set. It is important that when they are set it is an open process and the targets are flexible.

Incorporating socioeconomic costs into a marine spatial plan can be used to explore which areas are important to each sector and to investigate how marine space can be allocated. For example, when comparing the Lyme Bay conservation and recreation scenarios, it can be seen that in some cases different areas are selected for protection (Figure 6.3). Areas of high recreation use were chosen less for the NTZ, from which recreation activities were excluded in this scenario. In the SoM modified and unmodified scenarios the planning units containing wrecks were highly likely to be included in a zone from which mobile fishing gear was excluded (Table 6.17).

The weightings used in both case study areas were the frequency of an activity in a planning unit or the percentage of a planning unit that an activity occurred in. Other studies have used equal weightings between sectors (MMO 2012*c*) and the MARS (Marine Resource System) DST developed by the Crown Estate uses multi-criteria analysis to identify areas that are suitable for marine renewable energy deployment. They are many other ways to weight sectors against one another, for example a report produced by the MMO and Marine Scotland (2012*a*) recommends that weightings can be devised using: multi-criteria assessment, trade-off analysis, and life-cycle analysis to create monetary or expert values. Ban and Klein (2009) highlighted how using variable costs, such as fishing activity data, instead of uniform costs, e.g. area, can reduce the impact of marine conservation planning on marine resource users. Giakoumi et al. (2011) developed three proxy cost indices to indicate cost implications for fishers and recreational activities. The three indices were then used to identify priority areas for conservation. The proxy measures were: (i) planning unit distance from the nearest port, (ii) planning unit wind exposure and (iii) tourism benefits. The study found that using costs i and ii best represented fishing activity and led to different areas being chosen for protection. Areas selected for protection would exclude fishing activity. Therefore, it is important that how sectors were weighted against one other was an open process and that once agreed they are applied consistently. The UK Marine Policy Statement discusses the need to weigh sectors against each other and their potential impacts on the environment. It recommends that actions be taken to minimise impacts but if the benefits outweigh the risks then the activity should be allowed to proceed (HM Government 2011).

This study has shown that incorporating weighting into marine plans can show what compromises have to made and where. Using the recreation data in the Lyme Bay study highlighted that if conservation were to be considered more important than recreation over 80% sites currently used for recreation would be unavailable. Using the fishing data in both the Lyme Bay and SoM scenarios ensured that the most heavily fished areas were not included in protected areas of the marine plans. In both the case study areas much of the area was fished, so a large reduction in some fishing activities was required for the conservation targets to be met (Figure 6.4 and Table 6.17).

Habitats that are heavily fished are likely to be degraded and have low quality habitat, so this weighting also encourages Marxan with Zones to choose higher quality habitats for protection. For example, in Lyme Bay in the fishing scenarios and the marine plan scenario, the most heavily fished areas are rarely included in a protected zone (Figure 6.4 and 6.3). Whereas in the conservation and recreation scenarios (which do not contain fishing cost data) different areas, which are heavily fished, are chosen for protection (Figure 6.3). By not including areas important to the fishing industry, it is probable that the amount of displacement of fishing activity to previously unfished areas will be reduced. The implementation of the closed area in Lyme Bay in 2008 lead to displacement of scallop fishers, who used to fish in the closed area (Stevens and Attrill 2013), to less productive areas and areas fished by static gear fishers (Fleming and Jones 2012). This has resulted in increased conflict between scallop fishers and static gear fishers. Scallop fishing now occurs more intensively in smaller parts of Lyme Bay.

In the Lyme Bay marine plan scenario, when sectors were weighed against each other each sector had to compromise. Biotopes which had a large area in Lyme Bay and were less sensitive had reduced targets so that more sensitive species could be included in the protected zones. The IUCN states that MPA networks should be representative (IUCN 2003) as does the ecological guidance for the creation of a network of MCZs (Natural England and Joint Nature Conservation Committee 2010). The guidance document also states that each of the 23 broad-scale habitats be protected between 13-42%. In the SoM marine spatial plan, no protection has been given to sensitive species although the plan was created to help sustainable development (SSMEI 2010*b*). This thesis did not attempt to assess cumulative impact but as some areas of the SoM are used for multiple activities it is likely this will be a factor for some species and this analysis under-reports the impacts. A report (Cefas 2010*a*) assessed the intensity of human pressures using common generic pressures (such as abrasion, smothering and siltation) to produce a GIS multi-criteria analysis tool that could be used to quantify risk of cumulative impacts.

In the SoM marine spatial plan the wrecks that are not designated (under the Protection of Wrecks Act 1973) are potentially impacted. There are 61 designated wrecks in UK waters (8 in Scottish waters) with over 40,000 marine sites over the English coast registered with the

National Monuments Record. There are 13,500 known wreck sites and no studies have been carried out to assess the impacts of human activities on wrecks (Roberts and Trow 2002). There is a requirement under the Marine and Coastal Access Act 2009 to protect sites of a historic or archaeological nature. This study has highlighted how many potential historic marine sites are affected by human activities and how little protection an important part of the UK's heritage receives. In the SoM marine spatial plan no socioeconomic activities were affected. It is likely that by not changing the way the SoM is used, socioeconomic activities will be affected in the long term. For example, various fish stocks (e.g. cod, herring, saithe) have declined and are no longer viable in some Scottish waters over the past 40 years and now the main fisheries are for prawns (*Nephrops norvegicus*) and scallops (Magill et al. 2009).

As shown in this study site selection tools can be used at a variety of scales. In larger areas they may be used to indicate general areas to protect (Balanced Seas 2011*b*), in smaller areas they could assign each area to a specific zone (Watts et al. 2009). In this study Marxan with Zones produced fewer solutions for the case study with the smaller area (SoM). This is because the whole area was used for at least one activity and there were small areas of highly sensitive habitats (seagrass and maerl) scattered throughout the planning area. In the Lyme Bay case study because fewer habitats were spread over a larger area, Marxan with Zones was able to produce many highly flexible solutions although fisheries were affected. If a representative network of MPAs was created around the UK coast this issue would be reduced at the local scale.

By adding each data layer in to the program one at a time, this study has shown which areas of Lyme Bay were important for each sector, and has been able to investigate multiple scenarios for each sector. For example, by using fishing data and conservation data the study could determine at which point the different sectors' objectives began to compromise the other sector. When all of the data were added to the program to create the marine plan, it was necessary to ensure that while as much biodiversity was protected as possible that the larger biotopes, that were shown to be robust by the sensitivity analysis, were not allowed to overly compromise the recreation and fishing sectors.

As each data layer was added to the analysis, the influence of each cost on the final configuration within the separate scenarios was considered. In some cases increasing or decreasing the weighting led to changes, as suggested in previous studies (Ban and Klein 2009; Giakoumi et al. 2011). In the fishing and conservation scenarios decreasing the importance of the conservation targets made little impact on the amount of fishing activity that was included in the fishing zone. This suggests that it was the combination of factors, such as the importance of reducing fragmentation and the configuration of the conservation features, that were important factors and these reduced the programme's ability to minimise the level of fishing activity that would be effected by the configuration.

This study has shown that, in the case study areas, each of the sectors needed to compromise, as highlighted in previous research (Christensen et al. 2009; Gleason et al. 2010; Stewart and Possingham 2005). For example, the conservation targets had to be reduced to ensure that the marine plan zones were practical (Figure 6.4 and 6.8) . In the Lyme Bay case study although fishery costs were included, because all the Bay is used by the fishing industry, a reduction of 17% was necessary to meet even the reduced conservation targets. If recreational activites were excluded from the no take zone the recreation industry would lose 12% of their potential sites to the no take zone. In the optimum solution for this study approximately 10% of the Lyme Bay area is completely protected from some damaging activities and about 30% from the most highly impacting activities. This means that up to 70% of the area is potentially impacted. In the SoM modified scenario the average reduction in fishery activity was 38%. As only a very small amount of the UK's seas are fully protected, up to 99% are potentially impacted by human activities. It is clear from this research and previous studies that there will need to be cooperation from each of the sectors that compete for space and there will have to be fair and transparent ways of addressing competing demands (Adams et al. 2011; Watts et al. 2009; Klein et al. 2009).

The creation of marine plans will need to ensure current and future sustainable use of the marine environment. This study has highlighted some of the compromises that will occur during the marine planning process. It has shown how using transparent methodology can aid the marine planning process by making the decisions used to reach the compromises explicit.

In this chapter the compromises required by each of the sectors within the two case study areas were assessed for them to fulfil or partially fulfil their objectives. The next chapter will evaluate the impacts of using confidence levels in habitat data on marine biodiversity protection.

Chapter 7

Incorporating modelled data confidence in marine planning

7.1 Introduction

Currently marine conservation assumes that data on habitats and species presented for use in marine planning are equal in accuracy, precision and value (Moilanen et al. 2006). This is not always the case with data based on a wide range of sources including routine government monitoring, specific innovative research and stakeholder based data gathering. Therefore, some data will undoubtedly have a greater certainty associated with them and it might be appropriate that they carry greater weight in the plan making process. How the different levels of certainty about datasets can be incorporated into the planning outputs is not clear but this is a challenge which needs to be addressed, especially given the widespread uncertainty in the marine environment (McBreen et al. 2011).

High quality habitat maps are important in marine planning. Fully-ground truthed seabed mapping data are only available for 6% of the UK marine environment (McBreen et al. 2011). To address this issue, modelled data for single species occurrence, presence only, presence/absence data (Marshall 2012; Monk et al. 2011) and habitats (Ierodiaconou et al. 2011; Robinson et al. 2011) are being developed. When using modelled data it is important to know the confidence of the models' predictions. Confidence assessments of modelled data are now being created to test and quantify the probability of the model predictions of where habitats are to be found (Robinson et al. 2011) and to compare the outcomes of different models (Ierodiaconou et al. 2011).

Explaining the uncertainty in environmental data to decision-makers is important so that they can understand why there is low confidence in data available and that data in which there is a high confidence are not likely to be obtainable in the near future. In the marine environment there are key problems associated with the data being used:

- widespread use of habitat data which are based on sediment type rather than field observation,
- uncertain species identification,
- uncertainty of exact position of samples,
- changing benthic and hydrodynamic conditions can reduce the reliability of datasets. These changes can be from human activity (e.g. physical removal of rocks and boulders by bottom trawling) or because an environment is dynamic (e.g. moving sandbanks as a result of storms),
- data may not refer to quality of habitat, rather scope for it to be present,
- the size of the marine environment means that complete ground-truthing is unfeasible,
- the distance between samples is often larger than the size of habitat patches or the resolution of the data used if the habitat patches are smaller than the resolution of the data (Stevens 2005) and
- the multiple layers used may have different scales and so not match up.

