University of Brighton

Identifying marine management priority areas by mapping environmental value and fishing intensity

presented by

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A thesis submitted to the University of Brighton in partial fulfilment of the requirements for the degree of

MSc Geographical Information Systems and

Environmental Management

August 2017

Abstract

The marine environment is complex and dynamic. It provides many benefits by way of provision of food and raw materials, recreational activities, climate regulation and scientific discoveries, to name but a few. However, these benefits are under threat from many pressures, such as climate change, plastic litter, pollution and over-exploitation. Fishing is both a key benefit and a major pressure; fishing provides food and income for millions of people worldwide and is the most pervasive pressure in coastal waters. The greatest impacts are on coastal zones where the marine environment is particularly productive and there is a concentration of people. Robust, evidence-based management is required to ensure that there is a balance between exploitation and protection. Yet managers have limited time and resources, so need to focus their efforts in priority areas to be most efficient and effective.

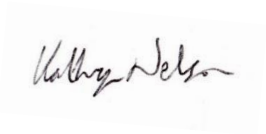
In this context, priority areas in Sussex coastal waters were identified by mapping environmental value and fishing intensity on a grid with 1km^2 cells. Environmental value was scored (0-5 very low to very high) based on seabed habitats and their ecosystem services provision, diversity and sensitivity. Fishing intensity was scored (0-5 very low to very high) based on the impacts and benefits of specific fisheries and their observed effort. Priority scores (0-5 very low to very high) for each cell of the grid were calculated by multiplying the environmental value with the fishing intensity.

The highest priority area was identified between Selsey and Bognor Regis, with other areas of high priority to the west and south of Selsey, between Brighton and Newhaven and near Eastbourne, but covering just 5% of the study area. This is where there were habitats with high environmental value (rocky reefs and seaweed dominated sediment) concurrent with high fishing intensity. These areas should be the focus of further research and potential management measures. Marine Protected Areas are an important part of current management measures and the spatial concurrence of MPAs with the priority areas and environmental value was examined.

Each element of the study individually advances understanding of the value of the marine environment and the importance of the fisheries in Sussex coastal waters. Together, the multiparameter approach strengthens the knowledge of the processes and interactions, building a robust evidence base for management decision making.

Declaration

I declare that the research contained in this thesis, unless otherwise formally indicated within the text, is the original work of the author. This thesis has not been previously submitted to this or any university for a degree and does not incorporate any material already submitted for a degree.

Signed: 

Date: 30th August 2017

Word count: 15,459

Acknowledgements

The author would like to sincerely thank their supervisor Dr N. Burnside, the Sussex Inshore Fisheries and Conservation Authority and Mr P. S. Nelson for all their advice and support. Additional thanks to the Sussex Inshore Fisheries and Conservation Authority for funding this Masters course.

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1. Introduction

1.1 Background

Oceans cover over 70% of the Earth's surface. They regulate the climate, are a source of food, raw materials and medicines, and provide innumerable benefits. Despite the scale and value of the marine environment, it is under threat from a range of anthropogenic impacts. Coupled with this is our lack of full understanding of the natural processes and therefore the consequences of the multitude of impacts. There is a need to understand more about marine ecosystems and how they can be managed sustainably (McLeod & Leslie, 2009).

Coastal environments are particularly vulnerable. Despite being only 11% of the ocean, areas less than 50m deep support 90% of global fisheries (UNEP, 2006). From the terrestrial side, coastal land which is less than 10m above sea level is 2% of the land area but supports 10% of the human population and two-thirds of cities with a population of more than 5 million (McGranahan et al, 2007). There is enormous pressure on the coastal environment from a range of sources.

1.1.1 Unprecedented pressure

The marine environment is dynamic, multidimensional and complex. There are long distance, interdependent linkages between systems, making it difficult to predict the consequences of any specific impact, as well as their interactions (Kenchington, 2014). The impacts are causing unprecedented pressure. Globally, increasing atmospheric carbon dioxide is causing climate change with effects including sea level rise, global temperature increase, ocean acidification and changes in the distribution of species (McLeod & Leslie, 2009). The combination of increasing water temperature and acidification is causing the decline of species which contribute to coral reefs (Hoegh-Guldberg et al, 2007). Whilst other, more mobile species can move their distribution patterns, corals, kelp forests and biogenic reefs are less able to respond rapidly (Polovina, 2005). Even those species which can change their migration are linked to other species in complex food webs, leading to decreased recruitment and shifts in community structure (Walther et al, 2002).

Other global issues include plastic pollution, eutrophication, invasive species, habitat damage and overfishing, which all act synergistically (Bellwood et al, 2004; Knowlton, 2001). Plastic takes a long time to break down and can cause damage by entangling and ingestion. If ingested, it can cause false satiation, digestive blockages and can be a vector for toxic chemicals (Li et al, 2016). Even very small particles of plastic can cause damage and can be transferred up the food chain (Farrell & Nelson, 2013). Eutrophication is caused by excess nitrogen and phosphorus runoff from agricultural land and can lead to hypoxia and the death of coastal species (Rabalais et al, 2001). Non-native invasive species can lead to decreased diversity and the extinction of vulnerable native species (Mack et al, 2000).

Fisheries are one of the most important benefits from the marine environment and provide food and income for 820 million people worldwide (FAO, 2016). However, fishing can cause environmental damage by over extraction leading to changes in population structure and food webs (Jackson et al, 2001), bycatch of vulnerable non-target species (Lewison et al, 2004), ghost fishing (Arthur et al, 2014; Bilkovic et al, 2014) and damage to seabed habitats (Collie et al, 2017). Overfishing is the most prevalent pressure on coastal ecosystems worldwide (Jackson et al, 2001).

1.1.2 Meaningful management

Fishing is an example of how the marine environment is closely coupled to society and the economy. Market forces can influence the fishing pressure on target species, affecting employment, wages and coastal communities as well as the marine environment (Aguilera et al, 2015). Often, humans are seen as exogenous to the environment, where the environment is a separate place in which to dump waste or extract resources and where humans are a threat to the environment, damaging and polluting it. This is the view of ‘the tragedy of the commons’ where there is inevitable overexploitation (Hardin, 1968). However, there is an alternative viewpoint which sees people as an intrinsic part of the environment, where communities are developing cooperative sustainable practices (Sampedro et al, 2017; Ostrom et al, 1999) and are working to improve ecosystems (Palmer et al, 2004).

Management of the marine environment and its exploitation is required to ensure that there can be a successful balance between protection and use. Management should be evidence based, requiring rigorous scientific assessments of the marine environment and the impacts of the pressures, although this can be daunting in the face of complex systems undergoing rapid change and under multiple pressures (Cloern et al, 2016). Managers have only limited resources and so need to prioritise their efforts to areas where there is highest risk of environmental damage and greatest rewards for conservation efforts (Wilson et al, 2006).

Management solutions are varied, with an emphasis on taking a whole ecosystem approach (McLeod & Leslie, 2009), having a diversity of management bodies (Ostrom et al, 1999) and being adaptable to change (Aguilera et al, 2015). The ecosystem approach involves looking at the whole ecosystem and all its connections and interactions. For coastal ecosystems, this means taking into account the land use, agricultural run-off, urban development, commercial and recreational activities, fresh to salt water transition and offshore processes. It also means managing all impacts holistically, not on the more traditional species or sector specific basis. This can result in more joined-up, cohesive management and contribute to sustainable development which is good for the economy and the environment (McLeod & Leslie, 2009).

Marine Protected Areas are an important part of marine management. They are specific areas where activities are restricted to protect environmental features such as fragile habitats or breeding hotspots (Ruiz-Frau et al, 2015). Just 2.3% of the oceans worldwide are designated Marine Protected Areas despite their demonstrable benefits including increased abundance and size of species, increased diversity and increased public engagement (Jones, 2014).

1.1.3 Identifying priorities

The marine environment needs to be managed in a way that protects the ecosystems from harm and yet allows people to benefit from the services it provides. Fishing is both a key benefit and pressure. There has to be a balance between allowing the people of today to meet their needs and ensuring that there will be healthy seas to meet the needs of future generations. Managers have limited time and resources so need to prioritise their actions.

Coastal zones are hotspots where the marine environment is highly productive and at high risk of damage from anthropogenic pressures. The inshore waters off the coast of Sussex, southern England, are an example of a temperate coast with typical pressures and the focus of this study. Within this area, the environmental value and fishing intensity will be assessed to identify priorities for marine managers.

1.2 Aim and objectives

1.2.1 Aim

To identify priority areas for marine managers by using a multiparameter approach to assess the relative value of the marine environment and the intensity of fishing activities.

1.2.2 Objectives

1) Assessment of marine environmental value: the mapping of seabed habitats in Sussex coastal waters (out to 6 nautical miles) and the scoring of each habitat based on ecosystem services provision, diversity and sensitivity.

2) Assessment of fishing intensity: the mapping of fishing activities in Sussex coastal waters and the scoring of each fishery based on observed effort and the relative economic, environmental and social impacts and benefits.

3) Assessment of management priority areas: the combination of environmental value and fishing intensity to identify marine management priority areas.

1.3 Overview of report

Following the introduction, there is the review of literature; a critical discussion of marine management options, the valuation of the marine environment and the assessment of fishing activities. Then there will be the description of the methodology used and the results of the analysis. The next section will be a discussion of the results of this study in the context of the published literature and finally, the conclusions of the study. The methods and results are laid out in sections as set by the three objectives (section 1.2.2).

2. Literature review

2.1 Marine management

The marine environment is vast, multidimensional and highly complex (Kenchington, 2014). It provides many benefits from global-scale climate regulation to local-scale beach holidays. It means something different to each of us; food provision, flood protection, water quality enhancement, recreational opportunities, natural beauty and scientific discoveries. People rely on the marine environment for the many services it provides and are an intrinsic part of the seascape. Yet people are causing many negative impacts on the environment. The impacts are multiple and synergistic, from climate change to plastic litter, from pollution to overfishing. Each impact in isolation is causing detrimental impacts and together, are acting to change the environment at an unprecedented rate (McLeod & Leslie, 2009).

Whilst it is undeniable that there are many causes for concern, there are also many positive, inspiring stories of habitat restoration and stock recoveries. Recently, North Sea cod was certified as sustainable by the rigorous standards of the Marine Stewardship Council, following many years of efforts by the European Union to improve stock levels after near collapse in the mid-2000's (MSC, 2017). South Georgia Island in the South Atlantic Ocean was a major base for the whaling and seal fur trade in the early to mid 20th century. Now the waters around the island are part of a one million square kilometre Marine Protected Area and a haven for wildlife (Pew Charitable Trusts, 2017). Wild populations of native oysters in the Solent, south England, declined to almost non-existent in the last decade due to disease, poor water quality and over fishing. Now a collaborative project led by the Blue Marine Foundation is working to restore native oysters and their associated economic and environmental benefits (BLUE Marine Foundation, no date). These success stories and reasons for optimism should be shared and built upon. There are numerous solutions to the multitude of issues and a range of management options.

2.1.1 Managers

Marine resources are common property, not privately owned and it can be challenging to manage them in a way that is equitable and sustainable (Armitage et al, 2017). Management takes place under a range of governance structures and with the involvement of multiple parties. In England, the Marine Management Organisation manages vessel licencing, required for commercial vessels to legally sell their catch. They also monitor the amount of fish landed to ensure quota limits are not exceeded and are the consenting authority for marine activities such as aggregate extraction and marina development (MMO, no date).

Inshore Fisheries and Conservation Authorities (IFCAs) manage sea fisheries resources and the marine environment from mean high water out to six nautical miles. They have powers under the Marine and Coastal Access Act 2009 to write and enforce byelaws to manage the exploitation of sea fisheries resources. IFCAs are governed by a committee with members from local councils, executive non-departmental public bodies and stakeholders; local fishermen, recreational sea users and conservationists. In addition to this collaborative, regional governance structure, there is extensive consultation with stakeholders during the development of management measures, such as closed areas, closed seasons, permit schemes, effort limitations or species-specific size limits (Sussex IFCA, 2017a).

Other statutory organisations with an interest in marine management in England include the Environment Agency, Natural England, Crown Estate, Joint Nature Conservation Committee (JNCC) and the Centre for the Environment Fisheries and Aquaculture Science (CEFAS). Other numerous stakeholders are also part of the governance structure, from commercial fisheries groups to environmental non-governmental organisations (NGOs).

Managers need to prioritise their efforts to make best use of limited time and resources (Khamis et al, 2014). Areas for conservation priority can be identified by assessing the relative environmental value and the intensity of pressures (Kacoliris et al, 2016) and then the allocation of resources to these priority areas can be determined (Wilson et al, 2006). However, there is often limited data available and researchers have to make best use of what is available, whilst acknowledging the data gaps and not letting lack of data stop the development of necessary management (Palkovacs et al, 2014).

2.1.2 Policy context

There is a recognised need for more transparent, evidence based, fair distribution of access to natural resources. Seventeen Sustainable Development Goals, described in the 2030 Agenda for Sustainable Development, were adopted by world leaders in 2015. They set targets to tackle poverty, inequality and environmental issues. Goal 14 is to 'conserve and sustainably use the oceans, seas and marine resources'. Relevant targets under Goal 14 include (UN, 2017):

- 'sustainably manage and protect marine and coastal ecosystems to avoid significant adverse impacts'
- 'effectively regulate harvesting and end overfishing, illegal, unreported and unregulated fishing and destructive fishing practices'
- 'conserve at least 10 per cent of coastal and marine areas … based on the best available scientific information'

There are similar aims under the UK Marine Policy Statement, adopted for the purposes of the Marine and Coastal Access Act 2009, which sets out the UK Administrations' shared vision of achieving 'clean, healthy, safe, productive and biologically diverse oceans and seas' (HM Government, 2011).

There is an emphasis throughout the various legislation and guidance to consider the impact of human activities on the marine environment and use best available scientific information to make sound management decisions. However, often there can be fundamental inconsistency between the well-intentioned aims of policies and the implementation of them (Kareiva et al, 2011).

2.1.3 Management options

Strong evidence-based management is required to protect the environment from harm and ensure that people continue to enjoy the natural benefits. Spatial planning is required in multi-use areas where there is a risk of environmental damage from unregulated activities (Douvere, 2008). Marine Spatial Planning has developed rapidly over the past decade and aims to reverse biodiversity loss and build resilient, healthy ecosystems through multidisciplinary research and cross-sector initiatives (Ehler &

Douvere, 2009). In Europe, the Maritime Spatial Planning Directive (2014/89/EU) was adopted in 2014 to:

- ‘Reduce conflicts and create synergies’
- ‘Encourage investment’
- ‘Increase cross-border cooperation’
- ‘Protect the environment’

In England, the Marine Management Organisation are creating regional marine plans in consultation with coastal communities, considering the sustainable development of marine activities over the next twenty years (MMO, 2016).

Marine Protected Areas (MPAs) are a key part of marine governance, protecting and promoting biodiversity, ecosystem services provision and diverse socio-economic benefits (Russi et al, 2016). They are specific areas of the sea which are reserved to protect the natural or cultural features within the enclosed area (Kelleher & Kenchington, 1991). The level of protection can vary from no take zones where all extractive activities are prohibited to multi-use sites where lower impact activities are permitted (Jones, 2014).

The area of the marine environment covered by MPAs is increasing (Pollnac & Seara, 2011) and so is the understanding of the factors that influence the success of meeting the objectives of MPAs (Oliveira et al, 2016; Gallacher et al, 2016). Whilst MPAs can provide many benefits (almost 100 distinct benefits were found by Angulo-Valdés & Hatcher (2010)) there can be problems with effective governance (Jones, 2014). Where stakeholders have had their activities restricted without any perceived benefits in return, they will resist the new management measures (Diedrich et al, 2017). MPAs can take away fishing grounds, often from artisanal fishers who have limited alternative options (Pollnac & Seara, 2011). Without robust enforcement, MPAs can become ‘paper parks’ where the environment is protected on paper only and restrictions on activities are not enforced (Pieraccini et al, 2016). There are numerous factors which influence successful management of MPAs, a key one being effective dialogue between all of the parties involved in the use, protection and management of the area and its resources (Vasconcelos et al, 2013).

2.2 Marine environment

Understanding of the marine environment is essential for the successful management of it. Mapping seabed habitats is a top priority for supporting sustainable management of fisheries, followed by mapping of fishing effort (Kaiser et al, 2016). The advances in the use of geographical information systems (GIS) has helped facilitate this (Teixeira et al, 2013; Collin et al, 2014; Kruss et al, 2017). However, detailed seabed habitat maps are often unavailable at a suitable level of accuracy and detail, due to the high cost and complexity of collecting and analysing the requisite data (Stephens & Diesing et al, 2014). Acoustic devices are usually used to identify areas of distinct seabed type and then ground truthing – with videos, grabs or diver observations – is used to classify each area (Hamilton, 2001). Where the requisite data is not available, there can be opportunities to use novel techniques to make best use of the data that is available. For example, where ground truthing data points were available without the detailed acoustic data, a continuous surface was produced using Voronoi polygons (see section 3.2.1 for further details) at a higher spatial and descriptive resolution than the comparative maps created using lower resolution acoustic data (Tomline & Burnside, 2015).

2.2.1 Assigning value

There are a range of existing assessment frameworks for assigning environmental value; environmental impact assessment, strategic environmental assessment, environmental risk assessment and cumulative effect assessment, but they can lack simplicity, transparency and flexibility (Tamis et al, 2016). Assigning a value to the marine environment can guide decision making on the use of marine resources (Remoundou et al, 2009) and provide evidence for the development of management strategies (Derous et al, 2007). Often this involves attributing anthropocentric monetised value to natural capital and ecosystem services which can seem to imply ruthless exploitation but can result in greater protection for the environment (Kareiva et al, 2011). Economic valuation, including the distribution of the benefits, can show how dependent the economy is on the services provided by an ecosystem and what would be lost if it was not protected (Lange & Jiddawi, 2009).

A major step in this direction was the Millennium Ecosystem Assessment project which assessed the condition and trends in the world’s ecosystems and the services that they provided (Millennium Ecosystem Assessment, 2005). Such dynamic processes and feedback loops are complex yet understanding is required to support policies which intend to improve human well-being through intact ecosystems (Carpenter et al, 2009). Although humans are buffered against change by cultural and technological advances, we are ultimately dependant on the flow of ecosystem services (UNEP, 2006).

The Millennium Ecosystem Assessment (2005) recognised that marine and coastal ecosystems could provide a range of ecosystem services:

- Provisioning: seafood (wild caught and aquaculture), ornamentals for the aquarium trade, building materials (timber and fibre) and bioprospecting
- Regulating: climate, floods, shoreline stabilisation, disease, water quality, pollutants and wastes
- Cultural: recreation, spiritualism, tourism, public awareness, education, traditional knowledge and aesthetic value
- Supporting: soil formation, photosynthesis, nutrient cycling, carbon sequestration and habitats for important life stages of many fish and birds.

Another important aspect of valuing the marine environment is assessing diversity. Diversity is an important factor in the functioning and resilience of ecosystems (McLeod & Leslie, 2009) and the identification of biodiversity hotspots is used to prioritise conservation efforts (Wilson et al, 2006). There is often more diversity when the habitat is more heterogeneous and structurally complex (Bazzaz, 1975). However, this can vary between species and can depend of fragmentation and scale (Tews et al, 2004).

Bogaert et al (2005) argues that diversity, heterogeneity and entropy are interchangeable terms when used in reference to spatial habitat patterns. Entropy, a thermodynamic quantity, has been used in a variety of ways in ecology; pattern scale dependence, pattern dynamics and spatial heterogeneity (Vranken et al, 2015). In the study of spatial heterogeneity, entropy is considered a measure of disorder, where higher entropy indicates higher heterogeneity and greater habitat diversity (Vranken, 2015). This can be used to infer species distributions (Fahrig et al, 2011), urban sprawl (Sudhira et al, 2004) and habitat fragmentation (Cushman & McGarigal, 2003). Large connected areas of habitat will have a lower entropy than small scattered habitats with greater spatial diversity. In terrestrial systems, higher entropy can infer high levels of anthropogenic fragmentation, leading to genetic isolation and generally poorer environmental condition (Jaeger, 2000).

A further aspect to consider when identifying management priority areas is the sensitivity of habitats to damage (Tillin & Tyler-Walters, 2014). The effect of an activity can be assessed by determining the resistance – the amount of damage that the habitat or species can tolerate – and the resilience – the time which the habitat or species takes to recover from the disturbance (Eno et al, 2013). Some habitats are more sensitive than others to anthropogenic disturbance. Those habitats that are not naturally perturbed and those that are structurally complex are more likely to be adversely affected by fishing activity (Kaiser et al, 2002).

Nilsson and Ziegler (2007) used the Marine Life Information Network (MarLIN) to assess the effects of various fishing intensities on marine habitats, based on the assumption that the sensitivity of a biotope is dependent on the species within it. However, Tyler-Walters et al (2009) argued that this was flawed due to a limited knowledge of the structural or functional role of many species, particularly within sedimentary habitats. Another method used a size-based model – and took into account natural disturbance – to assess sensitivity as related to the recovery time of biomass (Hiddink et al, 2007). In the Celtic Sea, sensitivity to a range of fishing methods was assessed by assigning a resistance score to each habitat and a resilience score to each habitat and fishery combination (Eno et al, 2013). This resulted in a clear and easily understood assessment of the impact of fishing.

2.3 Marine fisheries

Fishing is a major source of income and employment for coastal communities, as well as being a significant part of their cultural heritage and identity (Natale et al, 2013). In the UK, over 4,500 vessels landed £772 million of seafood in 2015 (Lawrence et al, 2016). Fishing provides a distinct sense of place, value and culture to coastal communities and up to 20% of employment depends on fishing in towns on the south coast of England (MMO, 2016).

2.3.1 Fisheries management

Fisheries are often managed either on the basis of single species (quota systems) or on a basis of interaction with seabed habitats (spatial restrictions) (Singh & Weninger, 2009; Cryer et al, 2016). Fishing activity in the UK is regulated under a complex system of management. Currently, the main management policy is the Common Fisheries Policy (CFP) (European Council Regulation No. 1380/2013), although this may not be the case once the UK has left the European Union. First introduced in the 1970s, the CFP manages fisheries and aquaculture with the aim of maximising an economically viable industry while minimising environmental impacts. There have been several revisions, the latest in 2014 which set dates for bans on fish discards, a legally binding commitment to fish at scientifically assessed sustainable levels and decentralised decision making (European Commission, 2017).