Other issues include human or large scale impacts such as fishing, aggregates, dumping and climate change (Marshall 2012).

There are complex ways of expressing and incorporating uncertainty within marine planning software. For example, Beech et al (2008) incorporate uncertainty into marine reserve design by calculating the likely margin of error for habitats and incorporating this into a spatial algorithm as a cost function. This results in a potential network of MPAs with a probability distribution of the likely inclusion into network of planning units. However, the results from these methods are not currently able to be incorporated clearly into current marine planning software and need a high level of technical and mathematical ability to understand. For the methods of Beech et al. (2008) to be incorporated into current DSTs, further development of these tools would be necessary.

Decision-makers need to understand the implications of uncertainty of data to be better able to determine the appropriate course of action. Cabeza et al (2004) applied a single algorithm in spatial reserve design with the probability of occurrence over of 26 butterfly species in a highly surveyed area in north east Wales. This study found that a heuristic algorithm chose sites with the higher probabilities of species occurring for inclusion in the protected areas. This is likely to lead to higher quality habitat being selected. Moilanen et al (2006) estimated the probability of occurrence for seven fauna species of conservation importance in south eastern Australia and the confidence in the estimate. This information was then combined with conservation value, and using the site selection program Zonation, used to produce a protected area network. The program, Zonation, can be used to indicate sites important for conservation goals. The sites were more likely to be picked if they had a higher associated confidence. Preferentially choosing areas for protection in which there is high confidence may lead to selection of areas that have been highly surveyed but not necessarily important for conservation. Sites that have been highly surveyed are often close to the coast. Areas close to the coast tend to have higher levels of activity in them and including these sites for protection may increase conflict between conservation objectives and human activities.

Using modelled data with various levels of confidence means that, when using current data, it is not possible to know if MPA networks are representative. The data are so uncertain that some of the areas chosen to represent a certain habitat are likely to not contain it. The UKSeaMap 2010 data used in this study has various levels of confidence, with only 34% of the UKSeaMap 2010 data being above 50% confidence; much of the highly uncertain areas are offshore in the far north west region around Rockall Bank. If only the high probability areas are used much of data concerning the variability of the marine environment is lost.

This means that marine spatial planning cannot proceed with confidence in the data that are currently available. It is likely that as new data become available, marine plan zones will have to be changed. Zones may need to be moved or additional zones may be required. It will be important to ensure that decision-makers understand that marine plans may not be set in position and will require updating and adaptive management (Ehler and Douvere 2009). Planners may suggest that only data with the highest confidence levels are used but most marine habitat data has low confidence. Only using data with high confidence would lead to highly surveyed areas being protected.

7.1.1 Chapter aims and objectives

The aim of this chapter is to analyse the implications of differing uncertainty in data used for marine planning.

The objectives of this chapter are:

- to perform an analysis of the impact of using different confidence levels on habitat protection,
- to contrast outputs created using data of different confidence levels with modelled and ground-truthed (EUNIS) data and
- to consider how outputs can best be presented for decision-making fora.

This chapter will be fulfilling one of the overall objectives for this PhD:
Objective 6. to evaluate the impacts of using confidence levels in habitat data on marine biodiversity protection.

7.2 Methods

7.2.1 Study area

The case study area is the eastern part of the English Channel (Figure 4.15). This area is part of the Balanced Seas Marine Conservation Zones project region (Balanced Seas 2011*b*) and has recent (2010) high resolution biotope data. It is a much larger area than the previous case study areas allowing a comparison to be made on a different scale using Marxan with Zones.

Table 7.1: The scenarios explored in this analysis, the confidence level of the data for each scenario and the proportion of data available for each confidence level.

Scenario name	**Confidence level**	**Proportion of data available (%)**
CLover0	All data	100.0
CLover10	Over 10%	98.5
CLover20	Over 20%	80.7
CLover30	Over 30%	48.8
CLover40	Over 40%	24.2
CLover50	Over 50%	9.5
CLover60	Over 60%	6.1
CLover70	Over 70%	2.2
EUNIS	EUNIS data	N/A

More information on this area can be found in the case study chapter (chapter 4). This area is used intensively by many users. The main activities are fishing, aggregate dredging, shipping, a wind farm development and recreational yachting. The methods used to manipulate the data and create the plans are described in Chapter 3.

Two zones are used in this study: an unprotected zone and a protected zone.

7.2.2 Confidence levels within the data

The data used in this study are: the UKSeaMap 2010 data and biotope data for the Eastern English Channel (James et al. 2011). The UKSeaMap data were split into 10% confidence bands (Figure 7.2 and Table 7.1). The confidence of the UKSeaMap data was assessed by calculating the confidence of each data layer used to create the UKSeaMap 2010 habitat data (McBreen et al. 2011), for a further discussion of this see the Case Studies chapter (Chapter 3). The confidence is low for much of the UKSeaMap data over the whole of the UK (Figure 7.1). The darker patches indicate areas which have been surveyed and therefore confidence is higher. Only a very small amount of the area has data with confidence over 70% (2%) with over half of the data having a confidence of below 40% (Figure 7.3).

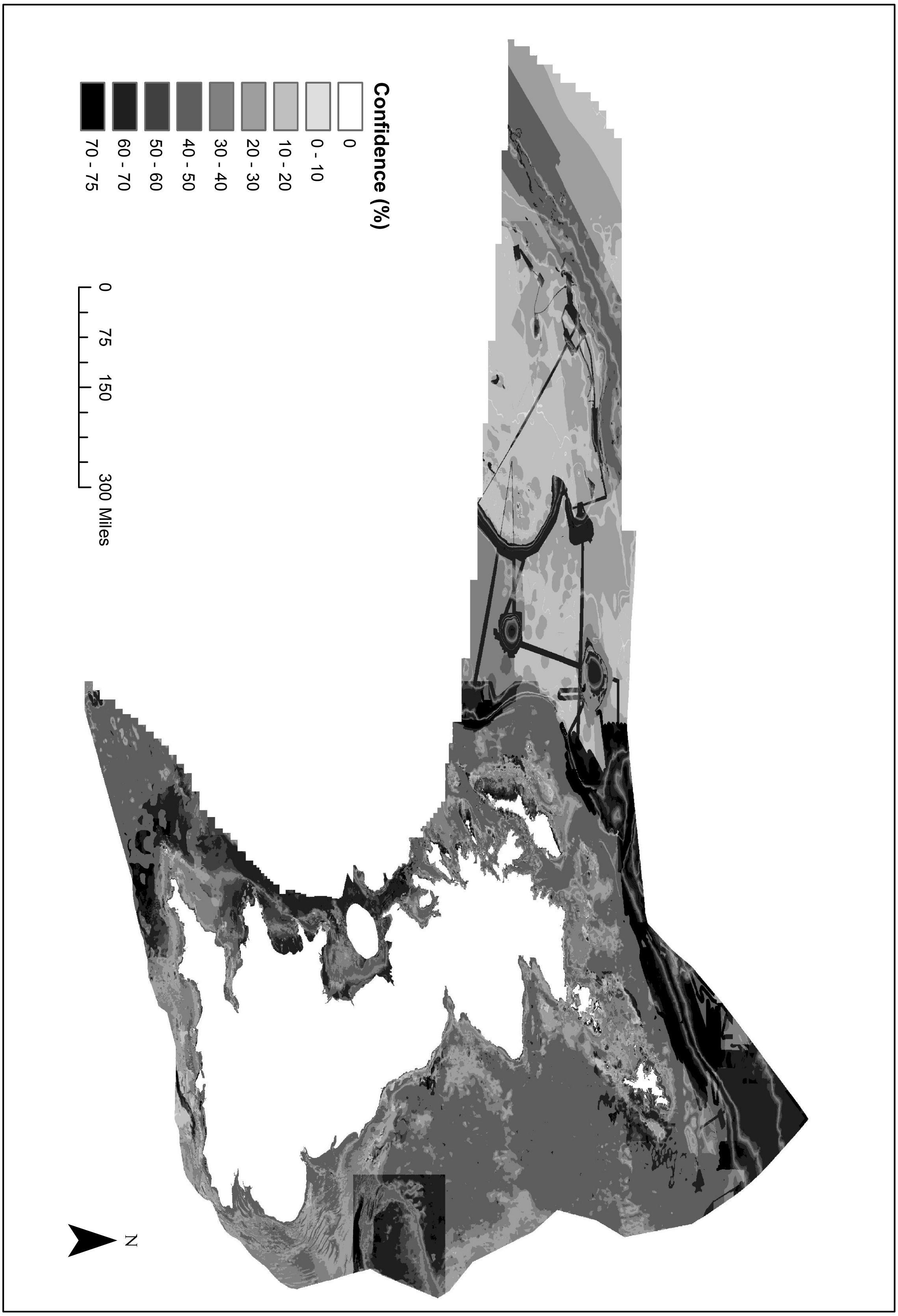


Figure 7.1: Confidence of UKSeaMap 2010 data for UK in 10% bands.

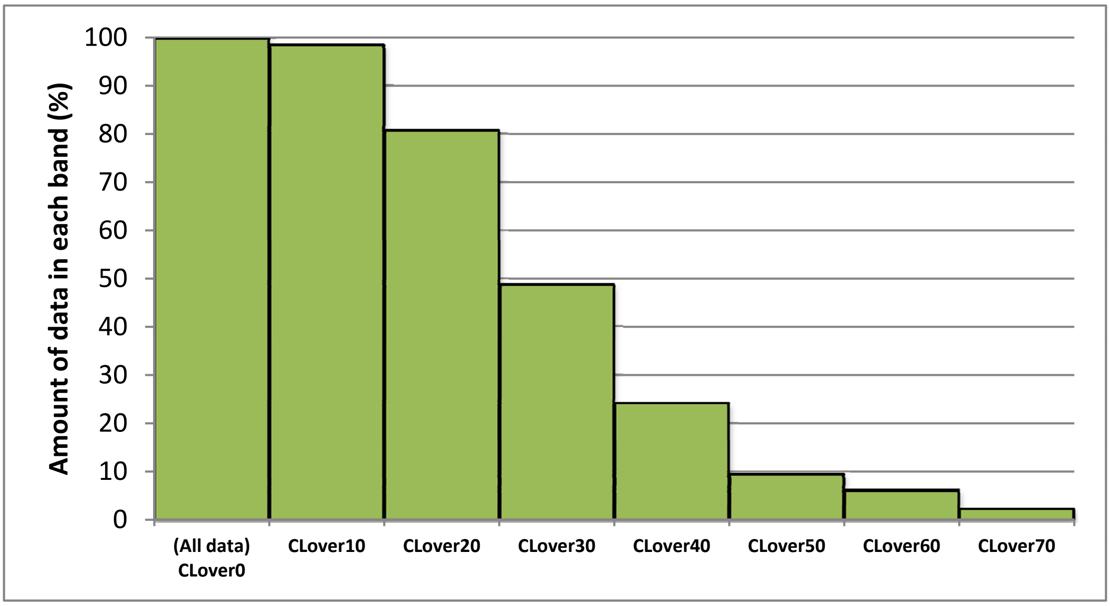


Figure 7.2: The proportion of UKSeaMap data over each confidence level (for the entire UK dataset)

7.2.3 East Channel Scenarios

To explore the impacts of using different levels of confidence data this study will run nine scenarios in Marxan using two datasets. Eight scenarios will use different subsets of the UK-SeaMap data depending on their confidence levels (Table 7.1), while the ninth scenario will use EUNIS data. The EUNIS data is a good comparison because EUNIS is used across Europe. Also the data layer has a high level of confidence because it was created from sample data and has been ground-truthed. Here, scenario refers to a separate Marxan analysis with similar parameters and protection of habitat target area using different habitat data layers, for example, Scenario CLover0 uses all of the UKSeaMap data with no regard to the confidence level of the data, Scenario CLover10 uses all data with a confidence of over 10% or above, Scenario CLover20 over 20% and this will continue up to over 70% confidence (Scenario CLover70). There are no data for this area with confidence over 75%. Scenario EUNIS uses EUNIS data. There is high confidence that the EUNIS data used in this area are correctly predicting the occurrence and distribution of habitats (James et al. 2011).

A Marxan analysis will be performed using a target of 20% for each habitat (UKSeaMap 2010 and EUNIS scenarios) within a protected zone for each of the features. The target was set of

20% of the total area of each of the habitats and determined from the full dataset regardless of level. This target remained the same for each of the UKSeaMap scenarios to ensure that the target area remained the same in each scenario therefore the area within the protected zone would be similar. The cost applied was area and a BLM will be applied to ensure appropriate clumping. The methods for the Marxan analysis and calibration of the scenarios are described in the methods chapter and are the same as those used in chapter 5. The UKSeaMap scenarios outputs will be compared with the EUNIS data and scenario in the Eastern Channel region to determine how effective each scenario was at representing 20% of the EUNIS habitats.

The UKSeaMap 2010 scenario output that has the best level of protection for habitats combined with a good degree of fragmentation will have its protected zone reformulated into a plan with zones with well-defined edges. This output will then be assessed for habitat protection. This further output will show if Marxan outputs can be used as a basis for a network of MPAs.

A Marxan output will be combined with the UKSeaMap (in three dimensions) to show the data confidence used in each of the planning units. This information would allow decision makers to prioritise areas with a higher confidence and will also emphasise the low confidence for predictions across much of the UK.

7.3 Results

The scenarios have very variable input data with different amounts of area with habitat data and numbers of UKSeaMap habitats. Scenarios CLover0 up to CLover40 have all 16 UKSeaMap habitats, CLover50 14, CLover60 14 and CLover70 has 11. The UKSeaMap habitats within the planning area tend to have a lower confidence around the edge of a patch of habitat with higher confidence in the middle. This means that even the scenarios with higher confidence have most of the habitats (Figure 7.3) but in smaller areas. Scenario CLover60 has 14 habitats out of the 16 but as seen in Figure 7.3 the area the data covered is greatly reduced.

The areas selected for the protected zone in the scenarios are variable (Figure 7.4). All outputs included some of the north east of the study area because this area has many different habitats. The area of the scenarios is variable (Table 7.2). Scenarios CLover0, CLover10 and CLover30

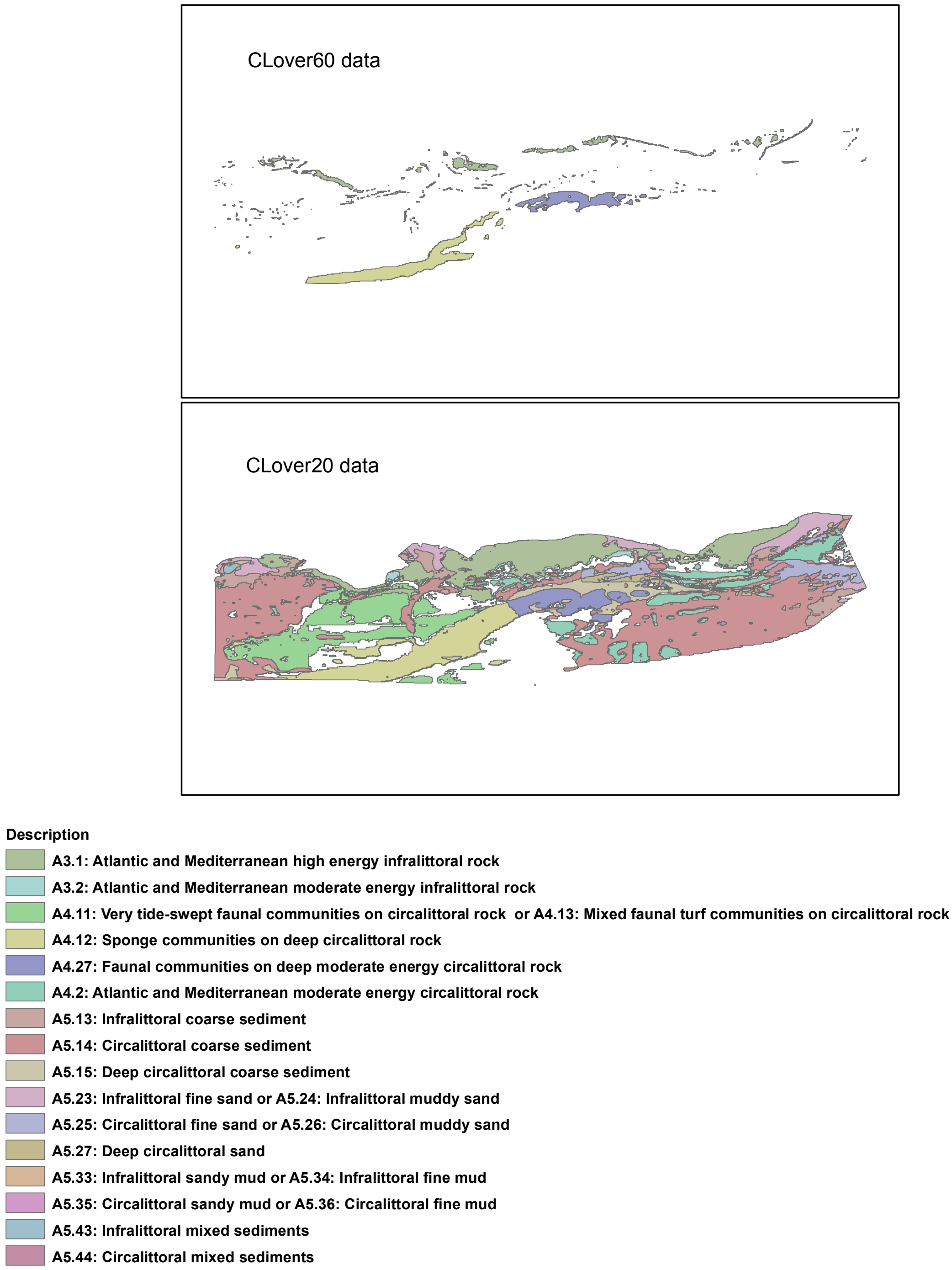


Figure 7.3: The UKSeaMap data over 20% confidence (CLover20) and over 60% confidence (CLover60) with habitat description

Figure 7.4: The best outputs for a)scenario CLover0 (all data) b)scenario CLover20 c)scenario EUNIS (all EUNIS habitats are protected by at least 20%) and d)scenario CLover20 - MSP. Green = selected for the protected zone, white = unprotected zone.

have a larger proportion of the study area covered with habitat data (100%, 98% and 81%) (Table 7.1) and have smaller areas selected for the protected zone (Table 7.2).

A general trend is that as the amount of habitat available for protection is reduced and the protected zone area becomes more fragmented. In scenarios CLover60 and CLover70 the amount of area in the protected zone reduces because Marxan is unable to fulfil the targets set. In the scenarios with reduced and fragmented habitat data the outputs become more fragmented (Figure 7.4 a and b). Scenarios where more data were available are less fragmented (Figure 7.4 a and c).

The selection frequency of planning units in the scenarios with smaller proportions of data is very similar to the number of planning units selected for the protected zone (Table 7.2). This highlights that reducing the amount of data available decreases the flexibility of outputs produced by Marxan. The EUNIS scenario has few (18 out of 2994) irreplaceable planning units. This suggests that there is a fairly large amount of flexibility when creating a network of MPAs for the East Channel.

Table 7.2: The number of planning units in the protected zone for each scenario. The number of irreplaceable planning units for each scenario. A planning unit is said to be irreplaceable within a scenario if it is selected in more than 90% of the best outputs produced by Marxan.

		Number of irreplaceable planning units	
Scenario	**Planning units in reserve (out of 2994)**	**100%**	**>90%**
CLover0	711	0	0
CLover10	713	0	0
CLover20	1069	1069	0
Clover20 - MSP	972	0	0
CLover30	1284	1284	0
CLover40	982	982	0
CLover50	1240	1127	13
CLover60	915	915	0
CLover70	887	887	0
EUNIS	851	1	17

7.3.1 Habitat protection by scenarios

Scenarios CLover0 and CLover10 had the lowest habitat protection (Table 7.3 and Figure 7.5). The UKSeaMap scenarios CLover20, CLover30 and CLover50 had the highest protection of habitats over 20% (26 out of 39) with the other scenarios protecting 23 out of 39. The scenarios that use higher confidence data have increased protection for rocky habitats, which are more sensitive to human impacts. When the level of protection is reduced to 10%, then scenario CLover20 protects 35 habitats out of 39 (Table 7.5). The lower target of 10% was selected because although this study recommends targets of 20% of habitats within protected zones, other studies have suggested that lower targets than this may be used for conservation purposes if the management outside the MPA is sustainable (National Research Council 2001; Rondinini and Chiozza 2010). It is also the target set by the IUCN for protection of the oceans by 2020 (Toropova et al. 2010). The scenarios that use higher confidence data protect more of the smaller habitats (habitats that are less than 1% of the planning area).

Scenario CLover20 was chosen to have its zones reformulated into a more manageable plan because it had one of the best levels of protection (Figure 7.4). When confidence levels of over

Table 7.3: The proportion of each EUNIS habitat included in the protected zone for each scenario. Cells highlighted red indicate that the protection for this habitat is below 10%.