Under the CFP, total allowable catches (TAC) are agreed by EU Member States each December in the EU Fisheries Council, with scientific advice from the International Council for the Exploration of the Seas (ICES). TAC, as well as stock recovery measures, limit the amount of certain species which can be landed into ports, with the aim of keeping catch levels appropriate for sustainable stocks. Each EU Member State is allocated a proportion of the TAC for each species. The UK's quota is divided between England, Wales, Scotland and Northern Ireland. England's quota allocation is managed by the Marine Management Organisation (MMO) (DEFRA & MMO, 2015).

Article 17 of the CFP requires Member States to use 'transparent and objective criteria' when allocating fishing opportunities. Social, economic and environmental factors should be considered, including contribution to the local economy, impact of the fishing activity on the environment and historic catch levels. Member States should support fishers who are using techniques which reduce environmental impact. However, this is not currently occurring in all fisheries and the emphasis is on maintaining historical fishing rights, often to the detriment of more sustainable methods (NEF, 2011).

In England, quota is allocated to producer organisations in proportion to the number of fixed quota allocation units held on over 10 metre (vessel length) licences that are members of a producer organisation. Quota available for vessels over 10m but not a member of a producer organisation or vessels under 10m is held centrally by the Marine Management Organisation and usually managed on the basis of monthly catch limits (DEFRA & MMO, 2015).

Management of fisheries can be complex but it is necessary, as destructive fishing methods can impact the marine environment by physically changing the seabed habitats and the community structure of target and bycatch species (UNEP, 2006). Defining the socio-economic and environmental benefits and impacts of specific fisheries can help managers ensure that fishing opportunities are allocated in a transparent and equitable manner (Williams and Carpenter, 2016). A number of studies have assessed the impacts and benefits of various fisheries and found that opportunities are not always allocated in a manner that is best for society (NEF, 2011; Williams and Carpenter, 2015; MRAG, 2014; Williams and Carpenter, 2016 (further details in section 5.3)).

2.3.2 Fisheries monitoring

Understanding the spatial and temporal distribution of fishing activities is essential for their sustainable management (Vanstaen & Silva, 2010). UK commercial fishing vessels which are over 12m in length are required to have a vessel monitoring system (VMS) which sends positional information to the Marine Management Organisation at least once every two hours when the vessel is at sea (MMO, 2014). Currently, there is no requirement for VMS on vessels under 12m, leading to a data gap in this fleet sector which makes up 80% of all fishing vessels in the UK (STECF, 2016).

There have been a number of approaches to fill this data gap such as interviews with fishers (Kafas et al, 2017; Turner et al, 2015; Moreno-Baez et al, 2010) and the use of tablet computers with bespoke apps (Succorfish, 2015). There can be spatial distortion associated with fishers' knowledge but many small-scale traditional fisheries have been fished sustainably for generations and the fishers' accurate knowledge of the local environment is important for their continued resource use (McKenna et al, 2008).

Another method was to use observations from fisheries authorities whilst on patrol at sea (Vanstaen & Silva, 2010; Turner et al, 2015; Strong & Nelson, 2016; Nelson, 2017a) as fishers are often reluctant to share information on the location of their fishing grounds. Fishing effort assessed from observations can be linked to catch data to develop a Zone of Influence around landing ports, highlighting areas of gear conflict and attributing monetised value to inshore areas. With several years' worth of observations, spatio-temporal trends can be elucidated (Vanstaen & Breen, 2014; Nelson, 2017b).

There are a range of limitations to using sightings data including only being able to capture data during patrols and therefore unable to capture 100% of fishing activity. There was greater confidence in the accuracy of represented activity in the areas which were more frequently visited by the patrol vessel (Vanstaen & Breen, 2014). However, with no alternative data sources, the observed fishing effort provided useful information for consideration in the designation of Marine Protected Areas, for identifying conflict with other marine activities and for marine spatial planning (Vanstaen & Silva, 2010).

2.4 Summary

The marine environment is dynamic with high variability, large-scale multidimensional connectivity and uncertainty around structure and function. There is a certain amount of ‘out of sight, out of mind’ relating to this environment. Along with the lack of property rights – most marine areas being under national jurisdiction with common access – there is a lack of a sense of responsibility and stewardship (Jones, 2014). Thus, there needs to be strong governance with evidence-based management measures.

Due to the complex nature of the marine environment, focussing on a single species or a single aspect is not sufficient to successfully manage the ecosystem as a whole. Multiple parameters should be assessed when the aim is long-term conservation to restore or maintain healthy functions and processes (McLeod &Leslie, 2009). When assessing environmental value, ecosystem services provision, diversity and sensitivity are all key parameters to consider. Assessing fishing intensity under multiple parameters can support access to the stocks which is equitable and sustainable (Williams and Carpenter, 2016).

There are limited resources and time available to managers so efforts need to be prioritised to areas where they will be most effective. This study aims to identify priority areas for marine managers by assessing the value of the marine environment and the intensity of fishing activities, making best use of available data.

3. Methods

3.1 Overview

The identification of management priority areas was assessed across the study area on a grid with 1km x 1km cells. This facilitated the combination of several datasets on a common spatial scale and layout. The use of 1km^2 grid cells was considered to be a suitable compromise between the detail required for inshore management of fisheries and the marine environment, the interconnected dynamic nature of the environment, and the spatial resolution of the available data (Turner et al, 2015). A priority score (0-5 very low to very high) was calculated for each of the 1987 cells of the vector grid by multiplying the environmental value score by the fishing intensity score, so that high priority was assigned to cells with high environmental value and high fishing intensity.

The environmental value was assessed as the sum of ecosystem services provision, diversity and sensitivity of seabed habitats. These were assigned a score of 0-5 (very low to very high) based on published literature and GIS analysis. The fishing intensity was assessed by multiplying the impacts and benefits of a range of fisheries by the observed effort of vessels engaged in those fisheries and also scored 0-5 (very low to very high).

The use of ranking and scoring has been used successfully in numerous studies to help prioritise management of the environment using multiple criteria (Homem et al, 2015; Gumma et al, 2016; Alvarez-Guerra et al, 2009). Each criterion in this study will have an equal weighting, as each was considered equally important.

To summarise, the ecosystem services provision, diversity and sensitivity of seabed habitats was combined to calculate a single environmental value score for each 1km^2 cell in the study area. The impacts and benefits score of specific fisheries was combined with the observed effort of vessels engaged in those fisheries to calculate a single fishing intensity score for each cell. The environmental value and fishing intensity scores were combined to calculate the management priority score and mapped across the study area (Figure 3.1).

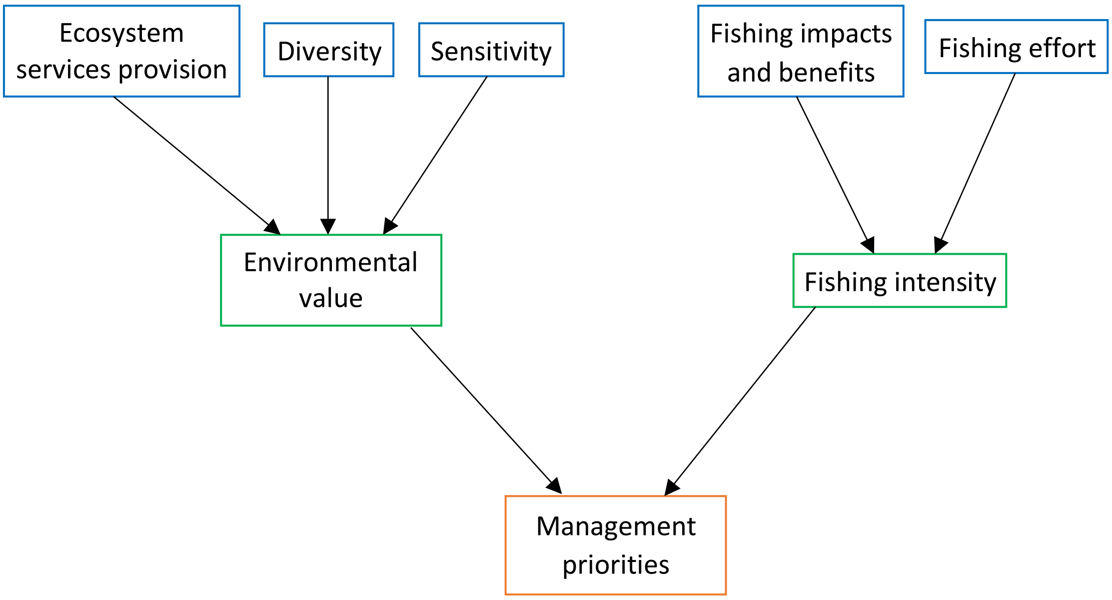

Figure 3.1: Summary of the main steps of the method; ecosystem services provision, diversity and sensitivity of seabed habitats combined to calculate the environmental value, fishing impacts and benefits combined with fishing effort to calculate fishing intensity, and environmental value and fishing intensity combined to calculate the management priorities score (0-5 very low to very high).

3.1.1 The study area

The study area was Sussex coastal waters out to the 6 nautical mile limit and inclusive of the whole of Chichester Harbour. The Hampshire-West Sussex county boundary is along the centre of the western most channel (Emsworth Channel) in Chichester Harbour but it made ecological sense to include the whole Harbour in the study area. The grid with 1987 1km^2 cells was overlaid on this area (Figure 3.2). For some of the elements, data was only available on a larger spatial scale and this has been described under those specific elements.

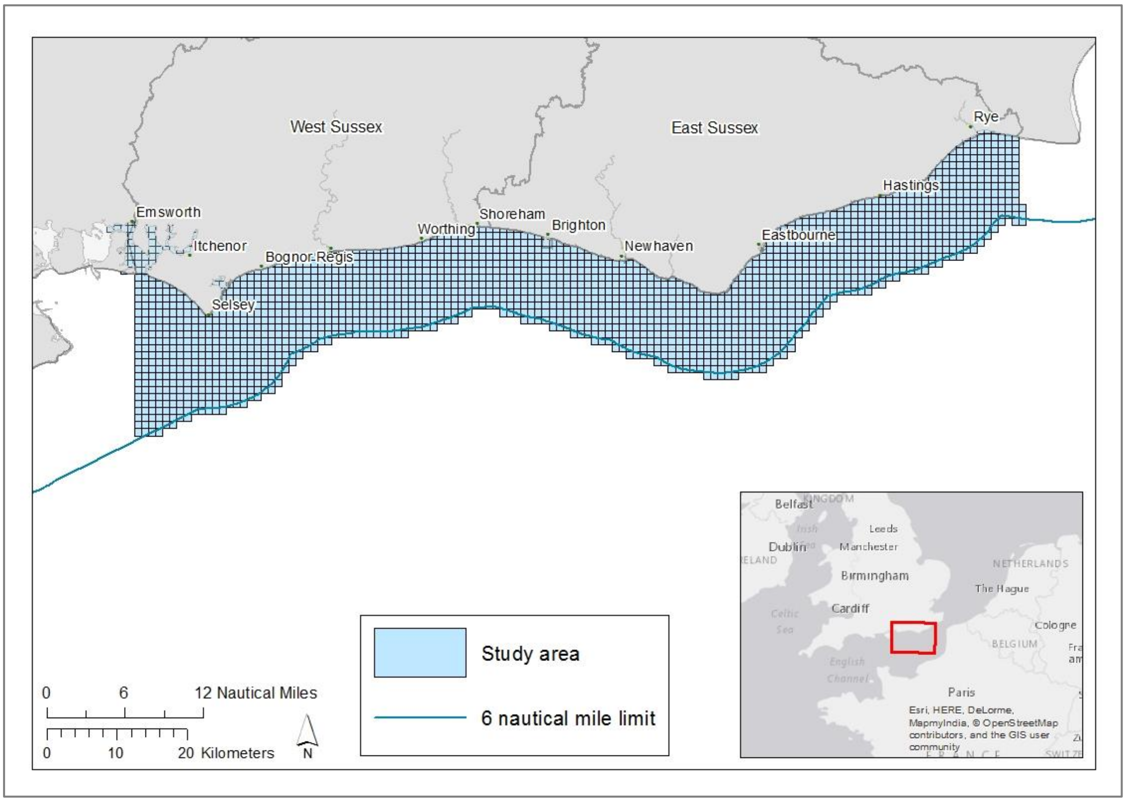

Figure 3.2: The study area; West and East Sussex coastal waters out to the 6 nautical mile limit and inclusive of the whole of Chichester Harbour, overlaid by a vector grid with 1987 cells 1km x 1km.

3.1.2 Coordinate system and software

Raw spatial data was in WGS84 latitude and longitude as recorded by GPS in the field. This was converted to British National Grid for better spatial evaluation.

GIS analysis was conducted using ESRI ArcGIS 10.4. Numerical analysis was conducted using MS Excel 2016.

3.2 Assessment of marine environmental value

The assessment of environmental value was based on seabed habitats. Data points were available across the study area at an average spacing of 240m, although they were significantly clustered (p value: <0.01, average nearest neighbour analysis). There were 177 distinct habitats and each one was assigned a score 0-5 (very low to very high) for ecosystem services provision and sensitivity based on information in the published literature and for diversity based on GIS entropy analysis.

To produce a continuous surface across the study area, Voronoi polygons were created from the data points and then intersected with the grid. The proportion of each Voronoi polygon which intersected with each grid cell was used to calculate the scores for each cell.

The environmental value score for each cell was calculated by adding together the scores for ecosystem services provision, diversity and sensitivity. Mapping the environmental value and component elements on a common grid facilitated the combination of environmental value with fishing intensity to calculate the management priority scores as described in section 3.4. The steps undertaken to map environmental value is summarised below (Figure 3.3). Further details are described in the following sections.

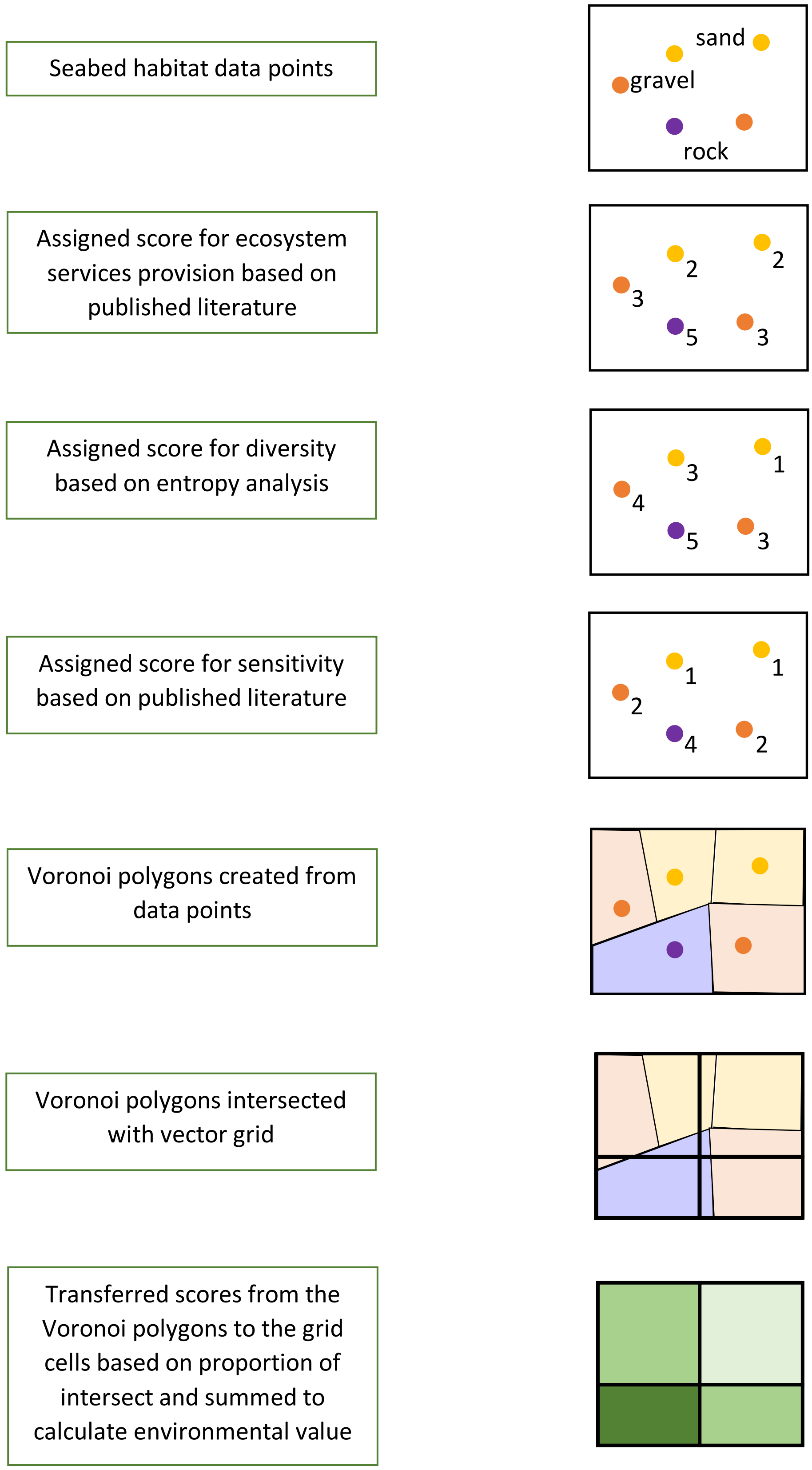

Figure 3.3: Summary of the steps involved in assessing marine environmental value; descriptive mapping of the habitats data points, assigning the scores for ecosystem services provision, diversity and sensitivity, creating the Voronoi polygons, intersecting these with the vector grid and calculating the overall environmental value score for each cell.

3.2.1 Seabed habitats

As the assessment of environmental value was based on seabed habitats, mapping of this data was the first stage. Two sources of seabed habitat point data were used: the Marine Recorder (JNCC, 2017) and Sussex IFCA survey data. The JNCC Marine Recorder Snapshot is a publicly accessible database which combines seabed sample data (video and diver observations and grab samples) from around the UK. The habitats were classified under the Marine Habitat Classification for Britain and Ireland. These were reclassified under the EUNIS scheme to the highest level possible to allow comparability with the Sussex IFCA data which was in the more commonly used EUNIS classification (see section 5.2.4 for further discussion of EUNIS).

In total, there were 4310 lines of data. Some of the data points had multiple habitats assigned to a single location. In most cases, this was due to the nature of the surveys. This was data collected during SeaSearch dive surveys where multiple divers had surveyed an area around the dive vessel, reported various habitats and recorded a single position, that of the support vessel. There were 2648 distinct positions, 75% (1988) of these had a single habitat. The other positions had 2-21 habitats assigned. All of the multiple habitats were kept as indicators of heterogeneity. There were 177 distinct habitats. Positions with more than one habitat, were designated with an 'x' to indicate a mosaic of habitats, as suggested by Connor (2006).

The Voronoi method was used to create a continuous polygon habitat layer from the point data (Tomline & Burnside, 2015). Also known as Thiessen or Dirichlet, Voronoi polygons were created from the point data by drawing lines equidistant between neighbouring sample points so that all locations within the polygon were the same as the sample point. This was an ideal method of spatial interpolation for categorical data but it can create unnatural sharp changes at the boundaries (Longley et al, 2011).

3.2.2 Ecosystem services provision

Data from the literature was used to assess the ecosystem services provision of the seabed habitats; namely studies in the European North Atlantic Ocean (Galparsoro et al, 2014), in European waters (Salomidi et al, 2012) and in UK Marine Protected Areas (Fletcher et al, 2012). The data was selected due to the suitability of the spatial extent, habitat classification and description of service provision. No attempt was made to assign a monetary value to the services, as this was outside the scope of this study. The provision of twelve ecosystem services (Table 3.1) was assessed.

Table 3.1: The twelve ecosystem services assessed using information from Galparsoro et al (2014), Salomidi et al (2012) and Fletcher et al (2012).

Category	Ecosystem service
Provisioning	Food provision
	Raw materials
Regulating	Air quality and climate regulation
	Disturbance and natural hazard prevention
	Photosynthesis, chemosynthesis and primary production
	Nutrient cycling
	Reproduction and nursery
	Maintenance of biodiversity
	Water quality regulation
Cultural	Cognitive value
	Leisure, recreation and cultural inspiration
	Feel good or warm glow

There was data for 46 habitats which were applicable to the study area. For each habitat, each service was assigned a score from 1 (negligible provision) to 5 (high level of provision) and then averaged to provide the overall score for each habitat. A similar scoring system has been successful in other studies (Galparsoro et al, 2014; Potts et al, 2014).

Those habitats in the study area for which data was not directly available, were assigned a score based on a different EUNIS level. For example, data was not available for A4.2142 so the score for A4.2 was used and an average of A5.13 and A5.14 was used as a score for A5.1. In this way, all 177 habitats were assigned a score for ecosystem services provision. For those positions where there was more than one habitat, the score was averaged.

3.2.3 Diversity

Diversity of the seabed habitats was assessed using the ArcGIS entropy option in the geostatistical analyst Voronoi tool. The entropy value for each polygon was calculated by assigning the polygon and its neighbours one of five smart quantile classes based on the habitat designation and assessing how many of the neighbours were in the same class (de Smith et al, 2007). Therefore:

$$\text{Entropy} = - \sum (p_i \times \log p_i)$$

where p_i is the proportion of polygons in each class. The minimum entropy of 0 occurred when all the neighbouring polygons were in the same class, indicating low diversity. Inversely, the maximum entropy of 2.322 occurred when all the neighbouring polygons were in different classes, indicating high habitat diversity (ESRI, 2016a).

To prepare the habitat data for this analysis, the EUNIS habitat codes were converted to numerical values by removing the 'A' prefix. Those positions where there was more than one habitat were assigned the value 6, as this value was not being used for any other habitat and could represent mosaic habitats, allowing these data points to remain in the analysis. The data table containing the positional and altered habitat data was added to ArcGIS and used to create a point shapefile, ready for creation of the entropy Voronoi layer.

As the ecosystem services provision and sensitivity scores were on a scale of 0-5, the entropy values were given a weighting of 2.2 to align the scales, so the maximum entropy would be 5.

3.2.4 Sensitivity

Sensitivity of the key species present in each of the 177 habitats was assessed based on information provided by the Marine Life Information Network (MarLIN) (2017a), selected as an extensive and easily accessible source of information. For each habitat, the typical and key species were noted. The resistance and resilience of the key species to abrasion was described and assessed as low, medium or high. The sensitivity score was assigned based on the matrix below (Table 3.2).