	Scenarios									
EUNIS Description	**CLover0**	**CLover10**	**CLover20**	**CLover20 - MSP**	**CLover30**	**CLover40**	**CLover50**	**CLover60**	**CLover70**	**EUNIS**
A3.1 : Atlantic and Mediterranean high energy infralittoral rock	0.0	0.0	18.1	56.3	30.4	17.2	18.1	17.2	17.2	50
A3.2 : Atlantic and Mediterranean moderate energy infralittoral rock	0.6	0.6	37.1	80.9	36.9	31.9	37.1	31.9	31.9	34
A3.3 : Atlantic and Mediterranean low energy infralittoral rock	0.0	0.0	29.5	66.6	47.6	21.6	29.5	21.6	21.6	51
A3.84 : High energy infralittoral rock and thin mixed sediments	0.0	0.0	0.4	59.1	73.3	0.4	0.4	0.4	0.4	100
A3.91 : Moderate energy infralittoral rock and thin coarse sediments	0.0	0.0	40.4	0.0	0.8	2.1	40.4	2.1	2.1	100
A3.92 : Moderate energy infralittoral rock and thin sands	37.7	37.7	33.9	50.5	42.7	32.2	38.0	31.4	29.8	50
A3.94 : Moderate energy infralittoral rock and thin mixed sediments	5.8	5.8	26.3	18.1	38.3	24.8	29.9	23.1	22.1	27
A3.A2 : Low energy infralittoral rock and thin sandy sediment	20.0	20.0	39.2	63.6	67.8	33.1	42.8	32.6	31.7	46
A3.A4 : Low energy infralittoral rock and thin mixed sediments	3.5	3.5	25.7	62.8	65.6	25.2	26.5	24.4	24.4	32
A4.1 : Atlantic and Mediterranean high energy circalittoral rock	2.8	38.3	3.1	24.0	39.6	2.6	4.4	2.6	2.6	20
A4.2 : Atlantic and Mediterranean moderate energy circalittoral rock	77.6	77.6	92.8	81.1	19.5	87.4	93.9	80.0	74.7	80
A4.3 : Atlantic and Mediterranean low energy circalittoral rock	0.0	0.0	100.0	100.0	100.0	0.0	100.0	0.0	0.0	100
A4.81 : High energy circalittoral rock and thin coarse sediments	0.0	0.5	0.3	17.2	43.5	0.3	2.3	0.3	0.3	20
A4.84 : High energy circalittoral rock and thin mixed sediments	20.1	5.3	7.4	14.6	32.0	6.6	9.1	5.4	5.1	20
A4.91 : Moderate energy circalittoral rock and thin coarse sediments	0.0	0.0	67.0	0.0	39.4	0.2	67.0	0.2	0.2	100
A4.92 : Moderate energy rock and thin sandy sediment	58.2	60.2	88.1	47.1	43.4	83.6	93.1	76.6	74.5	72
A4.94 : Moderate energy circalittoral rock and thin mixed sediments	4.8	5.9	63.2	48.2	36.1	57.2	72.6	52.6	50.7	20
A4.A2 : Low energy circalittoral rock and thin sandy sediment	97.5	97.5	97.7	100.0	97.7	70.1	97.7	70.1	70.1	99
A4.A4 : Low energy circalittoral rock and thin mixed sediments	98.4	98.4	1.6	1.6	100.0	1.6	1.6	1.6	1.6	98
A4D.1 : Atlantic and Mediterranean high energy deep circalittoral rock	18.7	43.3	1.9	10.0	20.9	0.9	1.9	0.9	0.9	20
A4D.2 : Atlantic and Mediterranean moderate energy deep circalittoral rock	50.8	50.8	97.6	41.3	46.9	91.4	97.6	91.4	91.4	53
A4D.3 : Atlantic and Mediterranean low energy deep circalittoral rock	0.0	0.0	0.0	0.0	100.0	0.0	0.0	0.0	0.0	100
A4D.81 : High energy deep circalittoral rock and thin coarse sediments	12.9	71.4	26.4	0.0	8.8	26.4	37.5	26.4	26.4	71
A4D.84 : High energy deep circalittoral rock and thin mixed sediments	21.2	26.8	5.2	0.1	18.0	4.6	6.6	3.7	3.7	21
A4D.92 : Moderate energy deep circalittoral rock and thin sands	28.0	30.5	94.5	40.0	58.7	85.1	99.6	77.2	76.6	52
A4D.94 : Moderate energy deep circalittoral rock and thin mixed sediments	9.0	10.8	81.9	52.0	62.5	76.3	94.1	70.9	68.8	21
A5.13 : Infralittoral coarse sediment	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100
A5.14 : Circalittoral coarse sediment	0.0	0.0	13.8	74.7	9.1	0.5	13.8	0.5	0.5	25
A5.23 : Infralittoral fine sand	62.8	62.1	49.9	32.8	56.0	48.3	54.2	46.5	44.8	53
A5.24 : Infralittoral muddy sand	45.6	45.6	86.0	55.7	86.2	84.0	88.5	81.9	79.7	48
A5.25 : Circalittoral fine sand	83.9	63.7	59.1	56.9	48.4	56.4	68.3	53.0	51.4	20
A5.25 : Circalittoral fine sand*	5.0	0.0	1.9	0.0	52.5	1.9	1.9	1.9	1.9	22
A5.26 : Circalittoral muddy sand	84.8	84.8	98.3	72.6	87.6	91.4	99.8	87.5	87.5	86
A5.27 : Deep Circalittoral sand	43.7	38.5	86.1	68.0	74.1	81.6	98.0	78.5	77.4	32
A5.33 : Infralittoral sandy mud	64.3	64.3	95.9	75.0	96.7	92.8	95.9	92.8	92.8	68
A5.35 : Circalittoral sandy mud	97.6	97.6	100	87.7	99.3	100	100.0	100	100	100
A5.43 : Infralittoral mixed sediments	11.5	11.5	50.9	41.9	57.3	49.4	54.2	46.6	46.5	48
A5.44 : Circalittoral mixed sediments	12.3	0.5	13.0	17.1	53.3	11.2	17.7	10.5	9.6	20
A5.45 : Deep circalittoral mixed sediments	5.4	2.5	30.5	28.3	51.2	25.0	54.1	23.5	23.0	20
Number of biotopes over 10% in the protected zone	21	21	29	31	35	25	29	25	24	39

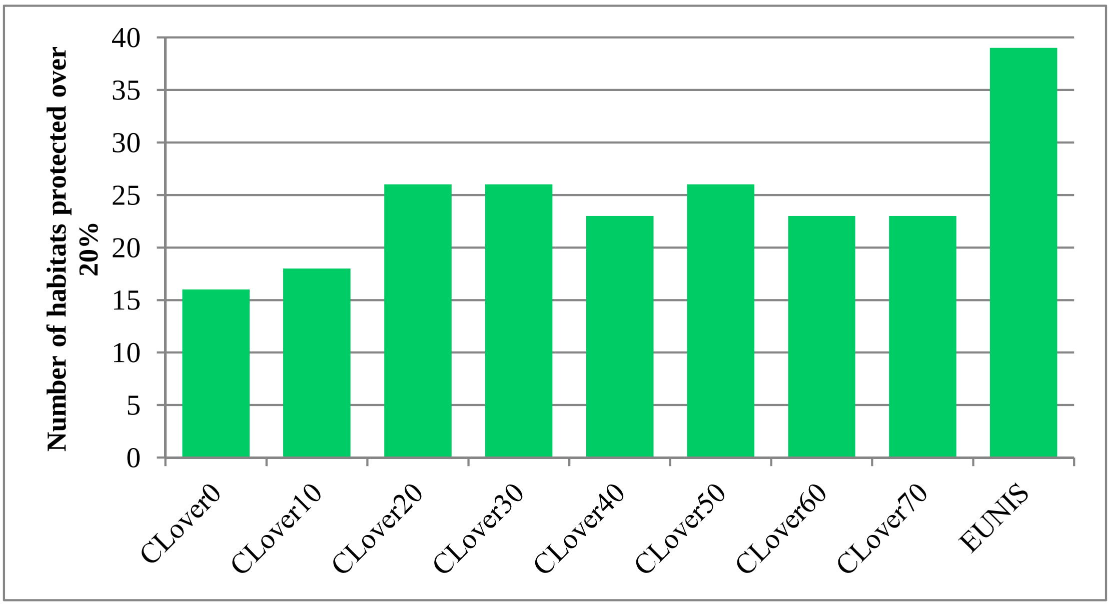


Figure 7.5: Number of EUNIS habitats protected (over 20% target) by each scenario out of 39 habitats

20% were used, the amount of data available (Table 7.1) reduced significantly leading to increased fragmentation and increase in the number of planning units included in the protected zone (Table 7.2). Scenario CLover20 had a good balance between habitat protection, fragmentation and number of planning units included in the protected zone. The areas selected for protection in Scenario CLover20 were reduced in size (Table 7.2) and re-constructed so they had well defined boundaries and, if possible, were near land to allow ease of use and enforcement. The areas chosen for the protected zones were based on planning units already protected by Marxan. Of the 39 habitats 26 were protected (Table 7.3) in this scenario.

A separate scenario was run using EUNIS data (Scenario EUNIS) to indicate which areas a representative MPA network in the East Channel area would be protected using best available data. All of the 39 habitats are protected by over 20%. It had a similar area to several of the other scenarios (Table 7.2) which do not protect all of the habitats (Table 7.3). Increasing the size of areas protected does not automatically lead to an increase in representativeness of the habitats protected.

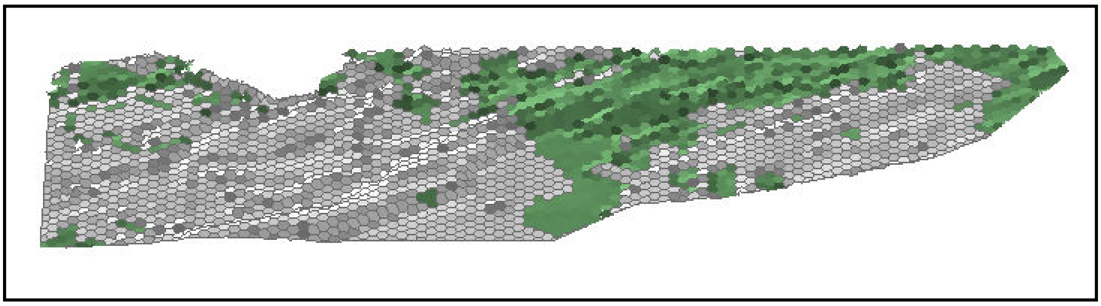


Figure 7.6: The best output for scenario CLover20 in 3D. Green shading = selected for protected zone. Increased height means a greater confidence of the habitats in that area. The shading indicates the change between confidence levels, the darker the shading the greater the change.

7.3.2 Decision-maker outputs from scenarios

Scenarios CLover20, CLover30 and CLover50 protect the greatest number of habitats (26) by over 20% (Figure 7.5). This figure is useful for decision-makers because it shows clearly which scenarios protect the greatest number of habitats and indicates at what percentage confidence data is required.

Figure 7.6 is a three-dimensional representations of the best output from scenario CLover20. The best output was overlaid on to the confidence data for UKSeaMap to indicate the level of confidence for the data in the planning area. The higher areas represent the areas of increased confidence. Three-dimensional figures are an effective way to demonstrate confidence levels but they provide the most information when they are on a computer and the image can be rotated. It is not always possible to choose one angle that can demonstrate all confidence levels.

7.4 Discussion

The UKSeaMap data outputs that best protected marine biodiversity used data over with confidence levels of 20% and over 30%. Scenarios using most of the data (CLover 0 and CLover 10) require fewer planning units (Table 7.2) but result in lower protection (Table 7.5). Scenarios using data with higher confidence (60-70%) protect fewer habitats (Table 7.5) because the input data is less diverse and contains fewer biotope types. Of the layers used to model UKSeaMap 2010 the substrate data layer had the highest level of confidence, in comparison to the other data layers used. UKSeaMap data have a high confidence level for the location of substrate but a much lower one for the habitats (McBreen et al. 2011). As discussed in the case studies chapter the confidence levels of each layer used in UKSeaMap were combined to create an overall confidence level for each area. It appears that the outputs using the data at all confidence levels reflect the substrate diversity rather the habitat diversity because the results are comparable to the protection of habitats to the results obtained using medium resolution substrate in chapter 5. The best outcomes at the confidence levels recommended led to a 66% of habitats being protected over 20%, one third of the habitats were not protected at the target set.

There is a need for a balance between the large amount of low confidence data and the small amount of good habitat data available. This study suggests that data over 20% appears to protect the most appropriate selection of protected areas as assessed by balancing area with the number of habitats protected by 20%. The data with confidence levels below this had comparable protection levels to the medium substrate in Chapter 5. In the UKSeaMap data layer above the 30% confidence level the amount of data available reduced from 80% to under 50%. This lead to the data being increasingly fragmented and reduced the flexibility of Marxan to produce many different solutions. Although more of the planned area was included in the protected zone by scenarios with higher confidence the number of habitats protected by over 20% decreased or remained the same. When comparing the UKSeaMap scenarios to the EUNIS scenario only two scenarios (CLover0 and CLover10) had a smaller number of planning units but these had much reduced protection. This highlights that using the correct habitat data when creating MPA networks can decrease the area needed for protection while still protecting marine biodiversity at a high level.

The output produced by Marxan using data over 20% was reconfigured to create a more realistic MPA network. The protected areas were based on the areas that Marxan had chosen. Areas with higher biodiversity were protected. The reconfigured zones had straight, well-defined edges and if by the coast were between points on land, where possible. There were few, large zones which would make them easier to enforce and reduce edge effects. Where possible the protected zones were away from the coast to reduce conflict with human activities. The overall area of the protected zones was smaller than in the original (CLover20) scenario. This reconfiguration protected 26 out of the 39 habitats, the same as the original CLover20 scenario. This highlights how the areas shown to be of conservation importance by Marxan can be rearranged into practical zones and still protect marine biodiversity.

Previous studies have shown that including confidence data in conservation planning increases the chance of high confidence areas being included in protected areas (Cabeza et al. 2004; Moilanen et al. 2006). Prioritising the protection of areas in which there is high biodiversity or sensitive species with high associated confidence is unlikely to lead to a network of efficient and representative MPAs (Stewart et al. 2003). Near-shore areas are more likely to be surveyed and have high confidence ground-truthed data, these areas are also have higher human activities leading to increased conflicts between conservation and other sectors.

A study by Maxwell et al (2009) created an additional confidence layer for use in marine planning from a commercial fish distribution model. This layer represented how much confidence could be placed in the prediction of fish distribution map. This confidence map and the one created for UKSeaMap 2010 can be used by decision-makers but need to be accompanied by clear information how to interpret and use them in marine planning. The method of breaking down the UKSeaMap data used in this study is simple to explain to decision-makers and can be demonstrated using clear figures. For example Figure 7.5 shows simply how using different confidence levels protects marine biodiversity and gives a clear message that using data above 20% leads to a more representative MPA network.

This study has assessed one way for the incorporation of of uncertainty into a site selection program to ensure representative protection of marine biodiversity. A study by Wilson et al (2005) incorporated confidence of species occurrence within Marxan by assuming a species was present if it reached one of three different thresholds. The study by (Wilson et al. 2005) found that three conservation planning outcomes: (i) fragmentation, (ii) areas chosen for protection and (iii) the expected protection of a species, were sensitive to the uncertainty generated by predictive species modelling and that each of the thresholds caused the outputs produced to be inefficient and to miss targets set for protection. Loiselle et al (2003) studied the effect of using modelled data which had more false-positives or more false negatives on a network of protected sites. The study used a complementary algorithm to identify the minimum number of planning units to protect the 11 bird species in Brazil. It found that modelled data that minimised false-positives provided a closer match to those chosen by experts and concluded that modelled data which over-estimated species occurrence may misdirect conservation action. Loiselle et al (2003) assumed that experts were more likely to be correct in species predictions than using modelled data, which may be true for a single species, this may not be the case marine habitat predictions. The study undertaken in this chapter has shown that site selection tools are sensitive to the confidence of the data used in them. It has highlighted the need to determine the effects of uncertainty of data on marine planning in the decision-making process.

Decision-makers can use the conclusions in the study to use data above 20% confidence if this data are available. Although the results in Chapter 5 have shown that using data such as this will not lead to representative marine protected areas. For approximately 94% of UK water high resolution, high confidence, habitat data are not available. This study has indicated that the diversity reflected in the UKSeaMap 2010 data is primarily from substrate McBreen et al. (2011). Therefore to properly reflect the likely diversity of the marine environment expert and stakeholder opinion should be sought.

If the only data that can be used are not high resolution, ground-truthed data, it would be better to use good quality (high resolution) substrate data, as shown in chapter 5, because these data are of high confidence for the UK. These data should be supplemented with socioeconomic data and expert/stakeholder opinion. With the data currently available for the UK marine environment it is not possible to be confident that a representative MPA network can be created. Adaptive management would need to be written explicitly into a management plan that used these data to ensure that zones could be moved as better data became available.

This chapter evaluated the impacts of using different confidence levels on marine biodiversity protection. In the next chapter the implications of the research findings in this thesis on marine planning will be discussed. Key recommendations for best practice in marine planning in the light of this research will be made.

Chapter 8

Discussion

8.1 Introduction

This thesis examined a range of features pertinent to the development of the use of the spatial decision support tools (DSTs) Marxan and Marxan with Zones in marine planning: by assessing the effects of using different types, complexity and resolutions of data and data with varying levels of confidence on the tools ability to protect the marine environment and to balance the needs of different sectors. This project has assessed how the spatial DSTs, Marxan and Marxan with Zones, can be applied in marine planning, highlighted how data currently available can be used and the potential problems with using this data. It has also shown the value of using the spatial DSTs Marxan and Marxan with Zones in the production of marine spatial plans and in systematic conservation planning.

The key issues that this thesis addressed are: how the spatial DSTs support marine spatial planning by providing a clear and transparent framework for the integration and weighting of data from all sectors (Objective 5), what are the best available data to use in marine planning (Objective 4) and the likely issues in using data in which there is not high confidence (Objective 6).

This thesis has evaluated previous studies that have used Marxan and Marxan with Zones (Objective 3). Suggestions have been made throughout this thesis on how this research should influence marine planning (Objective 7) and how to address the gaps identified (Objective 1).

The case study areas each have different activities and habitats occurring within them. Each has different data needs and availability and every area had its own set of challenges. Using these

Table 8.1: Contrasting inputs and outcomes of the four case studies

Case study	Lyme Bay	Lyme Bay	Sound of Mull	East Channel
Chapter number	5	6	6	7
Plan type	Conservation focused	Balanced MSP	Balanced MSP	Conservation focused
Scale	Medium	Medium	local	Regional
Data type	Biotope, substrate and no data	Biotope, fishing and recreation	Biotope, cultural, fishing, recreation and aquaculture	Biotope combined with confidence
No of datasets used per scenario	1	Maximum of 3	6	1

case studies has shown that site selection tools can be used at different scales (Objective 2) and with different drivers. They can also be used to produce a marine protected area network with no social or economic data and more complex marine planning that attempted to weigh many sectors spatial needs in a marine plan (Objective 5).

This thesis has added to the bank of knowledge on the creation of marine plans and the potential impacts that marine plans will have on conservation efforts and human activities.

8.2 Comparison of case studies

This thesis has evaluated the sensitivity of Marxan and Marxan with Zones outputs to: various types of data, both environmental and socioeconomic; conservation and multi-objectives plans and three different scales of marine plan (Table 8.1).

The four data analyses had different goals and objectives. The first analysis (chapter 5) was focused on conservation and a network of MPAs that best protected marine biodiversity, and socioeconomic objectives were not considered. The next chapter (chapter 6) contained two analyses: Lyme Bay and Sound of Mull. The Lyme Bay analysis evaluated how setting three different sectors activities as top priority impacted marine plans. Marxan with Zones chose some different areas depending which sector was top priority. The Lyme Bay analysis highlighted that each sector would have to compromise to create a fair marine plan. Conservation targets could not be met without severely compromising other sector activities. This agrees with examples found in the literature including Klein et al (2008) who found that using fishing activity as cost, in a Marxan analysis, reduced the impact of a MPA network on commercial fishing, but that conservation targets could not be met without some reduction in fishing activity. In the SoM analysis again the goal was to create a balanced marine plan where all sectors would have to compromise. The modified SoM plan highlighted that the most damaging activities would have to reduce their activity by the greatest extent to ensure conservation targets are met.

Different types of zones were used in each of the analyses. In chapters 5 and 7 two zones were used, a protected zone and an unprotected zone, because the focus of these chapters was the best use of data in marine conservation. The two analyses in chapter 6 were more complex marine plans. Each analysis used three zones, with different activities allowed in each zone. Using multiple zones allowed for more division of human activities, keeping non-compatible activities apart.