Table 3.2: Sensitivity matrix after MarLIN (2017b) and Eno et al (2013), where sensitivity was assessed as a combination of resistance and resilience.

		Resistance		
		Low Significant decline in species/habitat	**Medium** Some decline in species/habitat	**High** Very little decline in species/habitat but may affect function
Resilience	**Low** >10 years to recover	**5: Very highly** sensitive fragile habitat with long recovery time	**4: High**ly sensitive habitat with some resistance but long recovery time	**3: Medium** sensitive habitat with high resistance but long recovery time
	Medium 2-10 years to recover	**4: High**ly sensitive fragile habitat with medium term recovery	**3: Medium** sensitive habitat with some resistance and medium term recovery	**2: Low** sensitive habitat with high resistance and medium term recovery
	High <2 years to recover	**3: Medium** sensitive fragile habitat with rapid recovery	**2: Low** sensitive habitat with some resistance and rapid recovery	**1: Very low** sensitive habitat with high resistance and rapid recovery

In this way, all 177 habitats were assigned a sensitivity score. For those positions where there was more than one habitat, the score was averaged.

3.2.5 Overall environmental value

As in the sections described above, a score of 0-5 (very low to very high) was assigned to each seabed habitat data point for ecosystem services provision, diversity and sensitivity. A continuous surface was created from the data points by creating Voronoi polygons (as described in section 3.2.1). The Voronoi polygons were intersected with a grid with 1km^2 cells to facilitate the combination of the environmental value with the fishing intensity as described in section 3.4. The ecosystem services provision, diversity and sensitivity scores for each cell were calculated by multiplying the scores of each Voronoi polygon by the proportion of the cell with which it intersected (Figure 3.4). As each grid cell was 1km^2, the proportion was equal to the area of each intersected polygon.

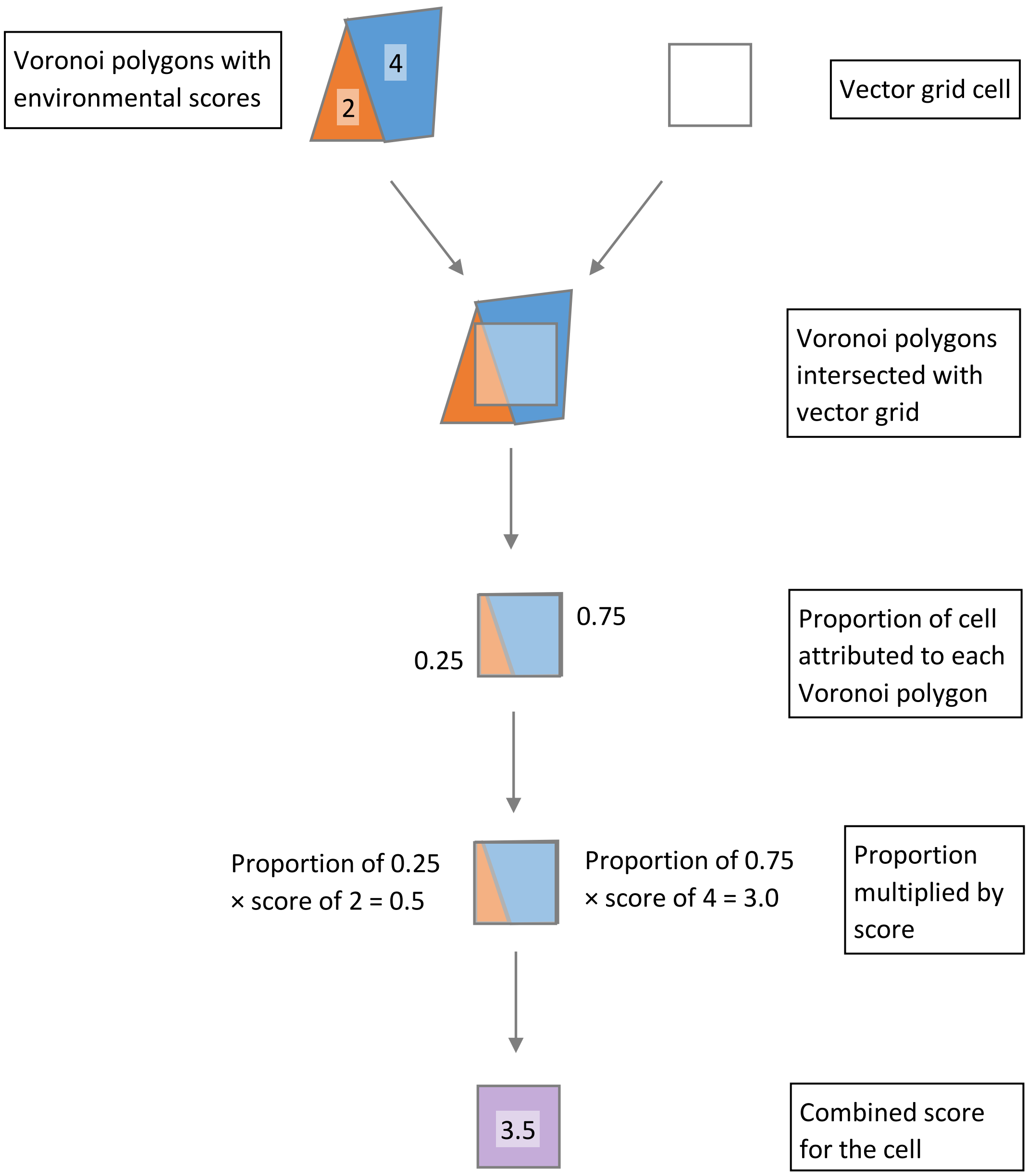

Figure 3.4: Summary of the steps involved in calculating the scores for each grid cell; the Voronoi polygons with their associated ecosystem services provision, diversity or sensitivity scores intersected with the vector grid, the proportion (area) of each intersected polygon multiplied by the score, and the sum of the intersected polygons to calculate the total score for each cell.

Once each cell had a score for ecosystem services provision, diversity and sensitivity, these were added together to calculate the overall environmental value score for each cell and then ranked 0-5 (very low to very high).

3.2.6 Confidence

As the environmental value was based on seabed habitat data points, it was assumed that there would be greater confidence in the accuracy of the habitat map, and therefore the environmental value, where there were more data points. To ascertain the confidence, point kernel density estimation was used to assess the density of the data points. This has been used successfully in other studies (Tomline & Burnside, 2015).

Kernel density mapping produced a continuous surface based on the number of points within a specified search radius. Conceptually, a surface was fitted over each point, highest at the point and decreasing to zero at the limit of the search radius. The search radius was defined by a variant of Silverman's Rule of Thumb which takes into account spatial outliers, although this algorithm may be too arbitrary (Williamson et al, 1999). Each cell of the output raster was calculated by summing all of the surfaces which overlaid the cell (ESRI, 2017).

The density surface was converted to contour lines, outlining areas of relative confidence in five classes from very low to very high. This could be used to identify areas where there was good confidence in the habitat map which could be used to assess changes over time by repeat surveys, and also areas where there was less confidence which could be the focus of future surveys to improve data coverage.

3.3 Assessment of fishing intensity

The fishing intensity was assessed through two parameters; 1) social, economic and environmental impacts and benefits and 2) fishing effort. First, however, the main fisheries (the target species and the method used to catch them) which occurred in the study area were defined and described based on publicly available data.

The selected fisheries were assessed for their impacts and benefits, recognising that different fisheries have different benefits that they can offer to the economy and society as well as different impacts on the environment. Scores were assigned by ranking the fisheries based on data from publicly available datasets and published reports. The impacts and benefits score for each fishery was averaged to calculate the score for each of five main fishing methods.

The fishing effort for the five main fishing methods was calculated from observed activity as number of vessels per kilometre squared and relative effort was ranked 0-5 (very low to very high) across the grid.

The fishing effort for each of the five main fishing methods was multiplied by the impacts and benefits scores to calculate the fishing intensity in each grid cell. Where there was more than one fishing activity in a cell, the intensity was summed.

To summarise, the impacts and benefits score was multiplied by the fishing effort score to equal the fishing intensity score of 0-5 (very low to very high). This process is summarised below (Figure 3.5) and described in further detail in the following sections.

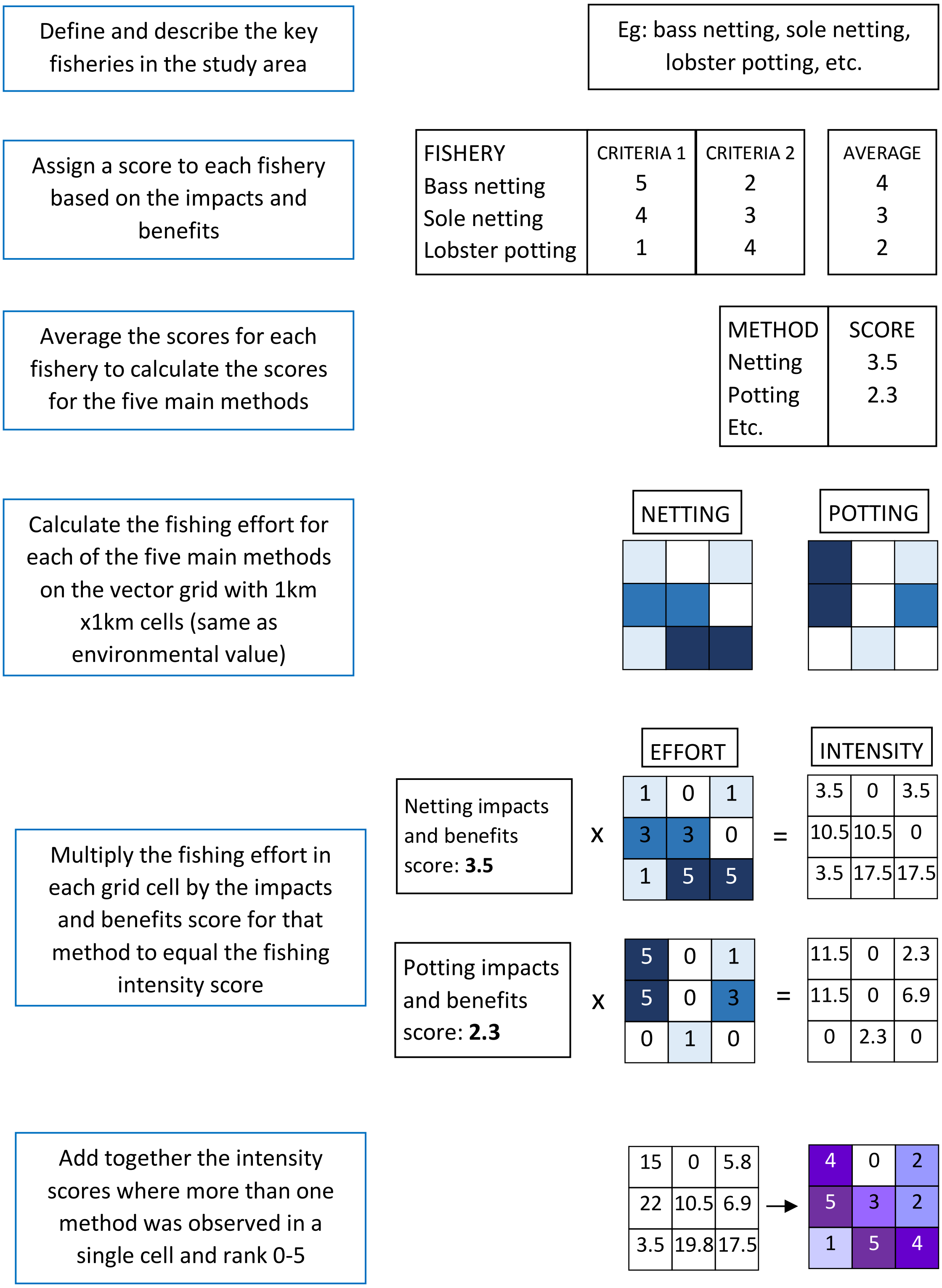

Figure 3.5: Summary of the steps involved in assessing fishing intensity; describing the key fisheries, assigning the impacts and benefits score to each fishery and averaging to calculate the score for each fishing method, mapping the fishing effort across the vector grid, multiplying the effort with the impacts and benefits score to calculate fishing intensity and summing the intensity to equal a single score for each grid cell.

3.3.1 Description of fisheries

The Marine Management Organisation collected data on the fish (finfish and shellfish) landed to English ports. Data was requested for all fish landed to Sussex ports (namely Bognor Regis, Brighton, Eastbourne, Emsworth, Hastings, Itchenor, Littlehampton, Newhaven, Rye, Selsey, Shoreham and Worthing) which was caught in ICES rectangles 30E9 and 30F0 (Figure 3.6). This was the closest spatial scale to the study area that was available. The study area was 40% of 30E9 and 30% of 30F0. Landings were from January 2012 to December 2016.

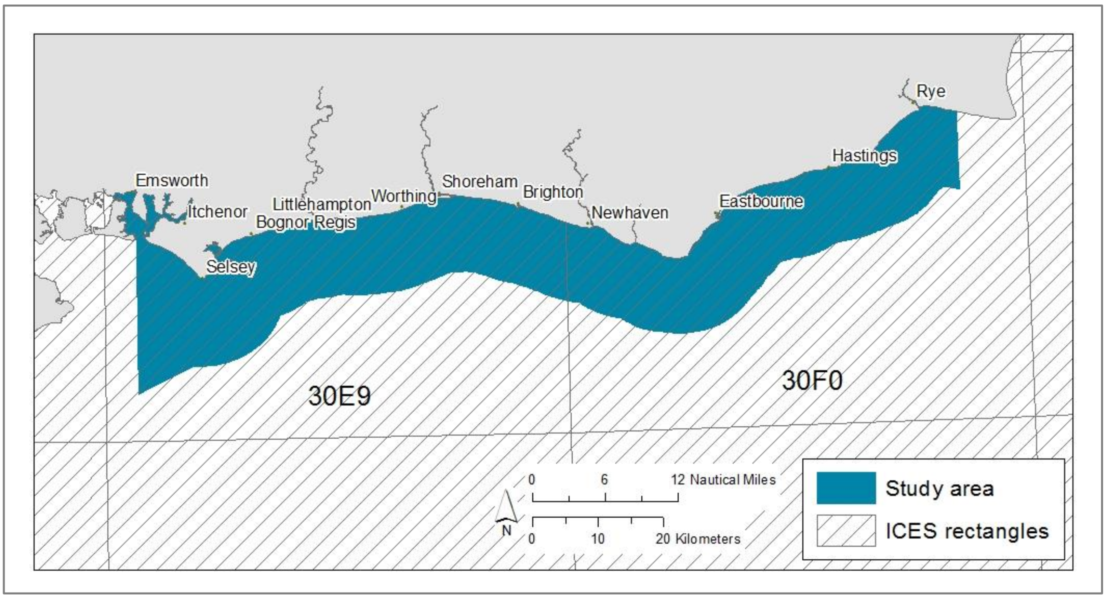

Figure 3.6: The study area in relation to the ICES rectangles. ICES rectangles publicly available, downloaded from www. data.gov.uk.

A fishery was defined as a combination of the species and the method used to catch it (Dapling et al, 2010). There was a total of 872 fisheries which included 104 species and 22 fishing methods. As some of the fishing methods were recorded differently to the fishing effort dataset (section 3.3.3) and to simplify analysis, the fishing methods were aggregated to five classes; angling, dredging, netting, potting and trawling. A major fishery was defined by a mean annual landings weight of greater than 10 tonnes and that the fishing method accounted for greater than 10% of the landings weight for that species. Under these parameters, 37 fisheries were selected for further analysis.

A brief description of the Sussex inshore fisheries included: fishing methods, target species, landing ports and number of vessels. Data for recreational fishing activity was not available and this has not been assessed as it was outside the scope of this study.

3.3.2 Impacts and benefits

The impacts and benefits of the 37 fisheries were assessed under nine criteria (Table 3.3) which were assigned a score from 1 (most desirable) to 5 (least desirable). The scores for each criterion were averaged to calculate the overall score for each fishery. This method has been used successfully in several studies ((NEF, 2011; Williams and Carpenter, 2015; MRAG, 2014; Williams and Carpenter, 2016).

The score for each fishery was averaged to calculate the score for each of five main fishing methods; angling, dredging, netting, potting and trawling, to allow for combination with the fishing effort (section 3.3.3).

Table 3.3: The nine economic, environmental and social criteria used to assess each fishery's impacts and benefits.

Theme	Criterion	Units	Data source	Data scope
Economic	Value per tonne	£ per tonne	MMO landings data	Annual average 2012-2016, Sussex ports, per fishery
Economic	Final economic output	£ per tonne	MMO landings data and Seafish multiplier	Annual average 2012-2016, Sussex ports, per fishery, multiplier per sector
Economic	Gross profit	Thousand euros	European Commission	2014, UK, per fleet, <12m vessels
Environmental	Fuel use	Litres per tonne	European Commission	2014, UK, per fleet, <12m vessels
Environmental	Ecosystem damage	Descriptive	Seafish RASS	UK stock areas, per fishery
Environmental	Bycatch	Descriptive	Seafish RASS	UK stock areas, per fishery
Social	Port dependency	% of total landings	MMO landings data	Annual average 2012-2016, Sussex ports, per fishery
Social	Employment	Number of FTE	European Commission	2014, UK, per fleet, <12m vessels
Social	Wage	Average wage (thousand €) per FTE	European Commission	2014, UK, per fleet, <12m vessels

Value per tonne

The MMO landings data (section 3.3.1) was used to calculate the annual average value per tonne. Higher value per tonne was more desirable as fewer fish would have to be landed to reach the same value, compared to a less valuable species.

Final economic output

The value per tonne was combined with a final economic output multiplier as estimated by Seafish (2007). This was the impact of wild capture seafood on the UK's economic output. The multiplier was greatest for shellfish (7.2), followed by pelagic fish (6.5) and demersal fish (5.9). A higher value was more desirable as an indicator that the fishery was important to the economy.

Gross profit

Data was taken from the 2016 Annual Economic Report on the EU Fishing Fleet (STECF, 2016). The report included the structure and economic performance of fishing fleets for each Member State for an eight year period from 2008 to 2015. Data for the whole UK for 2014 was used at a fleet level eg: drift and fixed nets for vessels less than 12m long. Whilst the data was not available at an ideal spatial scale or on an individual fisheries basis, it was suitable for assessment of relative impacts and benefits. A greater profit was more desirable as an indicator of the value of the fishery to the economy.

Fuel use

The data was also taken from the 2016 Annual Economic Report on the EU Fishing Fleet (STECF et al, 2016). Relatively less fuel use was desirable as an indicator of less resource use, overheads and greenhouse gas emissions.

Ecosystem damage and Bycatch

Data was taken from the Seafish Risk Assessment for Sourcing Seafood web tool (Seafish, no date). Where available, data for each fishery in the eastern English Channel was used. If not available, the closest sea area or equivalent fishing method was used. Least damage to seabed ecosystems and least amount of bycatch was most desirable.

Port dependency

The MMO landings data was used. The proportion that each fishery contributed to overall value and weight landed was calculated. The greater proportion was more desirable as an indicator of the fishery's importance. If a large proportion of the seafood landed to Sussex ports was from a single fishery, this would indicate a dependence on that fishery and there may be a negative impact on local communities if the fishery declined.

Employment and Wage

The data was taken from the 2016 Annual Economic Report on the EU Fishing Fleet (STECF, 2016). Employment was number of full time equivalent (FTE) jobs and wage was the average wage per FTE in thousands of euros. Greater employment and higher wages was more desirable as these fisheries provided more value to society.

3.3.3 Fishing effort

Fishing effort was calculated as the annual average (2012-2016) number of fishing vessels observed per kilometre squared of the sea patrolled by Sussex IFCA's fisheries patrol vessel (FPV) Watchful. The Sussex IFCA methodology was followed (Sussex IFCA, no date).

When the FPV was at sea on routine patrols, the fisheries officers recorded the location and activity of observed fishing vessels. The maximum distance at which a fishing vessel could be identified was 2km, under average conditions, and this was used as a buffer around the vessel track, as recorded by the navigation equipment. The buffered track was intersected with a 1km^2 grid to calculate the patrol effort; the area of sea patrolled.

The number of fishing vessel observations was also intersected with the 1km^2 grid, for each of five fishing methods; angling, dredging, netting, potting and trawling. The number of observations was divided by the patrol effort to calculate fishing effort (Figure 3.7 and further details in Appendix 8.1). This method has been used successfully in several studies (Vanstaen & Silva, 2010; Turner et al, 2015; Strong & Nelson, 2016; Nelson, 2017a).