Different types and numbers of datasets were used in each of the analyses to evaluate data sensitivity of Marxan and Marxan with Zones outputs. The analyses in chapters 5 and 7 used a single dataset in each scenario to assess how well each of the datasets protected marine biodiversity. In chapter 5 the results showed that using high resolution biotope data best protected marine biodiversity, therefore in the following chapters this type of dataset was used. In contrast the East Channel results showed that using data with higher confidence (over 30%) did not adequately protect marine biodiversity in part because this data covered only a reduced area (approximately 24%) of the study site). This demonstrates that having high quality data supports good decisions but that poorer quality data can be used especially when the confidence placed in data have been calculated.

In the two analyses of more comprehensive marine plans additional datasets were used. In the Lyme Bay analysis (chapter 6) three datasets were used to represent conservation, recreation and fishing. Using different datasets increased the complexity of the Marxan with Zones parameters and decreased the flexibility of the Marxan with Zones outputs. Marxan with Zones was trying to avoid the most heavily fished areas, some of which occurred in areas that a previous analysis (chapter 5) had indicated were important for conservation targets to be met.

The SoM marine plan was the most complex marine plan and had six data layers. The SoM is used extensively by the commercial fishing industry, skate anglers and divers. It also has several protected and highly sensitive benthic species (e.g. maerl). This meant that unlike the conservation focused plans that Marxan could not produce such flexible solutions. A recent study by Mazor et al (2014) found that increasing the complexity of marine plans, by increasing the number of zones and the types of activities included, increased the need for compromises between sectors to reach conservation targets as found in this study. This demonstrates that a wide array of data types including socioeconomic information can be included in Marxan and Marxan with Zones analyses, and this broadens the scope of what these tools can be used for.

This study has demonstrated that Marxan and Marxan with Zones can create marine plans effectively at three different scales. The smallest case study area (SoM) is used for many different marine activities and had large amount of biotopes (40) for a small area. Marxan with Zones was able to create a marine plan but because of restrictions of space and the many activities that occur within the planned area it was not able to create such flexible solutions as the Lyme Bay analysis in chapter 6. For example, Marxan with Zones was not able to create a complete buffer of medium protection zone around the highly protected zone. In the East Channel analysis Marxan with Zones was able to produce a variety of outputs for the EUNIS scenario and up to the 30% confidence level because the area was large and it wasn't constrained by costs except area. As the East Channel is an extensively used area, if human activity were added as cost, this would reduce the flexibility of solutions that Marxan with Zones would be able to produce.

8.3 Drivers for marine management

There are two main drivers for marine planning in the UK. The first is European legislation and international agreements (eg. OSPAR (1992)). The Marine Strategy Framework Directive recommends adopting the use of MSP (European Commission 2008) to ensure sustainable development and achieve "Good Environmental Status" by 2020. The second main driver for marine planning within the UK and Europe is from industry and the EU. It is that the current management of the marine environment is not allowing full economic opportunities to occur (Jay et al. 2013; European Commission 2010; MSPP Consortium 2006). The EU has also implemented the Integrated Maritime Policy which has been designed to be a framework for managing Europe's coastal and marine environment in an integrated way, and that encourages the "optimal development of all sea-related activities in a sustainable manner" (Commission of the European Communities (CEC) 2007).

As a result of these drivers the UK has created legislation, the Marine and Coastal Access Act (2009), to ensure the protection and sustainable use of the marine environment. The UK Marine Policy Statement (MPS) commits the UK to the creation of marine plans. The MPS is in favour of sustainable development and its high level objectives place emphasis on development. The Eastern plan is the first marine plan area to be implemented. The planning process began in April 2011, with a draft plan being released for consultation in Spring 2013, and the plan was adopted in June 2014. No specific habitat or species protection targets have been set, although an objective of the plan is to ensure that biodiversity is protected (MMO 2012*b*). The MMO considers Marxan and Marxan with Zones to be useful tools in marine planning (MMO and Marine Scotland 2012*a*) but there is no evidence that these tools were used to design the Eastern plan.

Targets for representativeness and replication of broad-scale habitats were made for the MCZ project (Natural England and Joint Nature Conservation Committee 2010). Natural England recommends that between 11-42% of each broad-scale habitat, within English waters, are protected within an MCZ and that best available evidence should be used (Natural England and Joint Nature Conservation Committee 2010). A report commissioned by the Marine Management Organisation recommended the use of site selection tools, including Marxan, in marine planning (MMO and Marine Scotland 2012*a*).

MCZs (Marine Conservation Zones) and socioeconomic factors must be integrated using tools such as those demonstrated in this thesis. It is not practical to integrate large numbers of datasets without these tools and the process will be more efficient if these tools are used. Using current MPAs is likely to increase the amount of area required to create representative MPA networks as also highlighted in Ban et al. (2009) and Giakoumi et al. (2011), and as demonstrated in this thesis. In the Eastern plan area process and the recent consultations on SACs (Special Areas of Conservation) and MCZs all current MPAs are accepted and only added to. As most MPAs in the UK have been created on an ad hoc basis to manage impacts on protected species it is not likely that current MPAs, with the 27 MCZs that have been designated in England, form an efficient and representative basis for a network of MPAs in the UK (Stewart et al. 2003).

8.4 Data management and availability

The data currently available for marine planning in the UK have some limitations. High quality biotope data are not available for most of the UK's marine environment. This thesis has shown the likely consequence of using lower quality data which is that marine biodiversity will be not adequately protected. There are no national datasets for most important recreational activities. The Royal Yachting Association (RYA) has some national data of marine use and the MCZ project created a dataset for England for some activities. This is recognised as a problem and the MMO have started a project to create a national dataset on recreational angling. There is also uncertainty of how much confidence we can place in the data that are available (Gallo and Goodchild 2012; Fleming and Jones 2012; Langford et al. 2009). A recent study has assigned confidence rankings to socioeconomic data (MMO 2012*a*) and this could be applied to further datasets. The confidence ranking was based on how much is known about the methodology of the data collection, if it is considered best practice and if the data were peer reviewed. The highest confidence was given to best practice, peer reviewed data and the lowest to no or little methodology provided. The rankings provided a useful guide to how much importance should be placed on datasets and highlighted the need to improve metadata.

An important future data need for marine planning is a national dataset of cumulative impacts on biotopes and historical sites. A recent study created a GIS tool that can be used to map and investigate cumulative impacts on marine habitats (Cefas 2010*a*). This study was limited by assessing impacts on broad-scale habitats created with low resolution data and by only using the impacts of six activities. Further research is required on cumulative impacts on habitats. There are many historical marine sites around the UK and these should be mapped further with the likely impacts investigated.

There are many datasets that could be used in marine planning but because: their metadata are poor, of the format they are in, or they cannot be available publicly because of data protection or commercial data confidentiality (MMO 2012*a*; MMO and Marine Scotland 2012*b*). Therefore, there is a requirement to catalogue data and to ensure that a national metadata standard is set and followed. Marine planning has many research needs and policy makers require researchers to undertake studies that can be used in real-world situations. If researchers are unable to access data, vital research will not be undertaken how to improve marine planning. Agreements must be put in place when data are collected to reduce the risk of this occurring.

8.5 Application of existing data

As this thesis has shown, using the ecological data currently available for marine conservation and marine planning have some limitations. When planning for conservation using current data, the representativeness of MPAs, as recommended by the IUCN cannot be guaranteed (IUCN-WCPA 2008). From the research presented in this thesis it is recommended that high quality biotope data are used to ensure efficient and representative MPA networks. This study recognises that this is not possible. Therefore, it is recommended that the highest resolution and most complex habitat data available are used in combination with expert judgement. It is also recommended that data are evaluated for confidence and that data of at least 20% confidence are used. When using modelled habitat data, the data used that impact the potential species the most is the layer in which there is the highest confidence - substrate (Marshall 2012). This study has shown that using data below 20% confidence results in similar protection as when medium resolution substrate data are used. In this study both substrate and below 20% confidence protected approximately 40% of biotopes. If high quality ground-truthed or modelled data are not available this study recommends that medium resolution substrate data are used.

Other ways to enhance representativeness in an uncertain environment are to include an element of randomness in conservation planning. As this thesis demonstrated sometimes using no data was better for habitat protection than using poor quality data. If only poor quality habitat data are available, randomly choosing areas to be protected could produce better results for conservation as shown in the chapter 5.

A study by Rees et al (2012) mapped the pathways between ecosystem services, processes and ecological functioning of benthic species for indirect ecosystem service provision. Rees et al (2012) demonstrate the links between benthic species and indirect ecosystem services but as currently there is no measure to quantify how much of a function is required to sustain ecosystem services, this study recommended protecting broad-scale habitats as a precautionary approach.

The socioeconomic data currently available in the UK is adequate for marine planning. In the UK the MMO and recent MCZ projects have collected many socioeconomic datasets and are continuing to gather more (MMO and Marine Scotland 2012*b*). The amount of socioeconomic data should not be considered a limiting factor in marine planning. In the UK the planning process will be highly participatory and stakeholders will be able to put forward any other data they think relevant.

8.6 Application of site selection tools

The flexibility of site selection tools in both systematic conservation planning and marine planning has been demonstrated in this thesis. Site selection tools can be used at different scales, the smallest case study area was less than 1% of the area of the largest. They can be used to indicate areas that are important for conservation targets and human activities.

Currently Marxan is most used in systematic conservation planning. As this thesis has demonstrated with the increased functions of Marxan with Zones, and with further studies that have been undertaken, the program can now be used in marine planning to incorporate socioeconomic costs (Watts et al. 2008; Mazor et al. 2014). Marxan with Zones is a decision support tool, how much should its outputs determine the final proposals of a marine plan? Previous studies using Marxan have used the outputs to recommend areas for protection but have not accepted the outputs in their totality and made some changes (Balanced Seas (2011*b*); Fernandes et al. (2005), Klein, 2008). The Balanced Seas project which was set up to select MCZs in the south east UK sea, used Marxan to assess where the highest quality areas of habitat were that would meet the targets set. The scenarios run locked out areas already selected by stakeholders. The results were presented to a stakeholder group (Balanced Seas 2011*a*). The areas selected were used to guide the recommendations for some of the sites chosen for protection with the rest selected by stakeholders. This study demonstrates how to use Marxan outputs to guide decision making.

It is recommended that the marine planning process should include the evaluation of different scenarios, when various objectives and sectors are prioritised (Agardy 2010; Kidd et al. 2011). Marxan with Zones could be used to evaluate the scenarios and test different weightings. These outputs could then be used to guide discussion to ensure that the objectives and targets could be met, and stakeholders would not feel that one sector has been prioritised over others (Jay et al. 2013). If stakeholders do not feel that the process is fair they may not re-engage when the MSP is reviewed. Marxan with Zones outputs should be used to guide the MSP process but ultimately how human activities are managed and whether this results in the marine environment being used sustainably is a choice society has to make.