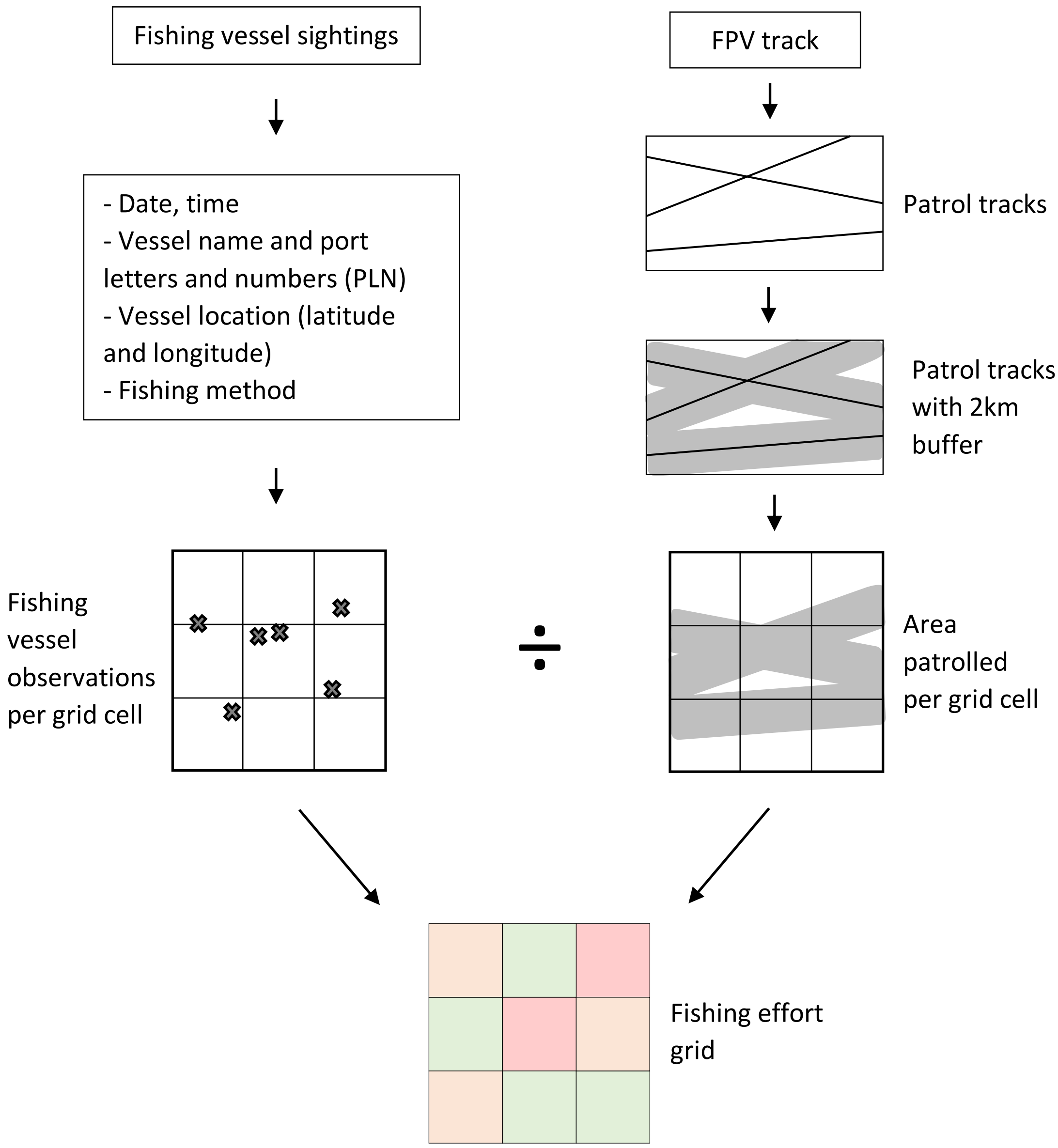

Figure 3.7: Summary of the fishing effort methodology; the observed fishing vessels data points intersected with the vector grid, the fisheries patrol vessel's track with the 2km buffer intersected with the vector grid, the division of the number of fishing vessels per cell by the area of the cell observed by the fisheries patrol vessel to equal the fishing effort.

The fishing effort for each method was ranked so that the effort was on a comparable scale (0-5) to the impacts and benefits score.

3.3.4 Overall fishing intensity

Fishing intensity was calculated by multiplying the impacts and benefits score by the fishing effort score. This was done by first taking each of the five main fishing methods separately and mapping their observed effort across the grid. Then the effort in each grid cell was multiplied by the impacts and benefits score for that method. This equalled the fishing intensity for each of the five main methods. These were then combined into a single layer by adding together the intensity scores in each cell. The overall fishing intensity score was ranked so that it was on a comparable scale (0-5) to the environmental value (section 3.2). A flow diagram summarising this process is in section 3.3.

3.3.5 Confidence

Mapping of fishing intensity was based on observations of fishing activity made by Sussex IFCA fisheries officers. There were fishing vessels observed across the study area with an average spacing of 425m but with significant clustering (p value: <0.01, average nearest neighbour analysis). Where no fishing vessels were observed, it cannot be assumed that no fishing took place, only that the activity was not observed. Despite this limitation, this dataset was the best available at the time of the study and the annual average effort 2012-2016 was considered to be suitable for the assessment of relative fishing effort.

To assess the confidence in this data, kernel density was used to assess the density of the data points (as in section 3.2.6). The density surface was converted to contour lines, outlining areas of relative confidence in five classes from very low to very high. In addition, the annual average patrol effort (km^2 of the sea patrolled) was calculated. This highlighted areas where there was greatest confidence that the observed fishing effort was representative of the true effort.

3.4 Assessment of management priority areas

The grid containing the environmental value scores was joined with the grid containing the fishing intensity scores and the scores for each cell were multiplied to equal the management priorities score. These were ranked so that they were on a comparable scale (0-5 very low to very high). This multiparameter, step-wise model can be summarised arithmetically as:

P = EV x FI

Where EV = ES + D + S

And where FI = IB x FE

The designations used in the equations are described below (Table 3.4). The steps involved in assessing the management priority areas is described diagrammatically in section 3.1.

Table 3.4: The description of each element used in the identification of management priority areas as summarised in the above equation, including how each element was assessed and its data source.

Equation designation	Element	How assessed	Data source
P	Priority	Environmental value x fishing intensity	
EV	Environmental value	Ecosystem services provision + diversity + sensitivity of seabed habitats	JNCC Marine Recorder and Sussex IFCA seabed habitat data points
ES	Ecosystem services provision	Provision of 12 ecosystem services for each of the 177 seabed habitats in the study area, scored from 1 (negligible provision) to 5 (high level of provision).	Galparsoro et al (2014), Salomidi et al (2012), Fletcher et al (2012)
D	Diversity	Diversity of seabed habitats as calculated by the ArcGIS entropy tool, scored from 0 low diversity, habitat similar to neighbouring data points to 5 high diversity, habitat different to all neighbouring data points.	GIS analysis: ArcGIS entropy option in the geostatistical analyst Voronoi tool

Equation designation	Element	How assessed	Data source
S	Sensitivity	The combined resistance and resilience of the 177 seabed habitats and their key species, score from 1 low sensitivity, high resistance to abrasion and high resilience (quick recolonization) to 5 high sensitivity, low resistance to abrasion and a long time to recover.	Marlin sensitivity assessment
FI	Fishing intensity	Impacts and benefits x fishing effort, across 37 fisheries using five main fishing methods.	MMO landings data (2012-2016) was used to select the fisheries to be included in the study
IB	Impacts and benefits	Each of the 37 fisheries was assessed against 9 criteria, the overall score for each fishery was averaged to calculate the score for each of five main fishing methods, scored from 1 most desirable to 5 least desirable.	MMO landings data (2012-2016), Seafish (2007), Seafish, no date, Carvalho et al (2016)
FE	Fishing effort	The fishing effort (number of vessels per km^2 of the sea patrolled) was calculated on a grid with 1km x 1km cells for the five main fishing methods. The effort was summed in cells where more than one method was observed and ranked from 1 low to 5 high.	Sussex IFCA

3.4.1 Hot spot analysis

The method described above resulted in a priority score assigned to each cell, useful for assessing the management priorities of specific areas but looking at Sussex inshore waters as a whole, it was not necessarily particularly easy to identify broader areas of priority (see Figure 4.11). In the interest of making the results as clear and useful as possible, hotspot analysis was undertaken to identify areas of priority on a scale that was meaningful for management development.

Getis-Ord Gi* hot spot analysis was used to identify areas of statistically significant priority scores, where a cell and its neighbours had either particularly high or low scores. The Gi* statistic was calculated for the analysis of spatial clustering. Where there were clusters of cells with priority scores greater than could be expected by chance, these were identified as hot spots. Inversely, cold spots were identified where there were clusters of low priority scores (ESRI, 2016b). A fixed distance was selected for the conceptualisation of spatial relationships with a threshold distance of 2000m to ensure that all neighbouring cells were included.

3.4.2 Marine Protected Areas

The management priority areas as identified in this study were compared against existing management areas; Marine Protected Areas (MPAs). As described in section 2.1.3, the marine environment and its use is governed under a complex set of legislation and MPAs are only a single part of that. They are specific areas set aside for their environmental value where human activities are restricted (Jones, 2014) and as such, are useful for comparison with the management priority areas. It is expected that the MPAs will have higher than average environmental value but not be identified as management priority areas, as fishing intensity should be restricted in the MPAs.

MPAs included Special Areas of Conservation (designated under the EU Habitats Directive 92/43/EEC), Special Protection Areas (designated under the EU Birds Directive 2009/147/EC) and Marine Conservation Zones (designated under the UK Marine and Coastal Access Act 2009) (Figure 3.8). There are further MCZs and SPAs proposed but not yet designated and these were not included in the analysis as there is not currently management in place. Some MPAs overlapped (e.g.: Pagham Harbour SPA and MCZ). In total (excluding overlap), MPAs covered 126 km^2 (7.2% of the study area).

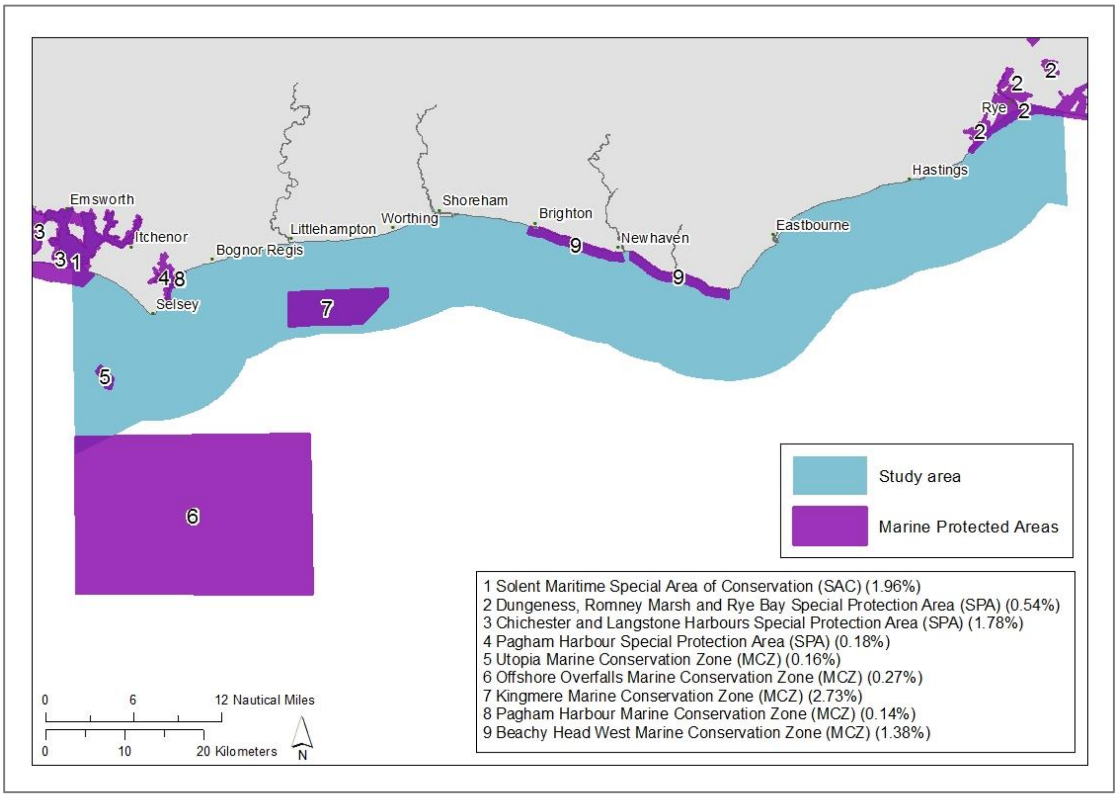

Figure 3.8: The designated Marine Protected Areas in the study area. Numbers in brackets are the proportion of the study area within the MPA. Note, some MPAs overlap. MPA boundary shapefiles publicly available, downloaded from www. data.gov.uk.

The number of cells and the area in the high and very high classes within MPAs was calculated for the priority score and environmental value. This will help to understand which areas are already protected and where there may be areas in need of protection. Two tailed t-tests were performed to assess if there was a statistically significant difference in priority score or environmental value inside compared to outside the MPAs.

4.0 Results

4.1 Assessment of marine environmental value

The marine environmental value was assessed through multiple parameters; ecosystem services provision, diversity and sensitivity, following descriptive mapping of seabed habitats.

4.1.1 Seabed habitats

There were 4310 seabed habitat records at 2648 locations which described 177 distinct habitats in the study area at the highest EUNIS level. Over a quarter (28%) of the records were at EUNIS level 5 or 6 which included details of the key species of those habitats. 94% of the records were at level 3 which reflects more physical than biological structuring and is a suitable level for mapping, assessment and engagement (Connor, 2006). At level 3, A5.2 Sublittoral sand covered the largest area (26.1% of the study area), followed by A5.1 Sublittoral coarse sediment (18.2%) and x Mosaic habitats (17.8%) where more than one habitat was recorded at a single survey location (Figure 4.1).

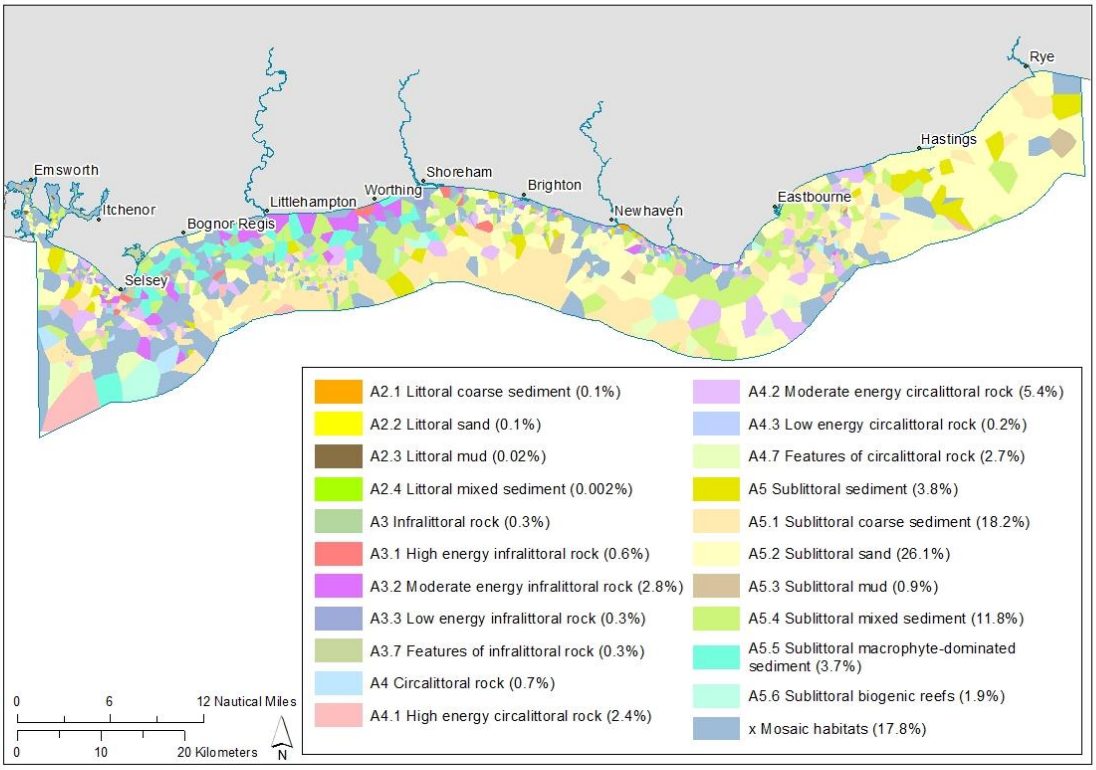

Figure 4.1: Seabed habitats at EUNIS level 2 and 3. Voronoi polygons from point survey data from Marine Recorder and Sussex IFCA. Colours follow the EUNIS standard. Figures in brackets are the proportion of the study area covered by the habitat.

Following the definition of the 177 habitats, each was assigned a score based on its ecosystem services provision, diversity and sensitivity.

4.1.2 Ecosystem services provision

None of the habitats provided all twelve of the ecosystem services at a high level, but high energy infralittoral rock (rock with algae) provided eleven of the services at a high level and one at a moderate level. Infralittoral rock and intertidal sediments had the highest average score (4.2). Subtidal sediments provided the least services (Table 4.1 for a summary at EUNIS level 2, Appendix 8.2 for further details).

Table 4.1: Summary table of the ecosystem services provided by the seabed habitats at EUNIS level 2 on a scale from 1 pale green (negligible provision) to 5 dark green (high level of provision). Assessed using information from Galparsoro et al (2014), Salomidi et al (2012) and Fletcher et al (2012).

Habitat name	EUNIS code	Food	Raw material	Air quality & climate regulation	Disturbance & natural hazard prevention	Photosynthesis and primary production	Nutrient cycling	Reproduction/ nursery	Biodiversity maintenance	Water quality	Cognitive value	Leisure, recreation, cultural	Feel good/ warm glow	AVERAGE score
Intertidal sediment	A2	5.0	2.5	4.0	5.0	4.0	4.0	5.0	4.5	2.5	4.5	5.0	4.5	4.2
Infralittoral rock (rock with seaweed)	A3	4.5	4.0	4.0	3.0	4.5	4.0	4.5	4.3	4.8	5.0	4.5	3.5	4.2
Circalittoral rock (rock with attached animals)	A4	3.5	3.0	3.0	2.0	1.5	4.0	4.5	5.0	4.0	5.0	4.0	3.0	3.5
Subtidal sediment	A5	4.9	2.8	1.7	2.0	1.8	3.7	4.0	3.5	2.8	1.7	2.3	2.3	2.8

When the scores for individual habitats were transferred to the grid, no cell had a score of less than 1 (very low) and just two cells were in the low class. 30% (590) of the cells had a score greater than 3 (high or very high), with the highest score of 4.8. The highest scores were in the west of the study area; inshore from Shoreham to Selsey, south of Selsey and in Chichester Harbour (Figure 4.2).

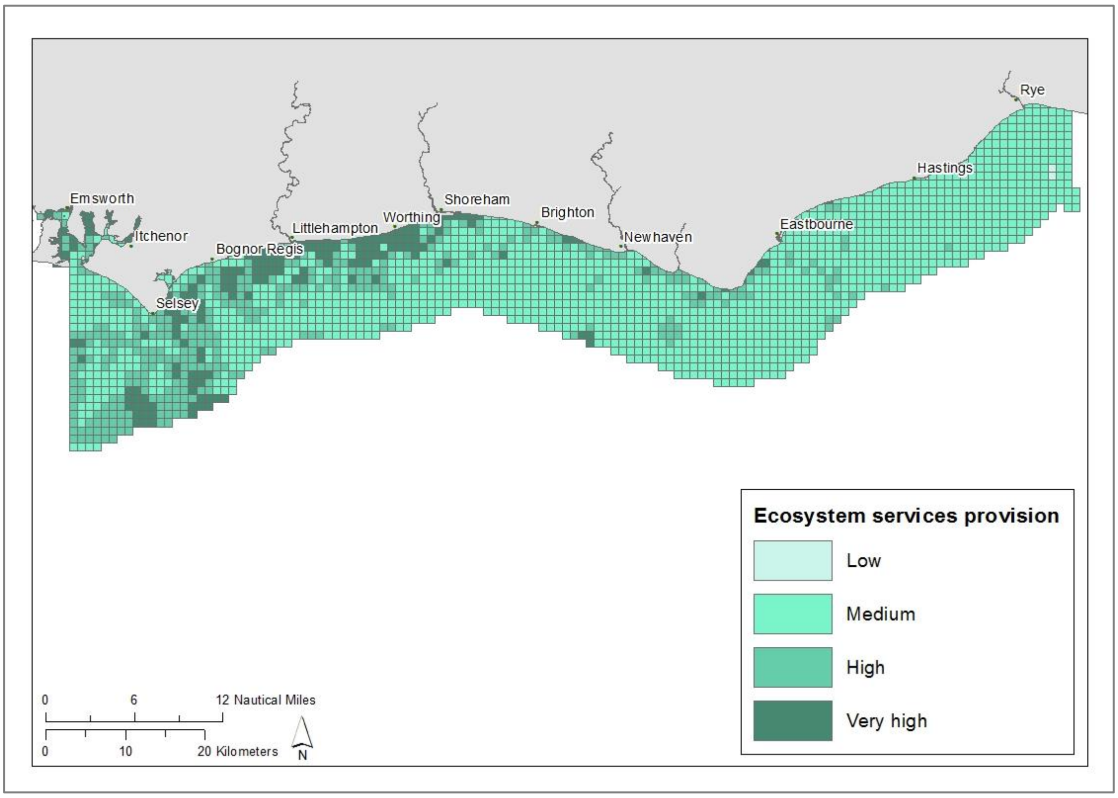

Figure 4.2: The ecosystem services provision across the study area based on seabed habitats scored 0-5 very low to very high level of provision. Four classes, equal interval. No cells in the 0.1-1.0 very low class. Score of 1.1 – 2.0 = low, score of 2.1 – 3.0 = medium, score of 3.1 – 4.0 = high and score of 4.1 – 4.8 = very high. Assessed using information from Galparsoro et al (2014), Salomidi et al (2012) and Fletcher et al (2012).

4.1.3 Diversity

Diversity was assessed by the entropy of the habitats and ranged from 0 (very low entropy, neighbouring habitats the same) to 5 (very high entropy, neighbouring habitats different). Over half (54%) of the cells had high or very high habitat diversity. There were areas of very high diversity throughout the study area, in particular south of Selsey, between Littlehampton and Shoreham, east of Eastbourne and near Rye (Figure 4.3).

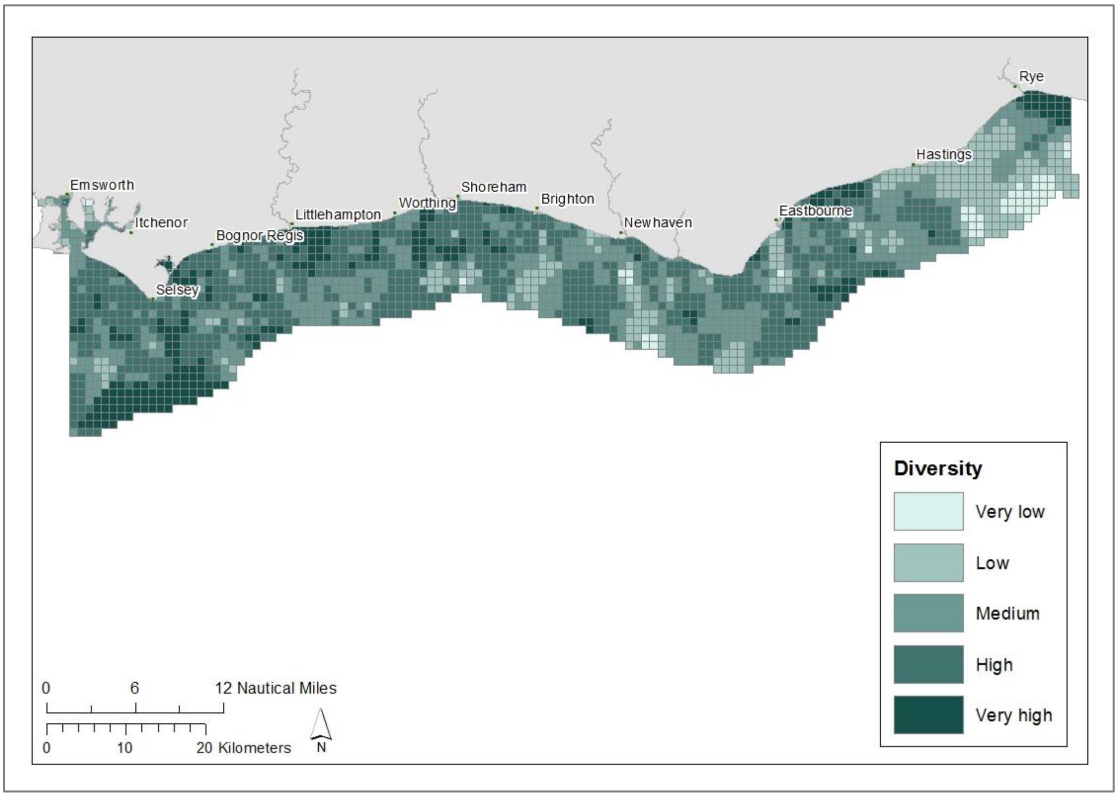

Figure 4.3: The diversity across the study area based on the entropy of seabed habitats as calculated through GIS analysis. Five classes, equal interval. Score of 0.0 – 1.0 = very low, score of 1.1 – 2.0 = low, score of 2.1 – 3.0 = medium, score of 3.1 – 4.0 = high and score of 4.1 – 5.0 = very high.