As has been demonstrated in this thesis Marxan and Marxan with Zones can be used to create outputs that recommend the most suitable sites for conservation and in wider marine planning. Marxan and Marxan with Zones are programmed so that when undertaking conservation planning it will be partly systematic. For example, Marxan cannot run without feature data, costs consideration and targets, which are an important part of systematic conservation planning. Although there is discussion in the literature on how to set meaningful targets (Rondinini and Chiozza 2010; Metcalfe et al. 2013). Marxan and Marxan with Zones highlight areas that are important for meeting targets, and can lead discussion among stakeholders on the importance of siting and fragmentation. Marxan and Marxan with Zones can provide objective discussion with stakeholders. The results produced do not need to be adopted entirely but can provide another layer of information to support decision making. This thesis has performed two analyses that evaluated how well different types of data represented marine biodiversity and made recommendations about the best types of data to use when selecting priority areas for conservation. The inclusion of costs when choosing areas for conservation can reduce conflict with human activities (Klein 2008; 2011). Marxan and Marxan with Zones can produce many highly flexible optimal solutions, as well as incorporate costs so that conflicts can be reduced (Watts et al. 2009), but they cannot be removed altogether, as this study has shown, particularly in high use areas. The outputs produced can be used to inform discussion to resolve conflicts.

Site selection tools, in combination with other DSTs such as multi criteria analysis, can be used in marine planning to create weightings for sectors. Site selection tools can then be used to show the effects of different weightings and management actions on the placement of zones. The findings in this thesis have shown that Marxan and Marxan with Zones can be used in the marine planning process to indicate priority areas for protection and areas of conflict. In two of the analyses in this thesis (chapter 6), using frequency of use or area were used as socioeconomic costs. In a real-world situation the costs would be created with stakeholders and using more rigorous methods including multi criteria analysis to judge trade-offs (Agardy 2010) or relative importance metrics (Klein2008).

Using DSTs can ensure that all sectors can see clearly the effects of marine planning. This will be particularly important with the sectors, such as fishing, that use a large proportion of the marine environment and have the highest impacts, who will have to make the largest compromises if marine plans are going to ensure that the marine environment is used sustainably. Therefore, it is important that each sector accepts marine planning and the creation of marine spatial plans.

Site selection tools require good data to produce useful outputs as this study has shown. This problem can be reduced by using randomness or by generating simple use data with stakeholders. A study by Ban et al (2009) used distance from shore as a proxy for fishing pressure. Areas closer to the shore were assumed to be more likely to be fished and had higher associated costs in the Marxan analysis. An alternative cost suggested was that MPAs closer to the shore were more easily enforceable and should have lower associated costs.

Smith et al (2006) reviewed the perceived limitations of systematic conservation planning, which are: the site selection software is difficult to use; it requires extensive biodiversity distribution data; it is not possible to set targets for conservation; it is expensive and identifies unsuitable areas. The study found that although setting targets was a difficult process all of the other concerns about limitations were misplaced.

An important part of MSP is that each plan is subject to periodic review (Ehler and Douvere 2009) and adaptive management (Kidd et al. 2011), so that when new data become available, new activities or pressures emerge, or when monitoring indicates that management actions are not successful, the plan is not static and will change. As has been previously discussed in this thesis (chapter 2) the GBRMP was rezoned using Marxan to indicate new MPA sites (Day 2002) in a process of adaptive management. Marxan and Marxan with Zones have been used to plan entire MPA networks (Watts et al. 2008; Great Barrier Reef Marine Park Authority 2004), with the assumption that all MPAs would be designated simultaneously, but often this is not possible (Defra 2014). Game et al (2011) assessed how Marxan could be used to identify a network of sequentially designated areas. A new Marxan with Zones analysis was run each time a new MPA was designated to reassess the areas most suitable to be next selected. This approach could be used as a form of gap analysis on a larger national scale. National MPA networks tend to be created on an ad hoc basis, with MPAs designated one or a few at time. A Marxan analysis could be run with currently protected areas locked in, so that areas of importance based on current levels of protection could be identified. Within a marine spatial plan review process, Marxan with Zones could be run to highlight areas important for emerging activities, so that new activities can be incorporated fairly into the plan.

Marxan and Marxan with Zones can be used create scenarios with varying targets, weightings and priorities. These scenarios can be used to indicate which areas are important to different sectors. Ehler and Douvere (2009) recommend the exploration of a variety of scenarios and suggest increasing the weighting for each sector over others to highlight the compromises that will have to made when one sector is prioritised over others. Each sector will want to continue to have access to the marine space they currently use, or increase their usage, Marxan and Marxan with Zones can be used to allow for negotiation between sectors. For example, if two sectors insist that a particular area is vitally important for them to operate, scenarios could be run in Marxan with Zones (incorporating other sectors' data), one scenario using the area and the other excluded and vice versa, and a further scenario with them sharing the space. Then both sectors could see how they and other sectors were likely to be impacted, and with this information would be able to negotiate for the use of the area.

A further benefit of using DSTs, such as Marxan and Marxan with Zones, is that if datasets are available for all sectors, these can included and fairly weighted. Whereas, in previously created marine plans (e.g. Germany, Jay et al. (2013)) some sectors felt that the activity with the most effective lobbying tactics gained access to the greatest marine space at the expense of others (Agardy 2010; Kidd et al. 2011).

Marxan has been used in previously in stakeholder participation, in the GBRMP rezoning (Fernandes et al. 2005), in the UK MCZ project Balanced Seas (Balanced Seas 2011*b*), and in the creation of an MPA in the seas of California (Klein, 2008) and in other systematic conservation planning exercises. In each case Marxan was used to prioritise areas that would be suitable for protection, and the only example mentioned above that included socioeconomic costs in a Marxan analysis was the study in California. In contrast, in the Balanced Seas project the cost used was range of biodiversity, so that more highly diverse areas were likely to be chosen for protection by Marxan.

The stakeholders in the California project seemed to have understood the use of Marxan. They used some of the areas indicated by the output and chose others that would not meet the targets set so efficiently but were considered important to protect (Klein, 2008). In the GBRMP rezoning the Marxan outputs were presented to an expert group and the Marxan outputs had further analysis undertaken on them. Marxan produced many different options for the MPA network, but because no socioeconomic cost layer was used, it was not able to select areas that minimised impact on human activities and was therefore less helpful (Game and Grantham 2008). In the Balanced Seas project Marxan outputs were presented to the stakeholder group. Some stakeholders felt that by using Marxan without the cost data generated by the stakeholders, it reduced the input they had on the proposals (Balanced Seas 2011*a*). The project team reassured the stakeholder group that the Marxan outputs were not "set in stone" and the the stakeholders could reject the Marxan output if they thought this was appropriate. When using tools such as Marxan, it is important that how Marxan produces outputs and how these outputs will inform the process are communicated well. Otherwise stakeholders may feel that once areas on a map have been chosen by Marxan their input in the selection of areas is reduced and this can lead to a lack of trust in the process(Kidd et al. 2011; Agardy 2010). As discussed in this thesis the use of simple figures and maps can convey important information clearly, and therefore help to communicate complex ideas to stakeholders and policy-makers. Marxan and Marxan with Zones can be used in stakeholder engagement, but are best used when stakeholders understand how these programs work, and stakeholders understand that the outputs are recommendations and that they (the stakeholders) play the central role in deciding on what areas are used for.

8.7 Key recommendations

1. Use Marxan to produce networks of MPAs, as has been demonstrated here can produce effective and efficient solutions.

2. Use Marxan with Zones in more complex marine planning situations, to integrate data and produce zones that allow different management regimes.

3. Use high resolution biotope data for marine conservation planning or if this is not available use the highest resolution data available.

4. If using modelled habitat data use data with over 20% confidence.

5. Include socioeconomic data on the major economic sectors in marine planning with data on non-monetary values, e.g. cultural or spiritual use, which can then be integrated using site selection tools.

Chapter 9

Conclusion

9.1 Introduction

This thesis aimed to evaluate the use of Marxan and Marxan with Zones as practical tools to enable the production of marine plans that integrate environmental and socioeconomic data and to suggest best practice in the types of data used. The first chapter introduced the need for improved marine conservation and marine spatial planning. The main issues affecting marine planning in the UK were established. The following chapter (2) reviewed the literature on marine conservation and marine spatial planning, demonstrated gaps in the current knowledge and identified the need for this study.

The methods chapter reviewed the literature on Marxan and Marxan with Zones. It described how Marxan and Marxan with Zones were set up and the main features of each programme. The following chapter (4) justified the use of the case study areas on their: data availability, scale, conservation importance, human activities and current marine planning activities, and described the data used in this thesis.

Chapter 5 evaluated the different types of surrogates for benthic habitat data and compared how well they protected marine biodiversity with high resolution biotope data. This chapter identified the data that would best protect marine biodiversity when used in marine conservation planning and highlighted problems of the availability of this data for the UK. The next chapter (6) addressed the challenge of balancing conservation and socioeconomic objectives in a marine plan. Two case study areas were used to evaluate how effectively Marxan with Zones could balance the needs of the various sectors (conservation - cultural and biological, recreation and commercial fishing and aquaculture). Area and frequency of use were used to weight the activities within the plan. These plans highlighted the difficulty of balancing all sectors and identified some of the compromises that are likely to required, such as: reduced protection of more robust habitats, reduced area available for commercial fishing and recreational activities.

The final analytical chapter identified the issue of the amount of confidence that could be placed in habitat data available for marine planning. The habitat data used in this chapter had an associated confidence layer, which contained the percentage confidence that could be placed on each area of habitat. These two data layers (habitat data and confidence data) were used to assess the percentage level of confidence that, when used in marine planning, best protected marine biodiversity. The key conclusions drawn were, that only small amounts of high confidence habitat data are available and they are not suitable for use in marine planning and that the confidence of 20-30% best protected marine biodiversity.

The discussion chapter made suggestions on how this research could influence marine planning and the further research and development required. Key recommendations were made on best practice in marine conservation planning and the use of Marxan and Marxan with Zones in MSP.

9.2 Reflection on thesis aims and objectives

The main aim of this thesis was to evaluate the use of spatial decision support tools as practical tools to enable the production of marine plans that integrate environmental and socioeconomic data and to suggest best practice in the types of data used. This thesis evaluated two types of data sensitivity, confidence and resolution and complexity, and made suggestions on best practice on these types of data. Other data types are used within MSP, including human activity data, and further research is required on the impacts of using these within MSP. This thesis has demonstrated that Marxan and Marxan with Zones can be used to develop marine spatial plans. It has also assessed several ways to weight data, and therefore sectors, within Marxan and Marxan with Zones. Further ways to weight sectors include using monetary data, but as this will not always be applicable or available, proxy measures will have to continue to be applied.