4.1.4 Sensitivity

Sensitivity was assessed as a combination of resistance to abrasion and resilience to disturbance. Generally, marine habitats were vulnerable to damage but were able to recover quickly. Only two habitats had very high sensitivity; caves and seagrass beds. Biogenic reefs and seaweed-dominated habitats had high sensitivity. At the other end of the scale, coarse gravel and sands with high natural disturbance and mud with the key species in deep burrows had very low sensitivity (Table 4.2 for a summary, Appendix 8.3 for further details).

Table 4.2: A summary of the resistance, resilience and sensitivity of the three main broad-scale habitat types. Based on information provided by the Marine Life Information Network (MarLIN) (2017a).

Habitat	Resistance	Resilience	Sensitivity
Mobile coarse sediment	Very few species present due to very mobile substrate, those present are robust	Very few species present due to very mobile substrate, those present have rapid recolonisation or are mobile and also inhabit other habitats	Low as habitat is subject to high levels of natural disturbance
Mud or sand with burrowing fauna	Generally soft bodied fragile fauna, low resistance for species near the surface but medium to high for those in deeper burrows	Generally short-lived species with high fecundity so rapid recolonisation	Low to medium as habitat and species could be damaged but likely to recover quickly
Fauna or algae on rock	Generally fragile erect species and spatially complex habitats which can be damaged by abrasion or disturbance	Generally quick to recolonise through larval dispersion, can take longer to reach full recovery, repair and asexual reproduction can support recolonisation	Medium to high as biotope could be damaged but likely to recover quickly for most species

When the scores for individual habitats were transferred to the grid, no cell had a score of greater than 4 (no very high class) and just 15% of cells (302) were in the high class. There were areas of high sensitivity across the study area but mainly in the west, in particular south of Selsey and inshore from Selsey to Eastbourne (Figure 4.4).

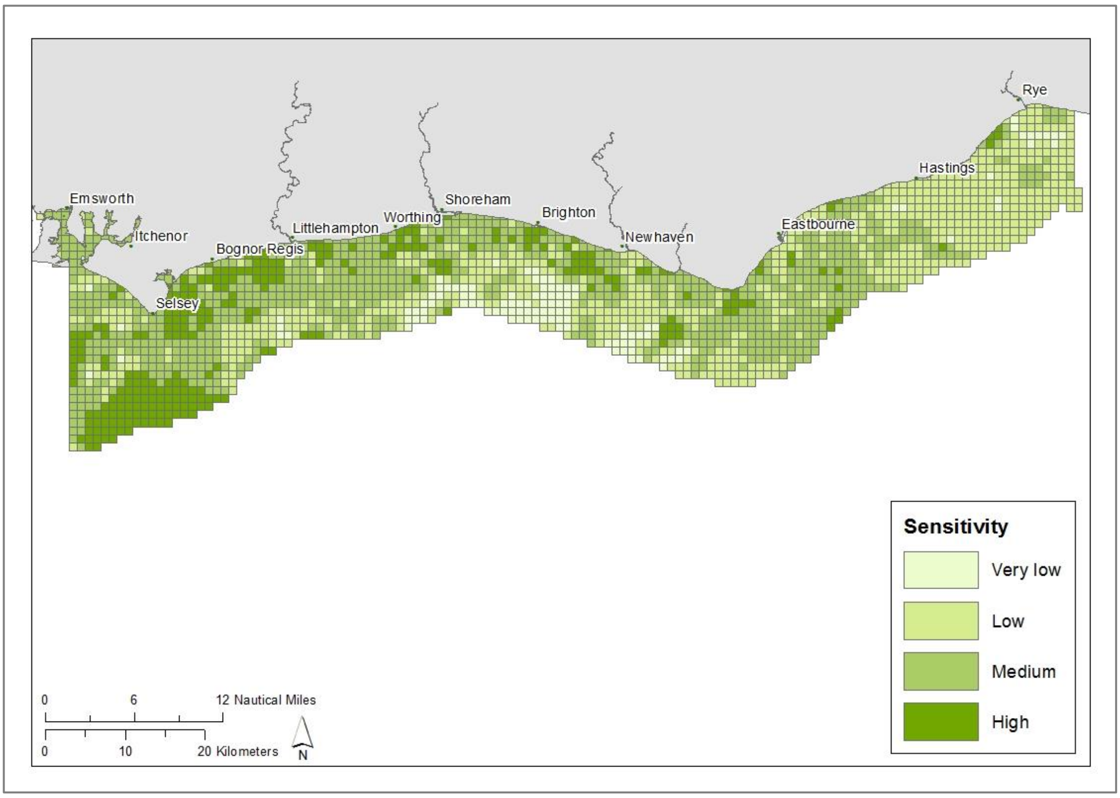

Figure 4.4: The sensitivity across the study area based on seabed habitats. Four classes, equal interval. Score of 0.1 – 1.0 = very low, score of 1.1 – 2.0 = low, score of 2.1 – 3.0 = medium and score of 3.1 – 4.0 = high. No cells in the 4.1 – 5.0 very high class. Based on information provided by the Marine Life Information Network (MarLIN) (2017a).

4.1.5 Overall environmental value

The ecosystem services provision, diversity and sensitivity scores for each cell were added together to calculate the overall environmental score. This was then ranked to be on a comparable scale of 0-5 very low to very high. There were no cells which were less than 1 (no very low class) and 30% of the cells (597) were high or very high. The highest environmental values were south of Selsey and near Littlehampton (Figure 4.5).

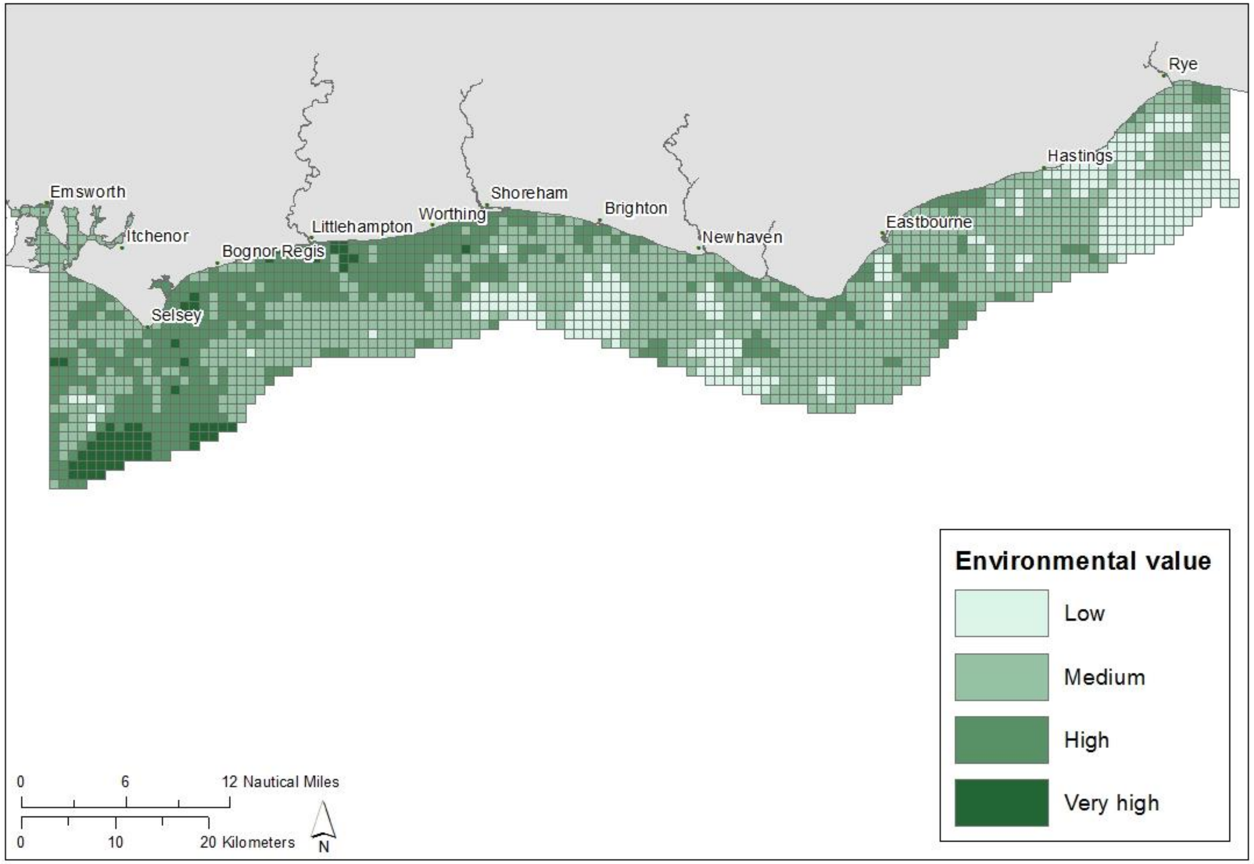

Figure 4.5: The environmental value across the study area based on the sum of the ecosystem services provision, diversity and sensitivity scores. Four classes, equal interval. No cells in the 0.1 – 1.0 very low class. Score of 1.1 – 2.0 = low, score of 2.1 – 3.0 = medium, score of 3.1 – 4.0 = high and score of 4.1 – 5.0 = very high.

4.1.6 Confidence

The seabed habitat data points were significantly clustered (z score: -58.12, p value: <0.01). Where there were more points per unit area, there was more confidence in the accuracy of the data. There was a maximum of 7.5 points per km^2. There was highest confidence south west of Selsey and south east of Littlehampton, coinciding with Utopia and Kingmere Marine Conservation Zones, respectably, where there have been extensive surveys to verify protected features. The area to the south of the study area between Shoreham and Eastbourne and east of Hastings had the least dense data points. This could be due the distance from shore and the lack of MPAs or features of interest such as wrecks which could be the focus of research and incentives for divers. These areas could be targeted for surveys in the future to improve confidence (Figure 4.6).

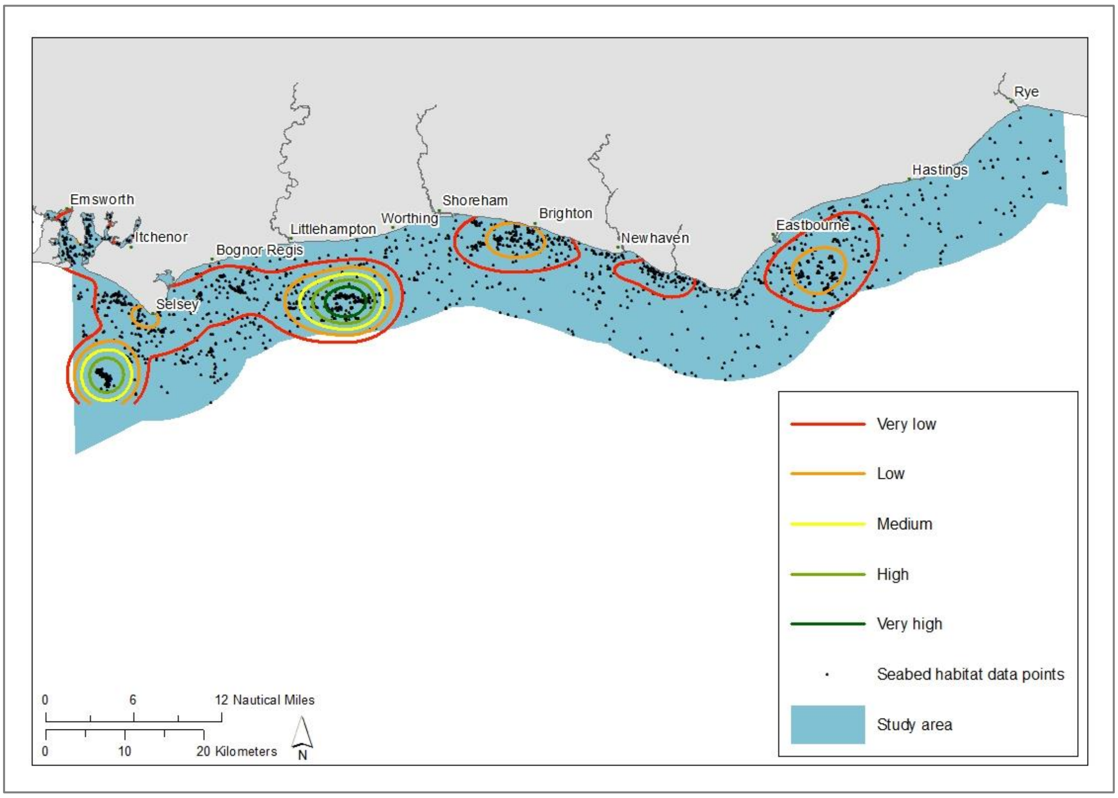

Figure 4.6: The confidence contours based on the density of the seabed habitat data points, where a greater density of points suggested a greater relative confidence.

4.2 Assessment of fishing intensity

The fishing intensity was assessed through two parameters; 1) social, economic and environmental impacts and benefits, and 2) fishing effort, following description and definition of the main fisheries.

4.2.1 Description of fisheries

Most fishing activity in the study area was undertaken by small inshore vessels with one to three fishers onboard and on trips of less than 24 hours duration. Fishing vessels longer than 14m were prohibited from fishing in the study area (Sussex IFCA, 2017b), as were non-UK registered vessels (*Fisheries Convention*, 1966). Most vessels engaged in several different fishing methods throughout the year, sometimes concurrently. There were twelve landing ports in Sussex. The most seafood was landed to Shoreham, followed by Newhaven and Eastbourne.

There were 37 fisheries selected for analysis in this study; the combination of 5 fishing methods and 25 species which are described below.

Netting was the most frequently observed fishing activity (see section 4.2.3 for further details). This method was a broad category for long rectangles of net which captured fish by entangling the body or gills of the fish, and were either anchored to the seabed or they drifted with one end attached to the fishing vessel. They had little direct impact on the seabed but can sometimes accidently catch cetaceans and seabirds. This was a mixed fishery, targeting several species at the same time (Jennings and Kaiser, 1998).

Potting was the second most frequently observed method. There were different types of pots or traps depending on the target species; whelks, cuttlefish or crab and lobster. The pots were attached to a line which was anchored to the seabed, with surface markers. The pots were baited and left for one to three days. Escape gaps allowed for juveniles to exit the trap and there was generally low bycatch (Seafish, 2015).

Trawling included all types of net towed behind a fishing vessel. There were many different configurations depending on the vessel, seabed and target species. When the net and other parts of the trawl were in contact with the seabed, damage to habitats could be caused (Hiddink et al, 2017).

Dredging involved towing across the seabed a metal chain link bag with a toothed bar at the front (Seafish, 2015). The two target species in the study area were native oysters and scallops. The oyster fishery was very small scale; restricted to Chichester Harbour and for only a couple of weeks a year, so not included in this study. Scallop dredging was prohibited inside of the 3 nautical mile limit (Sussex IFCA, 2017c) and mainly occurred outside of the study area. However, more scallops were landed to Sussex ports than any other species (from MMO landings data).

Angling included any configuration of hooks and lines used to catch fish. Only commercial angling on vessels which were licenced to sell the fish caught onboard were included. Recreational angling was more frequently observed but was not included in this study because no landings data was available as the fish caught were not sold. There was minimal impact on the seabed, especially if the vessel drifted rather than anchoring, and there was minimal bycatch (Seafish, 2015).

A brief description of the target species is in Table 4.3. Some species were caught by more than one method and so there were 37 fisheries in total.

There were 498 distinct vessels which landed seafood to Sussex ports in 2012-2016 and were involved in at least one of the 37 fisheries. The most number of distinct vessels landed bass caught in nets (309 vessels 2012-2016), followed by netting for sole (294) and netting for plaice (293).

Table 4.3: The category, common name, scientific name and brief description of the twenty five species included in the study, as well as the fishing methods used to catch them.

Species category	Description	Species	Fishing method
Flat fish	Flat fish live on sandy or gravelly seabeds where they are well camouflaged. They hatch as tiny round fish which swim near the surface for several weeks before moving to the bottom and metamorphosing into flat fish.	Brill (*Scophthalmus rhombus*)	Netting & trawling
		Dab (*Limanda limanda*)	Trawling
		Flounder (*Platichthys flesus*)	Trawling
		Lemon sole (*Microstomus kitt*)	Trawling
		Plaice (*Pleuronectes platessa*)	Netting & trawling
		Sole (*Solea solea*)	Netting & trawling
		Turbot (*Scophthalmus maximus*)	Netting & trawling

Species category	Description	Species	Fishing method
Pelagic fish	Pelagic fish swim in the water column from mid-water to the surface. Mackerel are a summer visitor to Sussex.	Mackerel (*Scomber scombrus*)	Netting
Demersal fish	Demersal fish swim in the water column, on or near the seabed, feeding on crustaceans, algae and other fish.	Bass (*Dicentrarchus labrax*)	Angling, netting & trawling
		Black seabream (*Spondyliosoma cantharus*)	Trawling
		Cod (*Gadus morhua*)	Netting & trawling
		Gurnards (*Chelidonichthys* spp.)	Trawling
		Monkfish/anglerfish (*Lophius* spp.)	Trawling
		Pouting bib (*Trisopterus luscus*)	Trawling
		Whiting (*Merlangius merlangus*)	Trawling
Shellfish	Shellfish all have hard shells, internalised in the cuttlefish and squid. Some have low mobility and spend their entire lifecycle in Sussex waters, others are seasonal visitors for specific life stages.	Cuttlefish (*Sepia officinalis*)	Netting, potting & trawling
		Edible crab (*Cancer pagurus*)	Potting
		Lobster (*Homarus gammarus*)	Potting
		Scallops (*Pecten maximus*)	Dredging
		Squid (*Loligo* spp.)	Trawling
		Whelks (*Buccinum undatum*)	Potting
Elasmobranchs	Sharks and rays have cartilaginous skeletons. They are long-lived, slow to mature and either give birth to live young or young hatch from egg cases.	Blond ray (*Raja brachyura*)	Trawling
		Lesser spotted dogfish (*Scyliorhinus canicula*)	Netting & trawling
		Smoothhound (*Mustelus* spp.)	Netting & trawling
		Thornback ray (*Raja clavata*)	Netting & trawling

4.2.2 Impacts and benefits

The impacts and benefits of each of the 37 fisheries were assessed against three economic, three environmental and three social criteria and scored from 0.1 (most desirable) to 5.0 (least desirable). Most fisheries had highly desirable scores for some criteria and less desirable scores for other criteria. Lobster potting had the most desirable average score (1.71), followed by bass netting (1.86) and sole netting

(2.03). On the other end of the scale, flounder trawling had the least desirable score (3.66), followed by pouting bib trawling (3.62) and dab trawling (3.53). See Appendix 8.4 for further details.

When the scores for the individual fisheries were averaged to calculate the scores for each fishing method, potting was the method with the most desirable score (2.16) and trawling had the least (2.98). Potting had the most desirable score for the economic criteria (1.85), jointly with angling, and dredging had the least (2.91). For the environmental criteria, netting had the most desirable score (1.76) and trawling had the least (3.98). However, netting had the least desirable score (3.19) for the social criteria and dredging the most (2.05) (Figure 4.7).

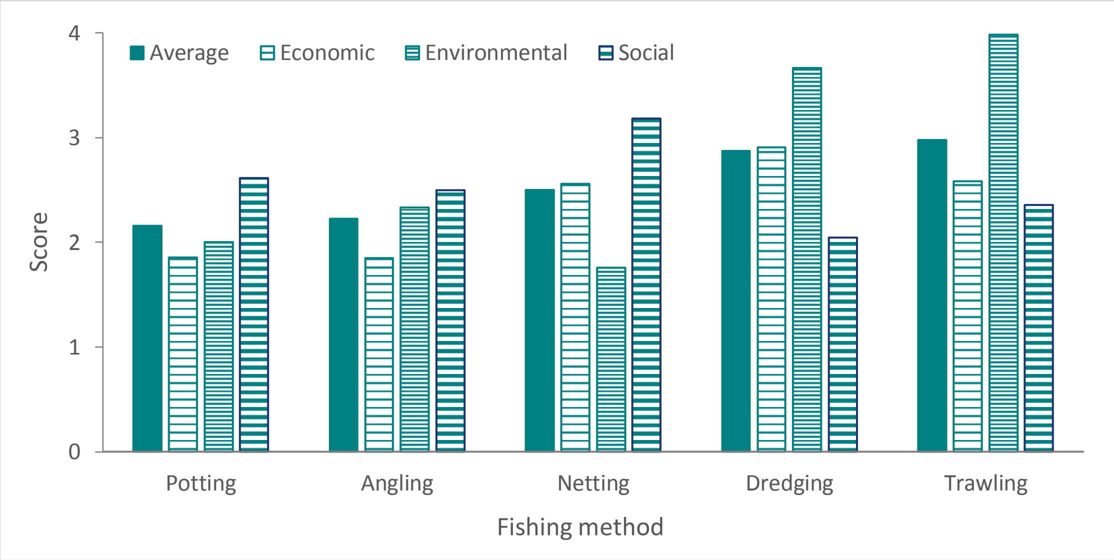

Figure 4.7: The average scores for the economic, environmental and social criteria, as well as the overall average score for each fishing method 0 – 5 most desirable to least desirable (least impacts and most benefits to most impacts and least benefits). Assessment made using data from STECF (2016), Seafish RASS (no date), Seafish (2007) and MMO landings data.

4.2.3 Fishing effort

Trawling was the method with the highest annual average fishing effort (0.45 vessels per km^2) and dredging the lowest (0.08 vessels per km^2). Dredging also occurred in the least number of cells (12), whereas netting occurred in the most (554), followed by potting (438). Overall, fishing effort occurred in 936 cells (47% of the study area) and the maximum effort was 0.62 vessels per km^2 all methods summed (Figure 4.8).

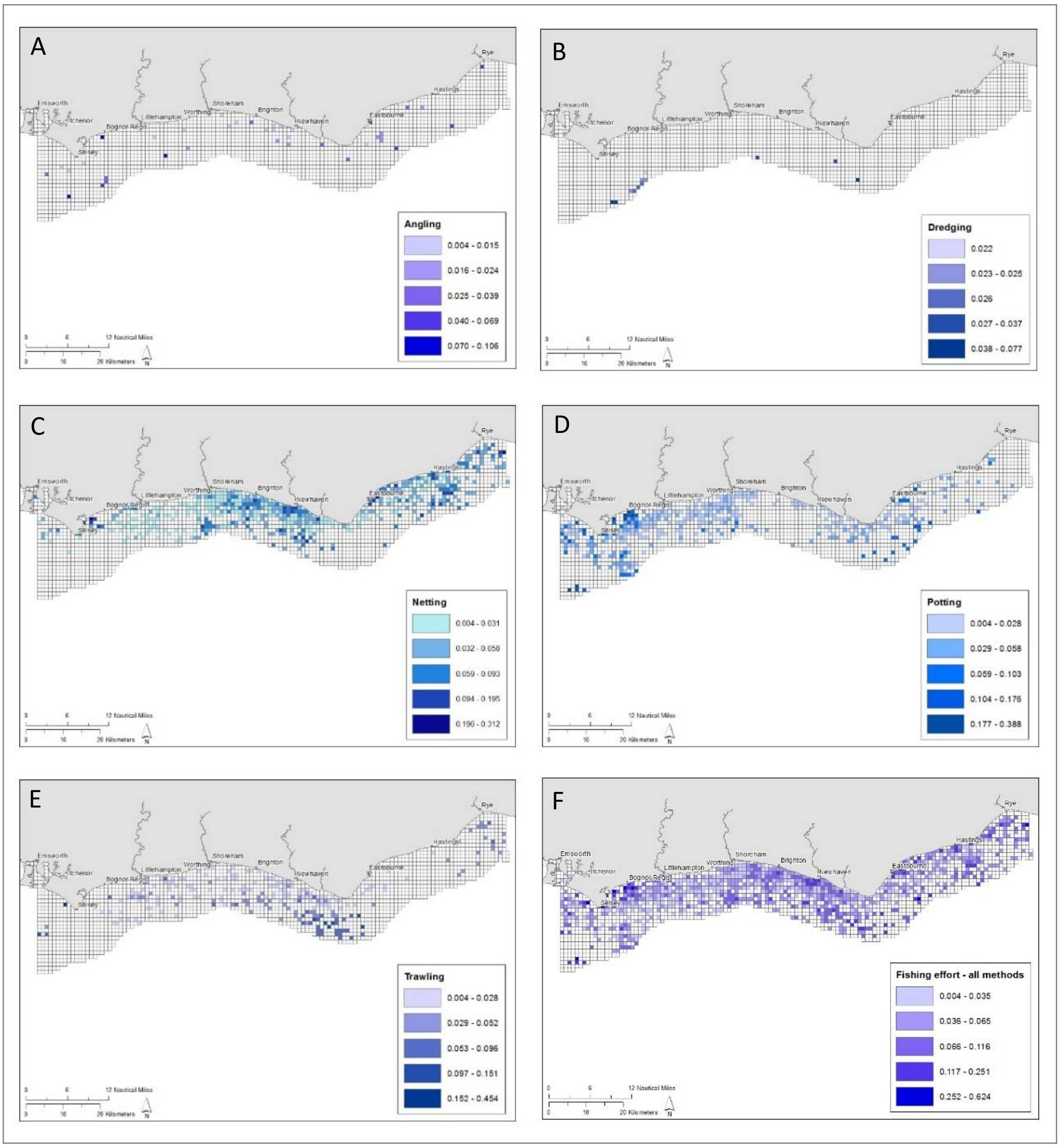

Figure 4.8: The annual average fishing effort (number of vessels observed per km^2 of sea patrolled) 2012-2016. Five classes, Jenks natural breaks. A) Angling. B) Dredging. C) Netting. D) Potting. E) Trawling. F) All fishing methods combined.

4.2.4 Overall fishing intensity

The fishing intensity score was calculated by multiplying the impacts and benefits score with the fishing effort score, and resulted in data that was highly skewed to low values (skewness: 5.3 and kurtosis: 52.0). Following log transformation, the values were more normally distributed (skewness: 0.4, kurtosis: 3.4) and classified into five equal classes. There were 163 cells (8%) which were in the high and very high classes. Most of the very high fishing intensity cells were between Selsey and Bognor Regis (Figure 4.9).

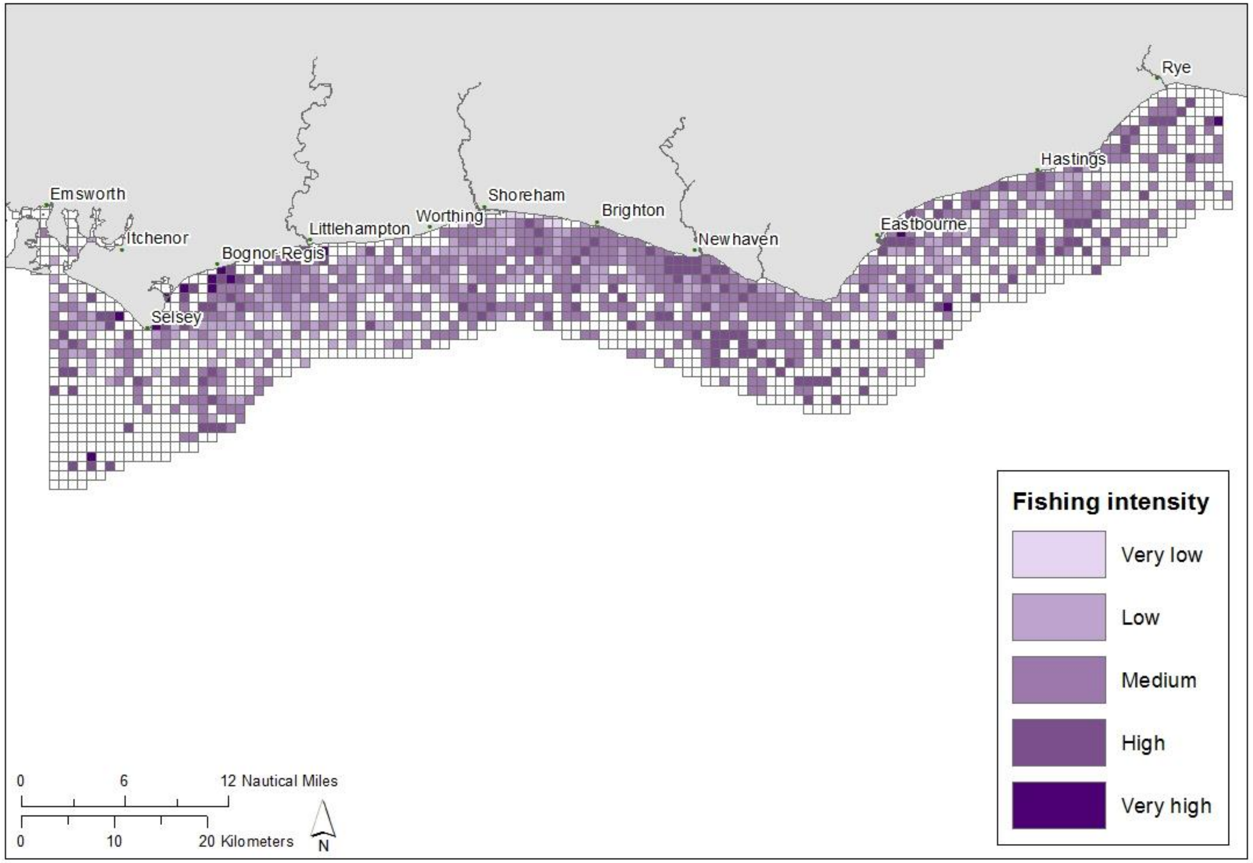

Figure 4.9: The fishing intensity across the study area, all fisheries combined, based on the impacts and benefits score multiplied by the fishing effort score. Five classes, equal interval. Score of 0.1 – 1.0 = very low, score of 1.1 – 2.0 = low, score of 2.1 – 3.0 = medium, score of 3.1 – 4.0 = high, score of 4.1 – 5.0 very high, log transformed.

4.2.5 Confidence

The fishing vessel observations were significantly clustered (Z score: -40.95, p value: <0.01). Where there were more data points, there was more confidence that the observations reflected the actual and total fishing activity. There was highest confidence inshore from Shoreham to Newhaven. This was expected as the fisheries patrol vessel's home berth was in Shoreham and the area around Shoreham was most frequently patrolled (Figure 4.10).

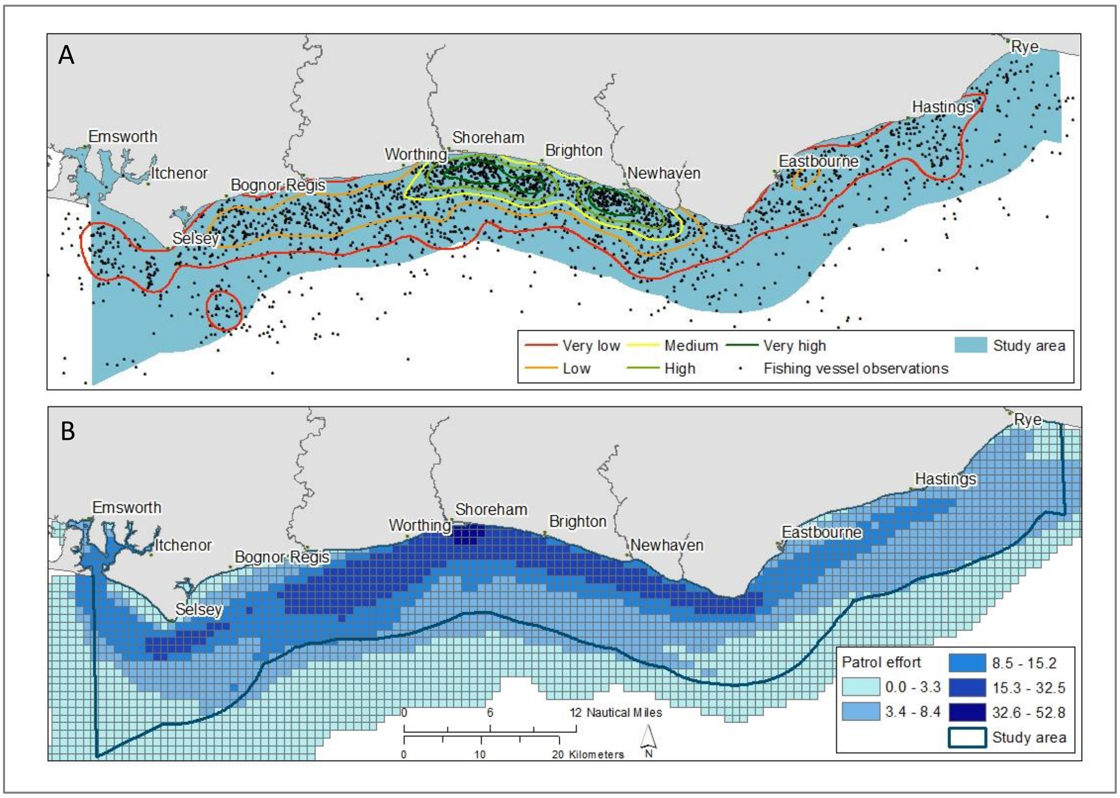

Figure 4.10: A) The fishing vessel observation data points and relative confidence contours. B) The annual average patrol effort (km^2 of sea patrolled) 2012-2016. Five classes, Jenks natural breaks.

4.3 Assessment of management priority areas

The environmental value and fishing intensity scores were multiplied to calculate the management priority score. This was ranked so it was a comparable scale 0-5 (very low to very high). 101 of the cells (5.1%) were in the high and very high classes and just 12 cells (0.6%) were very high. Most of these were south of Selsey and between Selsey and Bognor Regis (Figure 4.11).

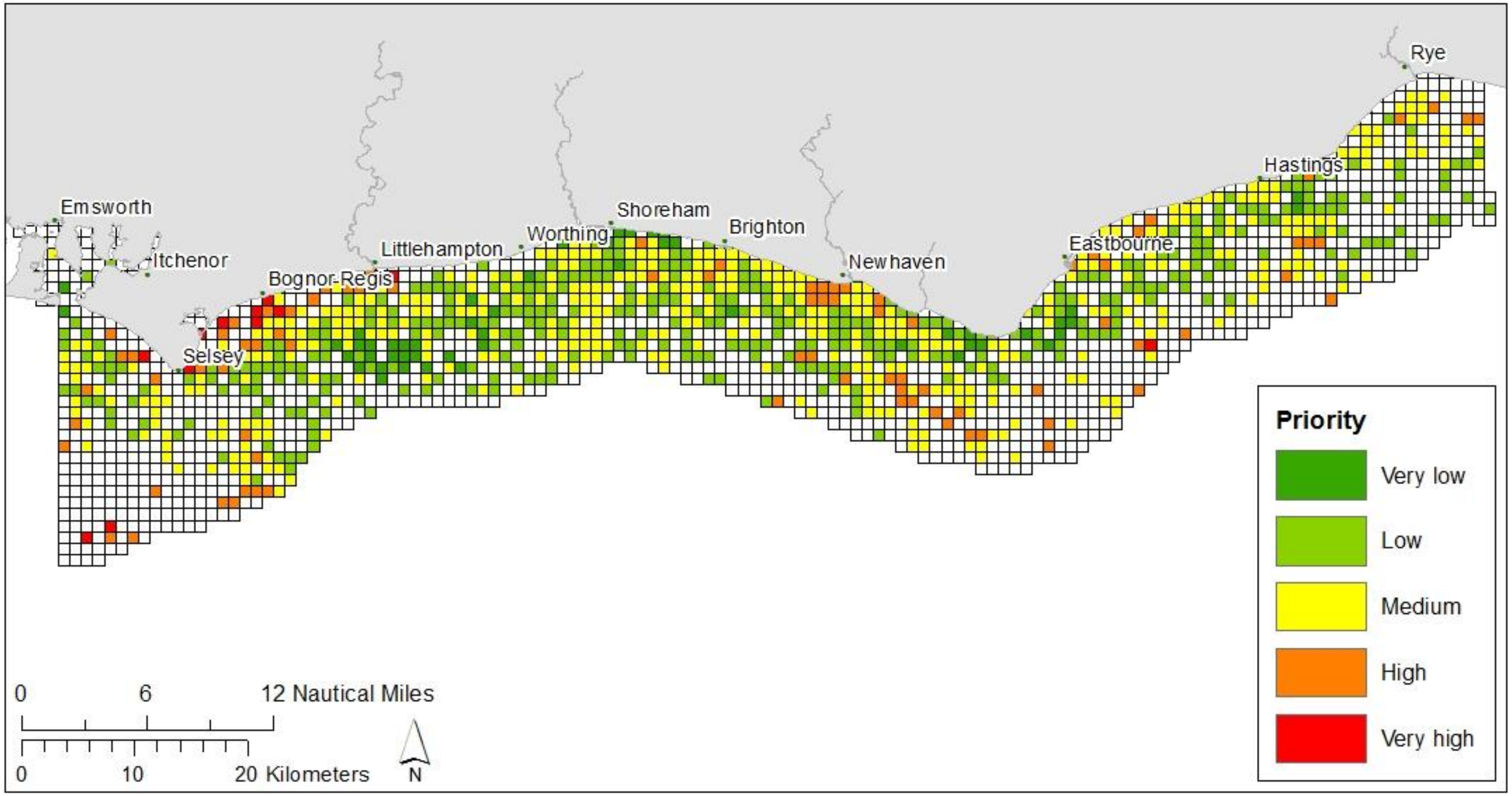

Figure 4.11: The management priority score across the study area, based on environmental value multiplied by fishing intensity. Five classes, equal interval. Score of 0 (white cells) = no observed fishing effort and therefore 0 priority. Score of 0.1 – 1.0 = very low, score of 1.1 – 2.0 = low, score of 2.1 – 3.0 = medium, score of 3.1 – 4.0 = high, score of 4.1 – 5.0 very high.

4.3.1 Hot spot analysis

Hot spot analysis (Getis-Ord Gi*) was used to highlight areas where there were clusters of cells with particularly high or low priority scores, emphasising these areas for clarity. There were statistically significant hot spots with high priority scores between Selsey and Bognor Regis, to the west and south of Selsey, between Brighton and Newhaven and near Eastbourne. There were 109 cells (5.5%) which were classified as hot spots with 99% confidence. There were cold spots with low priority scores in Chichester Harbour (between Emsworth and Itchenor), south of Selsey and south of Rye. There were 92 cells (4.6%) which were classified as cold spots with 95% confidence (Figure 4.12).

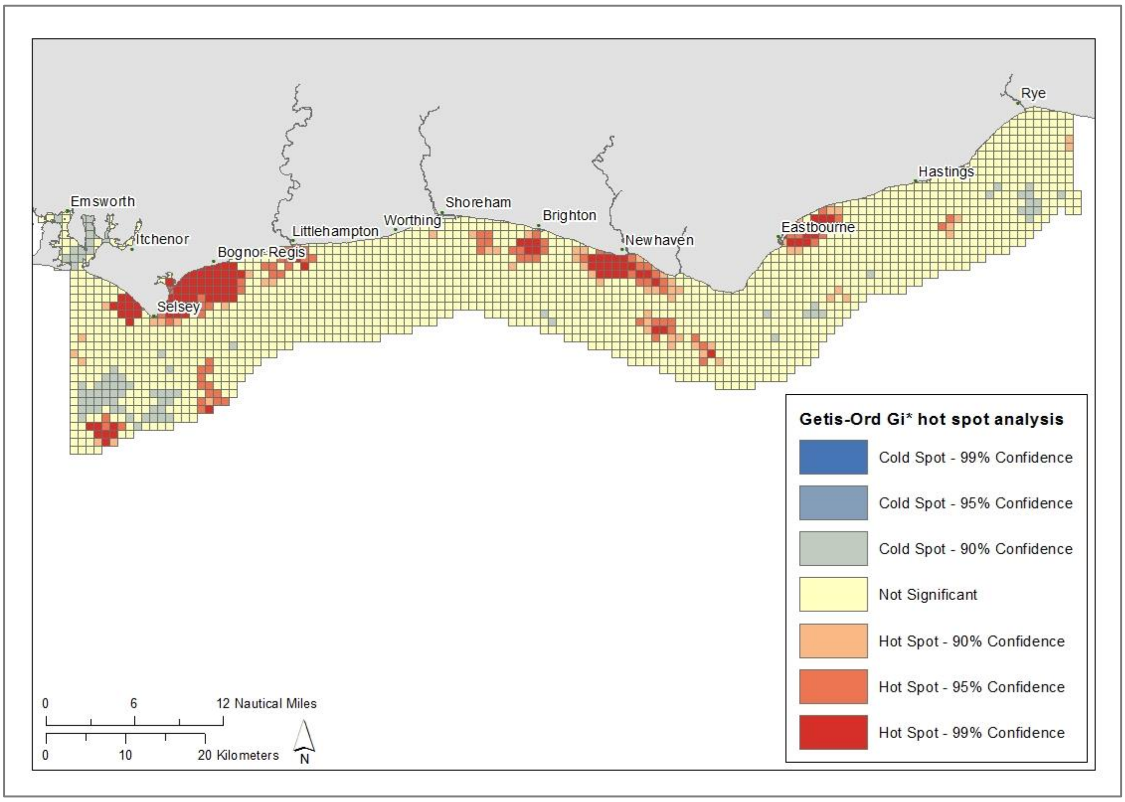

Figure 4.12: Getis-Ord Gi* hot spot analysis of the priority score across the study area. Seven classes, equal interval, based on Gi bins. Cold spot = low priority scores in cells and neighbouring cells, hot spot = high priority scores in cells and neighbouring cells. A fixed distance conceptualisation of spatial relationships with a threshold distance of 2000m was used.

4.3.2 Marine Protected Areas

There were only two very high priority cells which intersected with Marine Protected Areas. These were near the entrance to Pagham Harbour (north east of Selsey, Pagham Harbour SPA and MCZ) and covered just 0.67km^2. There were eight cells in the high priority class which intersected with a MPA. These were near Newhaven, within the Beachy Head West MCZ and covered 4.26km^2 (Figure 4.13). In total, 4% of the MPAs' area was classified as high or very high priority. There was no statistically significant difference in priority score inside the MPAs compared to outside (p value: 0.096).

There were 80 cells which were in the high or very high classes for environmental value which intersected with MPAs. Very high environmental value occurred within 2.8 km^2 of the MPAs and high environmental value within 29.0 km^2. In total, 25% of the MPAs' area was classified as high or very high environmental value (Figure 4.13). The environmental value score inside the MPAs was significantly higher compared to outside (p value: <0.01).