The first objective "to critically review marine planning and site selection tools, to evaluate appropriate decision support tools and identify gaps in research in marine planning and site selection tools" was addressed mainly in chapter 2. This chapter reviewed the development of MSP and evaluated the likely challenges in its implementation, with particular reference to identifying priority areas for conservation and the data requirements of MSP. This chapter demonstrated the requirement for the research undertaken in this thesis.

The second objective was "to demonstrate the rationale for case study choice, describe the case study areas and the data used in the analysis in the data chapters". The rationale for each case study was covered thoroughly in chapter 4. The case study areas were chosen because they represented a broad spectrum of size, data availability, conservation importance, human activities and current marine planning activities. As each of the case study sites will have similarities to many other areas around the UK, the findings in this thesis can be applied widely.

The third objective was "‘to evaluate the use of Marxan and Marxan with Zones in previous studies and explain the methods used"’. Chapter 3 contained an in-depth description of the methods used in this thesis, and demonstrated the rationale for their use. This chapter also evaluated previous studies that used Marxan and Marxan with Zones.

Objective four was "to assess the resolution and complexity of data required to protect marine biodiversity using currently available data". This objective was covered in chapter 5. This chapter evaluated the marine biodiversity conservation outcomes when using data with different resolutions and complexity. It also demonstrated that the data that best protected marine biodiversity is not available for the UK and identified likely outcomes of using sub-optimal data. The conclusions of this chapter fed into the type of data used in the following chapter.

The fifth objective was "to assess how to integrate biodiversity and cultural conservation and socioeconomic data, and objectives, focusing on recreation and fishing, in a marine plan using Marxan with Zones". This chapter demonstrated that Marxan with Zones could integrate objectives from different sectors, evaluated various methods that could be used weight sectors against one another and successfully produced two marine plans. It then contrasted the marine biodiversity protection in the two marine plans that were developed with the current level of impact on biotopes. Two key problems were identified whilst pursuing this study.

1. In the second Marxan analysis in Lyme Bay (chapter 6) the aim was to include two different data layers of fishing activity data that had been collected in two different ways: 1. the Fishermap data and 2. data provided by the Devon Sea Fisheries Committee. The Fishermap data collection has been described whereas the other data layer was collected by sightings, from a patrol vessel. This recorded the vessel, fishing gear type and home port. This second layer only went out to six nautical miles. It was felt that it would not be a good comparison because the Fishermap data covered the entire planning area. A relative fishing index was created, similar to the one in Klein (2008). However, the time spent creating the index and comparing the data types helped to contribute to the analysis even though it was not included in the final thesis.

2. The second major difficulty encountered was that for the final part of the data analysis in the thesis. The aim was to obtain the habitat data, recreation and fishing data used in the Balanced Seas region of the MCZ project (inshore and offshore water of south east England). To further evaluate the use of Marxan with Zones on a larger scale and with more data layers that could be incorporated as costs. This Marxan with Zones output would then be compared with the recommended MCZs to see if the areas identified as important for conservation were the same as those identified by stakeholders. The data were unavailable because of commercial confidentiality and data protection. Not all participants who had given their data were willing to share this with researchers who were not directly connected to the MCZ project. Budget constraints at the governmental bodies who held this data meant that time could not be devoted to stripping out data of participants who did not wish to share their data. Not obtaining this data meant that new ideas of applying Marxan or Marxan with Zones in marine planning, with available data had to be generated. A UK Government agency (JNCC) had produced a UK habitat map with confidence data and the literature had examples of applying data confidence within marine conservation planning. The research on this went well and provided useful information for application in marine conservation and marine planning (chapter 7).

The difficulties encountered here have been caused by the quality, coverage or availability of data and lack of resources, which reflect some of the challenges faced in marine spatial planning generally.

Objective six was "to evaluate the impacts of using confidence levels in habitat data on marine biodiversity protection". This objective was fulfilled in chapter 7 and that the research carried out has contributed usefully to marine biodiversity conservation. Many of the current suggestions for incorporating uncertainty and confidence in data require complex statistics and when combined with a program such as Marxan, may lead stakeholders to mistrust the results given, because they will not understand the statistics. The methods used in this study are more transparent and more likely to inspire confidence in stakeholders.

The seventh objective "to make suggestions on how this research should influence marine planning". This objective was covered in each of the analysis chapter's discussions, with the key conclusions from each of these chapters brought together and further examined within the discussion chapter.

The final objective (eight) was "to make key recommendations for best practice, focusing on marine biodiversity conservation and the use of Marxan and Marxan with Zones, in marine spatial planning". In the discussion chapter key recommendations were made which focused on best practice in using Marxan and Marxan with Zones in MSP, fulfilling this objective.

9.3 Future work

Site selection tools are useful in their current forms but need to be developed to respond to the needs of the marine planning process. DSTs can produce outputs that stakeholders do not understand and may not trust, which may lead to them resisting the use of DSTs. There is a need for the development of materials which can be used to explain to non-technical audiences what DSTs can do and how they do it. Simplified versions of programs could be created for use with stakeholders. These could be programmed with some of the data relevant to the marine planning process which the stakeholder is involved in. The programs could then be used to demonstrate the effects of different management actions. For example, the effect of increasing or decreasing the proportion of habitat or species to include in a protected zone.

Marxan and Marxan with Zones were developed for conservation planning, and only provide information on whether conservation feature targets have been met. The potential effects of the plan on other sectors cannot be directly derived from the outputs generated. In this thesis analysis was undertaken on the impacts of a marine plan on fishing, aquaculture and recreation activities which provided vital information for marine planning on the effects of different management actions. These analyses demonstrate how sectors could potentially be effected by reduction in frequency or value if a marine plan were implemented. If Marxan with Zones could be developed to produce outputs that analyse the effects on all sectors, these would make them more useful for discussion with stakeholders and would allow many more scenarios to be analysed.

DSTs should be developed for on-line use so that they encourage collaborative work and allow many users to generate outputs. Marxan and Marxan with Zones have recently been updated so that they can used freely online (Marxan.net) and the projects run through this site can be shared publicly or to a selected group of stakeholders. DSTs must be free to use and develop so that many people can benefit from their use and so that they may continue to develop.

The methods applied in this thesis on human impact assessment and on Marxan and Marxan with Zones can be applied to other sites, three potential examples are described here. A study could be performed using the Marxan with Zones methods, on the data (both marine biodiversity and human use) used in one of the MCZ project regions. It would be useful to compare which areas Marxan with Zones identifies as important to be included in an MCZ and with those chosen by stakeholders.

The marine environment is three-dimensional, and MSP will need to manage activities on the surface, in the water column and on the seabed (Schaefer and Barale 2011). Currently Marxan and Marxan with Zones cannot work in all three dimensions at the same time. A Marxan with Zones analysis could be run three times in the same area, each time working with the human activities, impacts and marine biodiversity associated with each level of the marine environment. The zones Marxan with Zones recommends for each level could then be compared to highlight potential conflicts between levels.

The success of a MPA is affected by the management regime within its boundary and the management that occurs outside its boundary (Agardy et al. 2011; National Research Council 2001). Impact assessments are often carried out within a MPA area, but it would be useful to evaluate the risks to a MPA from outside its boundary. For example, several similar MPAs (size, length of designation, activities that occur within it and etc.), could be compared; with some MPAs that are meeting their objectives and some that are not. The activities and potential impacts that occurred within a set distance could be assessed. Potentially, this could demonstrate why some MPAs seem to recover more quickly and increase the evidence for the need for large scale MSP.

It has been demonstrated that DSTs can support marine planning and the importance of stakeholder engagement during this process. Further research could explore how to use scenario testing to support stakeholder engagement. For example, research could be undertaken on how to communicate how DSTs perform the analysis so that stakeholders trust DST scenario outputs and learn how to incorporate them into marine planning.

9.4 Recommendations

Marxan has developed many extra extensions and functions since first being created 15 years ago (Ball 2000), such as the addition of a front-end to make it more user friendly (Zonae Cogito) and the development of Marxan with Zones has allowed the addition of multiple costs and zones. As computing power continues to increase, Marxan and Marxan with Zones will be able to run more complex problems, i.e. more data, larger areas with more planning units or with increased zones. A useful addition to Marxan would be to combine it with other DSTs, such as multi criteria analysis (MCA) tools. Using MCA to feed directly into the cost setting of Marxan with Zones, would mean the weightings used to develop the costs could be evaluated fully.

Currently Marxan and Marxan with Zones work in a flat plane and it is not possible to run a fully integrated three-dimensional analysis. To incorporate three dimensions the habitats used need to be broken into different depths. It would be useful to further develop Marxan so that it could include three-dimensional data to further allow the program to model more closely the real world. If Marxan could generate three-dimensional outputs the connections between the surface, water column and benthos could be seen more clearly.

Marxan and Marxan with Zones are primarily used for conservation and MSP, but have been used in other ways. Ban (2008) used Marxan to identify areas that were important to fishing off the coast of Canada. A further potential use of Marxan and Marxan with Zones could be to identify areas that are important for other reasons. For example, Marxan with Zones could be used to identify sites that could be useful in wave energy. The amount of wave energy in an area could be a feature, with higher penalty costs for not including areas with higher wave energy. The costs that could be applied might be the distance from a connection point which would increase the further away the site was, the suitability of the substrate, with higher costs associated with less suitable sites and the presence of sensitive species. Marxan and Marxan with Zones allow planning units to be included or excluded from zones, and this could be used to make sure that the sites known to be unsuitable, for example, in or near a shipping lane, would not be selected.

Studies recommend that in MSP various scenarios are run to evaluate what is likely to happen when sites are selected for certain activities to occur in or the prioritisation of some activities over others (Agardy et al. 2011; Douvere 2008). Marxan with Zones would be useful in this process to allow the evaluation of different scenarios quickly.

This thesis has shown how useful DSTs, such as Marxan and Marxan with Zones, can be in marine planning. What is now required are the resources and impetus to apply such tool in the marine spatial planning process. This could involve stakeholders, or simply as a means of better presenting and interpreting information. This would allow a far better view of the real world and human activities to presented. This thesis has demonstrated that these tools can be used even where available data is limited but it also provides an indication of what data could be most valuably collected in the future.

This thesis has demonstrated that site selection tools can aid the marine planning process and that the quality of data used during this process will affect the ability of a plan to meet its objectives. It has shown how to incorporate modelled data in marine conservation planning and how use the best available ecological data to protect marine biodiversity. It has demonstrated that Marxan and Marxan with Zones can integrate data from different sectors to ensure that each sector is treated fairly. The conclusions and recommendations of this thesis will inform marine planning and contribute to and inform best practice.

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