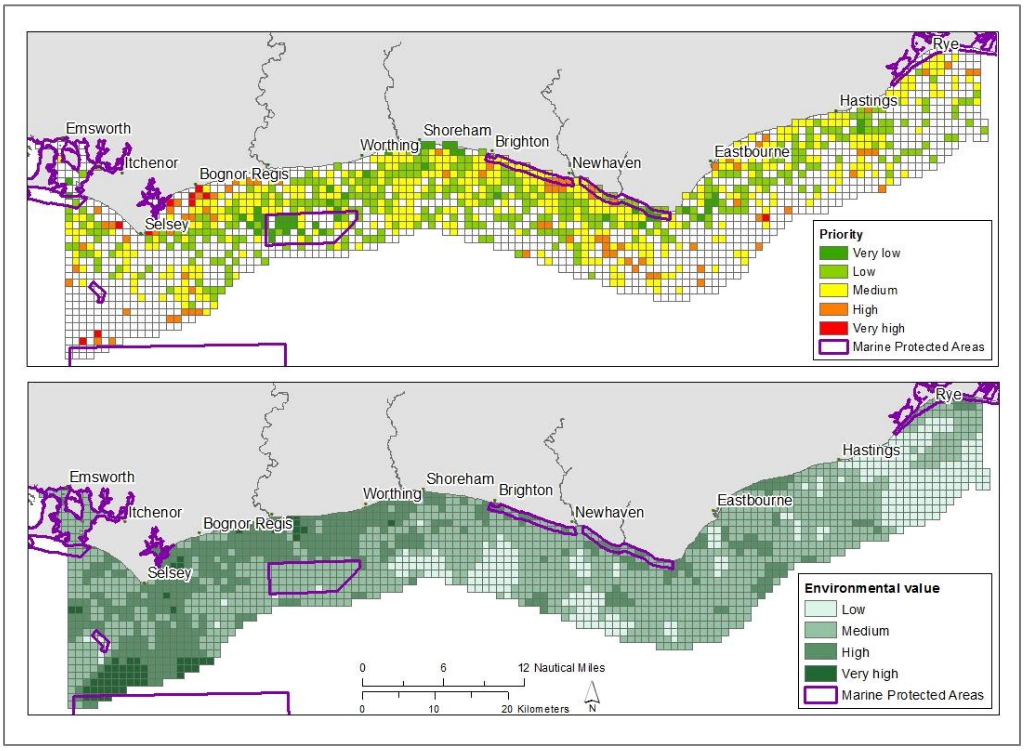

Figure 4.13: The interaction of Marine Protected Areas with A) the management priority score and B) the environmental value. Five classes, equal interval. Score of 0 (white cells) = no observed fishing effort and therefore 0 priority. Score of 0.1 – 1.0 = very low (no cells in the very low class for environmental value), score of 1.1 – 2.0 = low, score of 2.1 – 3.0 = medium, score of 3.1 – 4.0 = high, score of 4.1 – 5.0 very high. MPA boundary shapefiles publicly available, downloaded from www. data.gov.uk.

5.0 Discussion

5.1 Management priority areas

The high and very high priority classes occurred in just 5% of the study area. The highest priority area was inshore between Selsey and Bognor Regis. The seabed habitat was a mix of low lying rock with seaweed or with attached animals and some sediment, mostly dominated by seaweed. Rock with seaweed was one of the habitats which provided the most ecosystem services at the highest levels and rock or sediment with seaweed were some of the most sensitive habitats. This was also an area of high habitat diversity, resulting in high environmental value. This coincided with high fishing intensity where there was a relatively high level of netting and potting effort. This should therefore be a priority area for managers.

The hot spot analysis highlighted that there were also areas of high priority to the west and south of Selsey, between Brighton and Newhaven and near Eastbourne. The hot spot analysis helped to highlight these areas which should be the focus of management resources. In these areas, the seabed habitats were a mix of sediment and rocky reef with high intensity fishing. This was mainly netting with the addition of trawling near Newhaven and potting near Eastbourne and Selsey.

On the other end of the scale, cold spots were identified in Chichester Harbour, south of Selsey and south of Rye, where there was low priority. This was where there was less habitat heterogeneity, the habitats were mainly sediment and there was no or little fishing activity.

Having robust data to clearly highlight areas where limited resources should focus is essential for effective conservation efforts (Johnston et al, 2015). This systematic conservation planning can help to optimise conservation aims whilst acknowledging the challenges of meeting the needs of marine users and cost efficiency (McIntosh et al, 2016).

5.1.1 Management measures

Management should restrict the fishing activities which can take place in the high priority areas to protect the marine environment from damage and could include closed areas, seasonal closures or effort reduction. Restrictions on activities can be met with resistance (Diedrich et al, 2017) and result in greater conflict between users (Mangi et al, 2011). There can be displacement of fishers, increasing pressure on other habitats (Campbell et al, 2014) and fishers may have to travel further to their fishing grounds, increasing fuel use and costs (Mangi et al, 2011).

On the other hand, closed areas can increase stock protection and fishing reliability (Barnes & Sidhu, 2013) as well as the benefits of spill over of larvae from protected adults, increasing stock levels outside the protected area (Davies et al, 2015). In addition, there can be improved condition and functioning of marine ecosystems within the protected area, increasing resilience to a range of pressures and providing economic benefits, such as ecotourism (McCook et al, 2010).

2.1.2 Marine Protected Areas

Closed areas are often referred to as Marine Protected Areas. High and very high priority classes covered only 4% of the MPAs' area and there was no significant difference in score inside the MPAs compared to outside (p: 0.096). This suggested that the management that is in place is reducing fishing effort to relatively low levels and therefore these areas are not a priority as assessed by this study.

The current management within the MPAs is a complex combination of zonation, closed seasons, bag limits, gear restrictions and adaptive measures. They are multi-use sites with a range of activities taking place such as recreational and commercial fishing, leisure activities, diving, aggregate extraction and dredging disposal. Specific designated features have been protected and are monitored to assess their condition. There are some small areas where all fishing activities have been prohibited due to the sensitivity of the habitats (Sussex IFCA, 2017d).

High and very high environmental value classes covered a greater proportion of the MPAs (25%), compared to the priority score, and the environmental value within the MPAs was significantly greater than outside (p: <0.01). This suggested that the seabed habitats within the MPAs were more valuable and that is likely to be at least part of the reason that they were selected. Protection of valuable or vulnerable habitats is one of the main reasons for designating MPAs (Jones, 2014). These MPAs were selected for a number of reasons and the Marine Conservation Zones were designed with extensive consultation with stakeholders (Natural England, 2012). Site selection that uses a combination of science and stakeholder input can lead to MPAs which meet conservation objectives and are supported by marine users (Ruiz-Frau et al, 2015).

5.2 Marine environmental value

Generally, environmental value was higher in the west of the study area. This was where there was a coincidence of relatively higher ecosystem services provision, diversity and sensitivity. Whilst there was significantly higher environmental value within the Marine Protected Areas, only 13% of the cells which were in the high or very high environmental value classes were within the MPAs, resulting in 87% of these highly valuable areas not protected under MPAs.

5.2.1 Element overlap

There was greatest overlap of high and very high classes of ecosystem services provision and diversity. However, these two elements had the lowest correlation of scores (0.31) compared to the spatial concordance of other elements (diversity and sensitivity: 0.35, ecosystem services provision and sensitivity: 0.63).

Naidoo et al (2008) found areas that were protected for high biodiversity did not deliver more ecosystem services than other, less diverse areas, supporting the low positive correlation in this study. However, in terrestrial systems, increased spatial heterogeneity can increase biodiversity and increase provision of ecosystem services by the species present (Fahrig et al, 2011). The higher correlation between ecosystem services provision and sensitivity (0.63) could be due to the fact that rocky reefs were both highly sensitive and provided many ecosystem services at a high level, compared to mobile sediment which had low sensitivity and low ecosystem services provision.

5.2.2 Element weighting

Each element had an equal weighting and therefore an assumption that each was equally important but it could be argued that sensitivity was the most important element as this was likely to be the most impacted by physical damage from fishing activity. Fishing activity which interacts with the seabed, such as bottom towed gear, is the most widespread cause of disturbance to seabed habitats (Hiddink et al, 2017). Habitats have a range of sensitivities to fishing activities and understanding these interactions is important for informing environmental impact assessments, evidencing marine spatial plans and in supporting sustainable use of the marine environment (Hiddink et al, 2007).

Equally, diversity is an important element for assessment as it contributes to a robust, healthy ecosystem, better able to cope with changes (McLeod & Leslie, 2009) and habitat diversity is necessary to conserve marine biological diversity (Gray, 1997). Biodiversity hot spots – where there are concentrations of many different species – have been used to prioritise conservation efforts (Myers et al, 2000). However, coastal ecosystems are complex and dynamic, effected by a range of interconnected factors which need to be further understood to underpin evidence-based, successful management for biodiversity conservation (Ray, 1996).

Ecosystem services provision is also an important element in the way that it furthers understanding of coupled social-ecological systems and introduces a mechanism for assigning monetary value. Whilst this has its risks and limitations, such as inaccurate valuations, it at least recognises the anthropocentric importance of the services and the need to protect them (Kareiva et al, 2011). However, transferring values does not produce accurate valuations due to unique characteristics in each study area (Troy & Wilson, 2006).

In this study, the provision of twelve ecosystem services was considered but there are other services which could be considered and each looked at in more detail individually. The relationship between ecosystem services can be complex and management aimed at increasing one particular service can decrease another one (Bennett et al, 2009).

5.2.3 Additional elements

As each element was important in its own way, it was a strength of the method used in this study to combine all three elements in the assessment of overall environmental value. Now that this method has been demonstrated to be effective, it would be straightforward to add further elements or change the weighting of them, depending on the focus of the research study. Alvarez-Guerra et al (2009) also found the use of multiple criteria to be useful, but the reduction of complex issues to a single metric can lead to oversimplification (Katsanevakis et al, 2011).

If the data was available, it could be useful to add essential fish habitats as an element. These are areas which are important for feeding, spawning or as juvenile nursery areas (Valavanis et al, 2008). Understanding and protecting essential fish habitat can support successful management of fishery resources (Bergmann et al, 2004; Serra-Pereira et al, 2014), contributing to an increased population with associated environmental and economic benefits (Levin & Stunz, 2005).

Within the study area, Kingmere Marine Conservation Zone (MCZ) was designated for breeding black seabream as they use this area and its specific seabed habitats to make nests in which the female lays her eggs and the male guards (Sussex IFCA, 2017e). Although it is known that this is an area of high environmental value for the black seabream, no high or very high environmental value classes were found within the MCZ. This is a limitation of the method; that the environmental value assessment is only as strong as the data upon which it is based.

5.2.4 Base element

The assessment of environmental value was based on seabed habitat data points. These were not stochastically distributed across the study area, creating areas of greater confidence where there was a higher density of data points (see section 4.1.6). Where the data points were sparse, large Voronoi polygons were created and it was assumed that the area within each polygon had the same, uniform habitat as the data point, with a sharp straight change to the neighbouring habitat (Longley et al, 2011). This is unlikely to be a true representation of the seabed.

If suitable data was available, the data points could be used to ground truth acoustically distinct areas of the seabed and give a more realistic representation of seabed habitats. Data of this sort was available within the study area for a coastal 1km strip (Colenutt et al, 2016). This was not used in this study as data at this resolution was not available for the whole study area and the Voronoi method was considered suitable for use with the grid. However, if data of this sort became available in the future, it would be a simple matter of applying the environmental value scores to these more realistic polygons, instead of the Voronoi's.

The seabed habitats were assessed for their environmental value at the most detailed EUNIS level possible, taking into account biotic features as well as physical structuring where available. Several classification systems have been developed, all with the aim of providing an ecologically-based classification of seabed features to support the management of marine habitats (Connor et al, 2004). The European Nature Information System (EUNIS) is the accepted standard for habitat classification in Europe (James et al, 2011). A standardised system allows for cross comparison between datasets and reduces confusion of definitions (Dauvin, 2014). However, some habitats may be forced into classes which are not truly representative and could be misleading (James et al, 2011).

5.3 Fishing intensity

The main area of very high fishing intensity was between Selsey and Bognor Regis, where there was high netting and potting effort. Cells classified as high fishing intensity covered 8% of the study area and were found in particular around Newhaven and Eastbourne, two of the largest fishing ports in Sussex. Fishing activity can be linked to specific ports, furthering understanding of the socio-economic impacts of fishing on local coastal communities and the importance of nearshore fishing grounds (Vanstaen & Breen, 2014). It was beyond the scope of this study to investigate spatial trends in fishing activity in relation to landing ports or to link fishing effort to the value of seafood landed but these would be interesting areas for future study.

Bottom towed gear, such as trawls and dredges, are recognised as causing damage to seabed habitats (Hiddink et al, 2017) whilst the damage caused by netting and potting is considered to be less (Baer et al, 2010). Netting had the most desirable score out of the five main fishing methods for the environmental criteria in the impacts and benefits assessment, followed by potting (section 4.2.2). Potting had the most desirable score overall in the impacts and benefits assessment and netting was third most desirable, after angling. Whilst netting and potting are relatively low impact, all fishing impacts were considered cumulative so together they contributed to a relatively high intensity score in some areas.

5.3.1 Benefits for society

The socio-economic benefits of fishing were investigated in the assessment of impacts and benefits (section 4.2.2). Potting had the most desirable score (2.16), delivering most socio-economic benefits with least environmental impacts, and trawling had the least desirable impacts and benefits score (2.98). In a study of the Scottish Nephrops fishery (*Nephrops norvegicus*/ Norway lobster/ langoustine/ scampi), trawling and creels (pots/ traps) methods were compared to assess the best value to society and to inform spatial management. Overall, the creel fishery was determined to deliver greater benefit to society than trawling (Williams and Carpenter, 2016), the same as in this study.

However, in this study, trawling had the highest fishing effort (0.45 vessels per km2), in particular to the south west of Newhaven (see Figure 4.8), suggesting that trawling is not currently managed in the best interests of society. Potting had the second highest fishing effort (0.39), followed by netting (0.31) but netting had the greatest distribution, i.e. number of cells in which netting was observed (554).

In a study comparing trawling and netting for cod in the North Sea, trawling had a negative value of up to -£2000 per tonne of cod landed, compared to a positive value of £865 per tonne for netting, although netting accounted for less than 3% of the amount of cod landed (New Economics Foundation, 2011). This is useful for managing fisheries on the basis of gear type; understanding which fisheries deliver most benefits for society and therefore should be promoted, whilst other fishing methods are more detrimental and should be restricted. In particular, in the instances of specific species being caught by more than one fishing method, the more desirable method should be supported.

5.3.2 Value of fisheries

Eight of the twenty-five species assessed in this study were targeted by two fishing methods, bass and cuttlefish were targeted by three methods. Bass were caught by angling, netting and trawling. Netting for bass had the most desirable impacts and benefits score (1.86), followed by angling (2.23) and trawling (2.38). This contrasted with an assessment of the Eastern English Channel bass fisheries which found angling to have the greatest benefits – in terms of price and number of jobs per kilogram – and the least environmental impacts. However, there was agreement in that trawling had the least desirable environmental impacts, although it was the most profitable method (Williams and Carpenter, 2015).

Another study of bass in the Eastern English Channel found that there was up to 75 times higher economic output and employment per tonne of bass caught in recreational fisheries compared to commercial (MRAG, 2014). Recreational fishing was outside the scope of this study but it would be an interesting area for future research, considering the importance of the sector socially and economically, and the potential impacts on stock levels and marine ecosystems.

Assessing specific key fisheries (species and method combinations) allowed for more detailed understanding of the effects of fishing on certain species. Lobster potting had the most desirable impacts and benefits score and ranked first for value per tonne. The second rank for value per tonne was bass angling and this fishery also ranked highly for the environmental criteria but it performed less well for gross profit and wage. Scallop dredging was ranked first for wage and port dependency but performed less well for employment and the environmental criteria. Scallop dredging had the least effort and was observed in the least number of cells, so overall this fishery had a low intensity.

5.3.3 Monitoring of effort

The advantage of combining the impacts and benefits assessment with the mapping of the fishing effort was a clear understanding of the fishing intensity. The distribution of effort could be useful for identifying where fishing was taking place relative to specific habitats or specific mobile threatened species, Marine Protected Areas, ports and the occurrence of other activities (Campbell et al, 2014). The impacts of each fishing method varied (Jennings & Kaiser, 1998) so taking these into account was useful for identifying which should be restricted and which should be promoted to maximise benefits to society and minimise environmental impacts, helping managers identify priorities.

Monitoring the relative effort of fishing activities through high resolution, up-to-date maps is essential for the management of those fishing activities (Enever et al, 2017). Using data for 2012-2016 in this study, revealed that fishing activity was observed across just under half (47%) of the study area and that effort for each of the methods was generally aggregated. Other studies have found fishing effort to be aggregated (Turner et al, 2015; Shephard et al, 2012; Eigaard et al, 2017) and this can lead to de facto refuge areas for some species (Shephard et al, 2012). It also means that some areas are heavily impacted. Parts of the seabed in European waters were impacted by trawls up to 8.5 times per year which can be detrimental when the time for seabed species to recover from damage is longer than the trawling frequency (Eigaard et al, 2017). However, there have been declines in fishing effort in Europe in the past decade, following rapid increase in fishing effort globally in the preceding forty years (Bell et al, 2017).

Using observations of fishing activity as the basis of the fishing effort mapping did not necessarily capture all of the fishing activity. However, in Northumberland, the information on key fishing grounds from interviews with fishers was compared to data collected by fisheries officers' observations and there was good correlation, with observation data representing better variability in effort and the interview data revealing better overall extent of fishing grounds (Turner et al, 2015).

It was outside the scope of this study to interview fishers to understand more about their fishing grounds from their perspective and how that would compare to the fishing effort maps but this could be an area for future work. There have been several studies which have effectively used data from fishers' interviews (Kafas et al, 2017; McKenna et al, 2008; Enever et al, 2017).

As they are the ones who will be affected by management measures, the fishers should be involved in the development of those measures and stakeholder engagement can lead to better compliance (Kuperan et al, 2008). In the context of participatory management development, robust evidence presented in an easily understood format which promotes agreed priorities, can lead to the achievement of management goals (Castrejón & Charles, 2013). Identifying priority areas is key to successful management which balances the short term benefits of exploitation with the long term benefits of protection (Johnston et al, 2015; McIntosh et al, 2016).

6.0 Conclusions

The marine environment is vast and complex. It is rich with natural capital and processes which are essential for human life. Yet the oceans are under threat from multiple pressures. Management of the use of public resources is required to ensure that there is a balance between exploitation and protection. Yet management efforts are restricted by time, funding and resources so they need to be prioritised to maximise efficiency and effectiveness. This study aimed to identify areas for management prioritisation by mapping environmental value and fishing intensity within Sussex coastal waters.

Environmental value was based on seabed habitats and assessed as the sum of ecosystem services provision, diversity and sensitivity. Ecosystem services provision by the 177 seabed habitats in the study area was scored 0-5 very low to very high for the provision of twelve key ecosystem services from published literature (Galparsoro et al, 2014; Salomidi et al, 2012; Fletcher et al, 2012). Diversity was scored 0-5 very low to very high based on GIS entropy analysis of the seabed habitat data points, where high entropy equalled high habitat diversity. The sensitivity of each habitat was based on published literature collated by the Marine Life Information Network (MarLIN, 2017a). Each habitat and its key species were assessed for resistance to abrasion and time to recover from damage and scored 0-5 very low sensitivity to very high sensitivity.

Fishing intensity was calculated by multiplying fishing impacts and benefits with fishing effort. The impacts and benefits of the 37 main fisheries in the study area were assessed through three economic, three environmental and three social criteria and scored 0-5 most desirable to least desirable, after ranking using data in published literature and by analysing publicly available data. Fishing effort was calculated from observations of fishing vessels recorded by Sussex IFCA fisheries officers.

The environmental value and fishing intensity scores were mapped on to a grid with 1km^2 cells. The environmental value was multiplied with the fishing intensity to equal the priority score, producing clearly identified specific areas of priority.

The main priority area was found to be between Selsey and Bognor Regis with other priority areas to the west and south of Selsey, between Brighton and Newhaven and near Eastbourne (see Figure 4.11). This fulfilled the aim of the study:

To identify priority areas for marine managers by using a multiparameter approach to assess the relative value of the marine environment and the intensity of fishing activities.

The completion of the aim was due to the achievement of each of the three objectives:

1) Assessment of marine environmental value: the mapping of seabed habitats in Sussex coastal waters (out to 6nm) and the scoring of each habitat based on ecosystem services provision, diversity and sensitivity.
2) Assessment of fishing intensity: the mapping of fishing activities in Sussex coastal waters and the scoring of each fishery based on observed effort and the relative social, economic and environmental impacts and benefits.
3) Assessment of management priority areas: the combination of environmental value and fishing intensity to identify marine management priority areas.

Each element of each objective has value in its own right in contributing to the evidence base necessary for robust, scientifically-sound management measures. Combined, the elements are a strong, multiparameter approach to a clear and easily communicated management prioritisation tool. The successful completion of this study will contribute to the sustainable management of the marine ecosystems in Sussex coastal waters.

However, there are some limitations to the method. Scores were assigned on the basis of relativity, specific only to the study area for the time scale assessed. For example, very high environmental value was not an absolute score, it was only relative to other areas in the study area where there was lower environmental value. This was equally true for all of the elements. For example, very high fishing effort as an annual average 2012-2016, may be relatively low compared to other areas of the world or compared to other years. However, this was a restriction of the data which was available and the limited scope of this study, which still provided a useful assessment.

Another consideration is that fishing effort was based on observations of activity but where there was no observed activity, it did not necessarily mean that no fishing activity occurred there, just that it was not observed. When the priority score was calculated, those cells where no fishing was observed resulted in a zero priority score. There was potentially an underestimation of the fishing intensity and therefore also the priority score. In addition, by multiplying the environmental value and fishing intensity, the same priority score could be calculated if there was low environmental value and high fishing intensity or if there was high environmental value and low fishing intensity, although these clearly have different implications for management. However, for identifying areas which were relatively higher priority than other areas, based on available data, this method was useful. In application, this study would be just the starting point for further research and consultation, before any management measures were brought in to force.

There are many areas for future work following this study. It would be beneficial to continue to gather data on the seabed habitats, increasing the spatial accuracy of the habitat map. There could be a great deal of research around the ecosystem services provision, developing more accurate understanding of the provision of services by the habitats in the study area and their underlying natural processes, as well as starting to attribute monetary value to the services which would be useful for cost-benefit analyses.

There could be a greater understanding of the role of diversity in marine ecosystems at various levels – habitat, functional, genetic – and how data on species abundance could be integrated into the model. Sensitivity could be assessed for the impacts of various fishing gears, linking the distribution of fishing effort to specific habitats. Depending on data availability, additional elements could be added to the assessment of environmental value, such as essential fish habitat.

For fishing, there could be further analysis of the impacts and benefits to ensure that the fisheries that are low impact and provide the most benefits to coastal communities are being supported and encouraged. Fishing activity data could be analysed to elucidate trends temporally (across seasons or years) and spatially (in relation to habitats or ports). It would be useful to assess other activities, such as wind farm development, aggregate extraction and recreational activities, to take a multi-sectoral management approach, ensuring all activities are managed in an equitable manner that minimises environmental damage.

Thus, whilst there are recognised limitations and much additional work that would be beneficial to include, this study has achieved its aim and successfully identified priority areas for marine managers.

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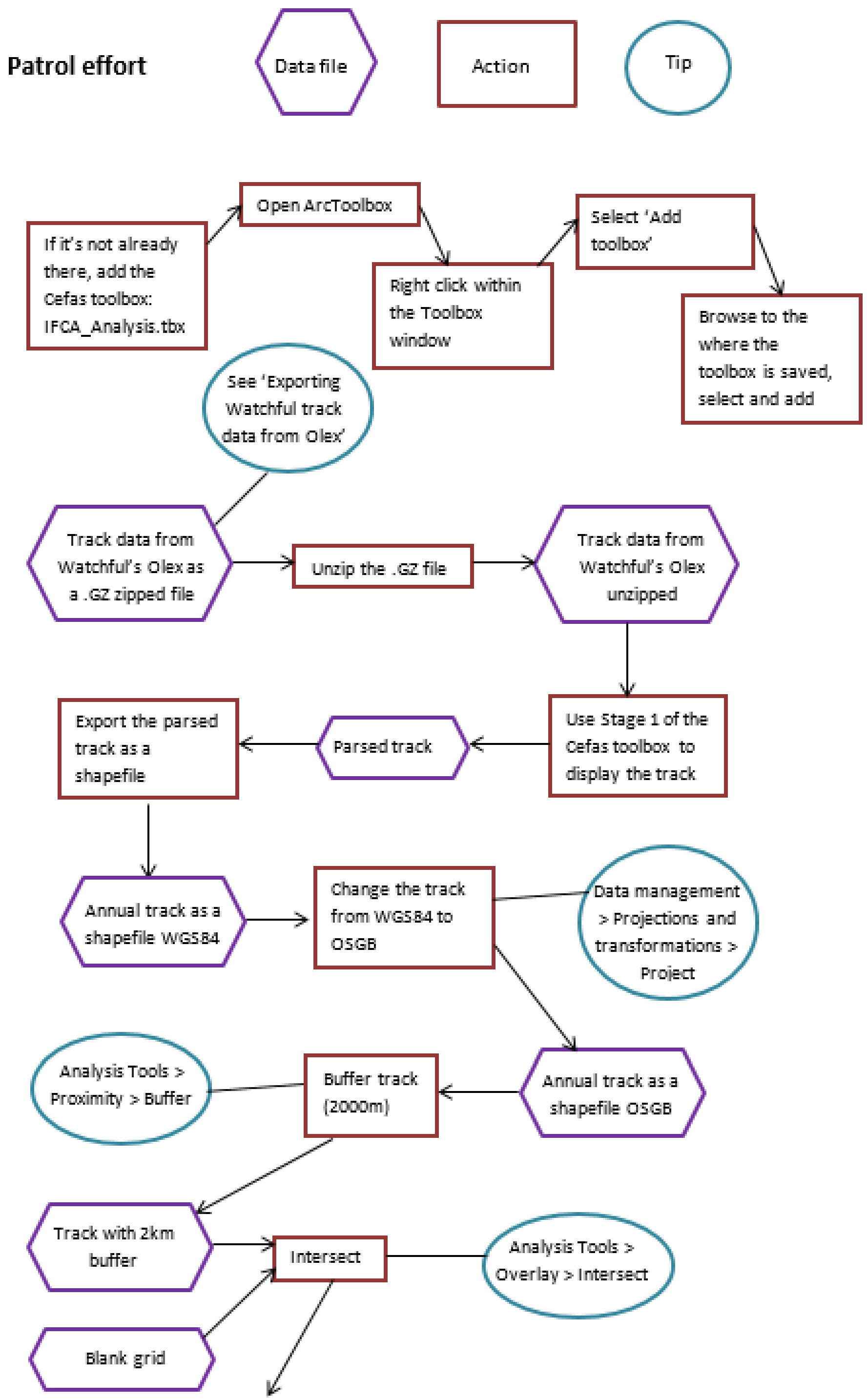
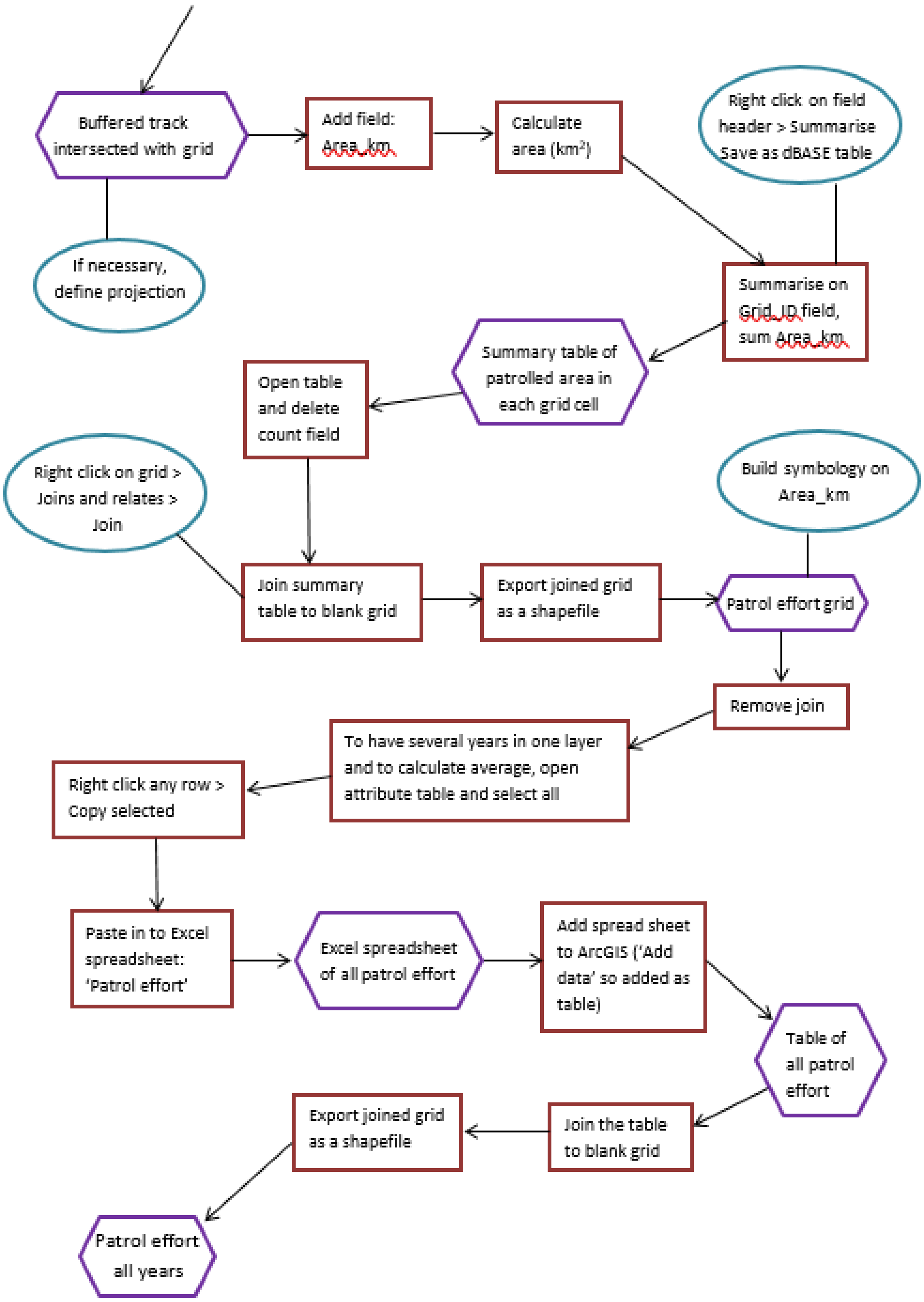
8.0 Appendices

8.1 Fishing effort methodology




Buffered track intersected with grid
Add field: Area_km
Calculate area (km²)
Right click on field header > Summarise Save as dBASE table
If necessary, define projection
Summarise on Grid_ID field, sum Area_km
Summary table of patrolled area in each grid cell
Open table and delete count field
Right click on grid > Joins and relates > Join
Build symbology on Area_km
Join summary table to blank grid
Export joined grid as a shapefile
Patrol effort grid
Remove join
To have several years in one layer and to calculate average, open attribute table and select all
Right click any row > Copy selected
Paste in to Excel spreadsheet: 'Patrol effort'
Excel spreadsheet of all patrol effort
Add spread sheet to ArcGIS ('Add data' so added as table)
Table of all patrol effort
Join the table to blank grid
Export joined grid as a shapefile
Patrol effort all years

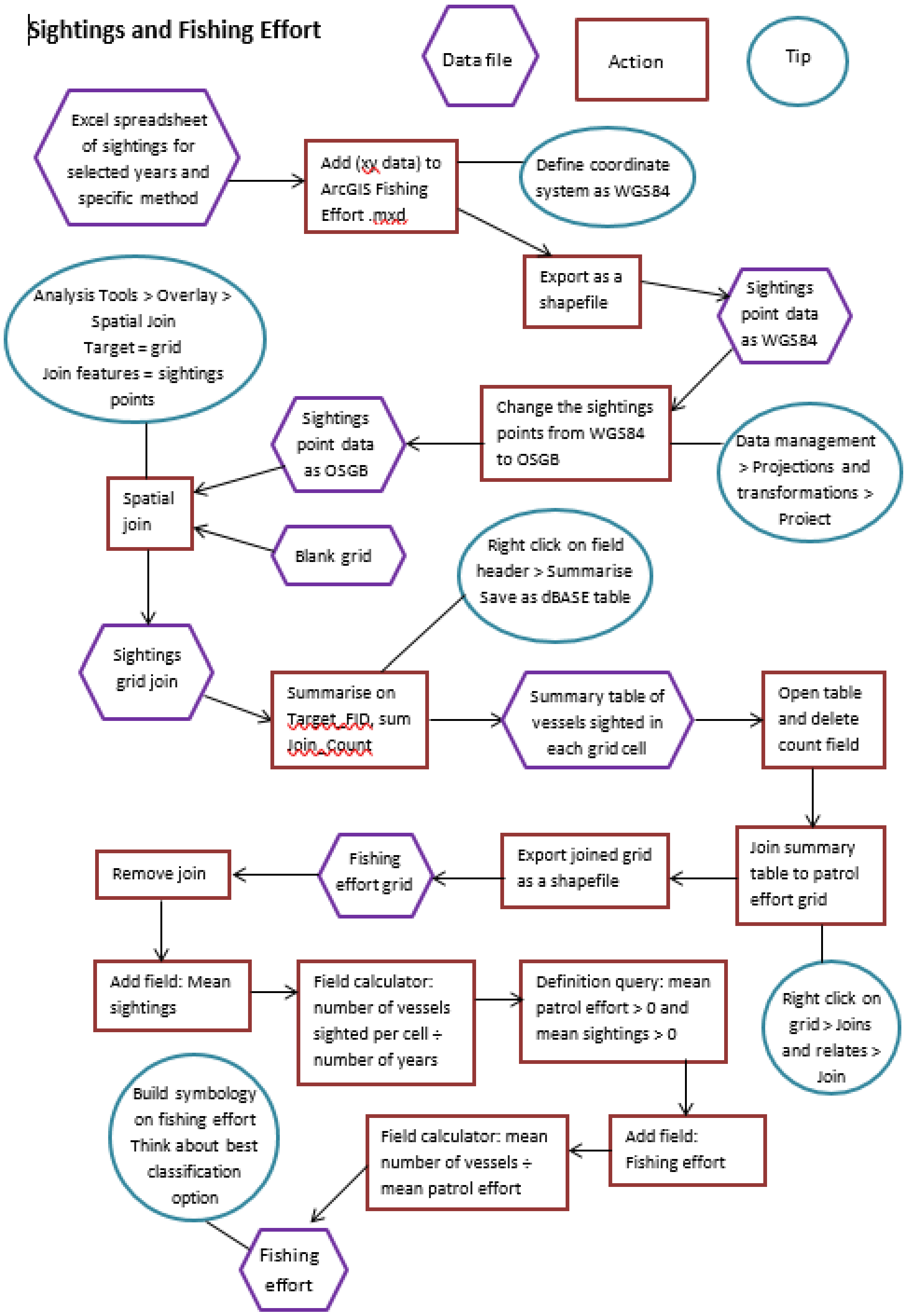


Figure 8.1: Summary of the Sussex IFCA methodology for creating fishing effort data layers in ArcGIS from observed fishing activity. Reproduced with permission from Sussex IFCA.

8.2 Ecosystem services provision results further details

Table 8.1: The level of provision 0-5 very low to very high by 19 seabed habitats at EUNIS level 3 for twelve ecosystem services A: Food, B: Raw materials, C: Air quality and climate regulation, D: Disturbance and natural hazard prevention, E: Photosynthesis and primary production, F: Nutrient cycling, G: Reproduction and nursery, H: Biodiversity maintenance, I: Water quality, J: Cognitive value, K: leisure, recreation, cultural and L: Feel good/ warm glow. In order of average score highest to lowest. Assessed using information from Galparsoro et al (2014), Salomidi et al (2012) and Fletcher et al (2012).

Habitat	EUNIS code	A	B	C	D	E	F	G	H	I	J	K	L	Average score
High energy infralittoral rock	A3.1	5	5	5	5	5	3	5	5	5	5	5	5	4.8
Intertidal sand	A2.2	5	3	5	5	5	5	5	5	3	5	5	5	4.7
Intertidal mud	A2.3	5	3	5	5	5	5	5	5	3	5	5	5	4.7
Intertidal mixed sediment	A2.4	5	3	5	5	5	5	5	5	3	5	5	5	4.7
Moderate energy infralittoral rock	A3.2	5	5	5	3	5	5	5	5	5	5	5	3	4.7
Low energy infralittoral rock	A3.3	5	5	5	3	5	5	5	5	5	5	5	3	4.7
Sublittoral macrophyte dominated sediment	A5.5	5	3	5	5	5	5	5	3	3	5	5	5	4.5
Intertidal rock (high, moderate and low energy)	A1.1/ 2/3	5	3	5	3	5	5	5	5	3	5	5	5	4.5
High energy circalittoral rock	A4.1	5	5	3	5	1	5	5	5	5	5	3	3	4.2
Low energy circalittoral rock	A4.3	5	3	5	1	3	5	5	5	5	5	5	3	4.2
Moderate energy circalittoral rock	A4.2	3	3	3	1	1	5	5	5	5	5	3	3	3.5
Sublittoral biogenic reefs	A5.6	5	2	1	3	2	5	5	5	5	1	3	3	3.3
Intertidal coarse sediment	A2.1	5	1	1	5	1	1	5	3	1	3	5	3	2.8
Features of infralittoral rock	A3.7	3	1	1	1	3	3	3	2	4	5	3	3	2.7
Communities of circalittoral caves and overhangs	A4.7	1	1	1	1	1	1	3	5	1	5	5	3	2.3
Sublittoral coarse sediment	A5.1	5	5	1	1	1	3	4	2	1	1	2	2	2.3
Sublittoral sand	A5.2	5	3	1	1	1	3	4.5	3	1.5	1	2	2	2.3
Sublittoral mixed sediments	A5.4	5	3	1	1	1	3	3	5	3	1	1	1	2.3
Sublittoral mud	A5.3	4.5	1	1	1	1	3	2.5	3	3	1	1	1	1.9

8.3 Sensitivity results further details

Table 8.2: The sensitivity of 26 seabed habitats at EUNIS level 2, 3 and 4 where appropriate to provide further details of the sensitivity analysis. In EUNIS code numerical order. Based on information provided by the Marine Life Information Network (MarLIN) (2017a).

Habitat	EUNIS code	Description of sensitivity	Resistance	Resilience	Sensitivity
Intertidal rock (and other hard substrata)	A1	Erect epifauna will be damaged by abrasion but other species have some resistance, recovery is likely to be rapid especially if some adults left nearby	Low	High	3
Intertidal coarse sediment	A2.1	These tend to have high natural disturbance and low abundance	High	High	1
Intertidal mud	A2.3	Generally burrowing fauna with some resistance to abrasion, generally rapid recovery	Med	High	2
Intertidal mixed sediment	A2.4	These tend to have high natural disturbance and low abundance but with some erect fauna	Med	High	2
Saltmarsh	A2.5	Some tolerance to trampling, can recover within 2 years	Med	High	2
Intertidal sediments dominated by aquatic angiosperms (seagrass)	A2.6	Not robust, roots near surface, annual regrowth but abrasion can induce negative feedback, could take long time to fully recover	Low	Low	5
Intertidal biogenic reefs - Sabellaria	A2.71	Some resistance to abrasion of tube dwelling species and they can repair damage, recolonisation can be rapid	Med	High	2
Intertidal biogenic reefs - Blue mussel	A2.72	Vulnerable to damage from abrasion, can take over 2 years to fully recover due to large interannual variation in recruitment	Low	Med	4
Infralittoral rock (and other hard substrata dominated by algae)	A3	Erect epifauna will be damaged by abrasion, but recovery is likely to be rapid	Low	High	3
High energy infralittoral rock	A3.1	There will be high natural disturbance, but erect epifauna will be damaged by abrasion, recovery is likely to be rapid	Low	High	3
Moderate energy infralittoral rock	A3.2	Erect epifauna will be damaged by abrasion, but recovery is likely to be rapid	Low	High	3
Low energy infralittoral rock	A3.3	Erect epifauna will be damaged by abrasion, but recovery is likely to be rapid	Low	High	3
Features of infralittoral rock	A3.7	Erect fauna vulnerable to abrasion but rapid recovery, especially if some adults left nearby	Low	High	3

Habitat	EUNIS code	Description of sensitivity	Resistance	Resilience	Sensitivity
Circalittoral rock (and other hard substrata dominated by fauna)	A4	Erect epifauna will be damaged by abrasion, but recovery is likely to be rapid	Low	High	3
High energy circalittoral rock	A4.1	There will be high natural disturbance, but erect epifauna will be damaged by abrasion, recovery is likely to be rapid	Low	High	3
Moderate energy circalittoral rock	A4.2	Erect epifauna will be damaged by abrasion, but recovery is likely to be rapid	Low	High	3
Low energy circalittoral rock	A4.3	Erect epifauna will be damaged by abrasion, but recovery is likely to be rapid	Low	High	3
Circalittoral caves and overhangs	A4.71	Some rare species, little interaction between species, slow recovery up to 25 years, some sponges elastic but others damaged by abrasion	Low	Low	5
Circalittoral fouling faunal communities	A4.72	Sponges, and ascidians to a lesser degree, are likely to be damaged by abrasion, sponges and hydroids are fast growing and recovery likely to be rapid	Low	High	3
Sublittoral sediment	A5	These tend to have high natural disturbance and low abundance but with some erect fauna	High	High	1
Sublittoral coarse sediment	A5.1	These tend to have high natural disturbance and low abundance	Med	High	2
Sublittoral sand	A5.2	Species poor mobile habitat with burrowing or mobile species, some burrows may be damaged by abrasion but there is rapid recovery, within weeks or months	Med	High	2
Sublittoral cohesive mud and sandy mud communities	A5.3	Generally burrowing fauna with some resistance to abrasion, generally rapid recovery	Med	High	2
Sublittoral mixed sediment	A5.4	These tend to have high natural disturbance and low abundance but with some erect fauna	Med	High	2
Sublittoral macrophyte-dominated communities on sediments	A5.5	Erect fauna vulnerable to abrasion but rapid recovery, especially if some adults left nearby	Low	High	3
Sublittoral biogenic reefs on sediment	A5.6	Vulnerable to damage from abrasion, can take over 2 years to fully recover due to large interannual variation in recruitment	Low	Med	4

8.4 Impacts and benefits full results

Table 8.3: The impacts and benefits scores for all 37 fisheries. Scored from 0.1 pale blue most desirable to 5.0 dark blue least desirable. In alphabetical order. Assessment made using data from STECF (2016), Seafish RASS (no date), Seafish (2007) and MMO landings data.

Method	Species	Value (per tonne) rank	Final economic output rank	Gross profit rank	Fuel use rank	Ecosystem damage rank	Bycatch rank	Port dependency rank	Employment rank	Wage rank	Average
Angling	Bass	0.27	0.27	5	5	1	1	1.49	1	5	2.23
Dredging	Scallops	2.57	2.16	4	3	4	4	0.14	5	1	2.87
Netting	Bass	0.54	0.54	3	1	1	3	0.68	4	3	1.86
Netting	Brill	1.35	1.35	3	1	1	3	3.78	4	3	2.39
Netting	Cod	2.30	2.70	3	1	2	3	1.89	4	3	2.54
Netting	Cuttlefish	1.89	1.76	3	1	1	3	2.43	4	3	2.34
Netting	Lesser Spotted Dogfish	4.73	4.73	3	1	1	3	4.05	4	3	3.17
Netting	Mackerel	2.70	2.84	3	1	1	3	4.32	4	3	2.76
Netting	Plaice	3.51	3.51	3	1	1	3	1.35	4	3	2.60
Netting	Smoothhound	4.05	4.05	3	1	1	3	3.24	4	3	2.93
Netting	Sole	0.95	0.95	3	1	2	3	0.41	4	3	2.03
Netting	Thornback Ray	2.97	3.11	3	1	1	3	2.84	4	3	2.66
Netting	Turbot	0.41	0.41	3	1	2	3	3.11	4	3	2.21
Potting	Cuttlefish	2.43	2.03	1	2	2	2	1.22	3	4	2.19
Potting	Edible crab	3.11	2.97	1	2	2	2	0.81	3	4	2.32
Potting	Lobsters	0.14	0.14	1	2	2	2	1.08	3	4	1.71
Potting	Whelks	3.78	3.65	1	2	2	2	0.27	3	4	2.41
Trawling	Bass	0.81	0.81	2	4	4	4	1.76	2	2	2.38
Trawling	Black Seabream	2.03	2.30	2	4	4	3	1.62	2	2	2.55
Trawling	Blond ray	3.24	3.24	2	4	3	4	4.86	2	2	3.15
Trawling	Brill	1.49	1.49	2	4	4	5	3.78	2	2	2.86
Trawling	Cod	2.16	2.57	2	4	4	4	3.38	2	2	2.90
Trawling	Cuttlefish	2.84	2.43	2	4	4	4	2.30	2	2	2.84
Trawling	Dabs	4.46	4.46	2	4	4	4	4.86	2	2	3.53
Trawling	Flounder	4.59	4.59	2	4	4	5	4.73	2	2	3.66
Trawling	Gurnards	3.92	3.92	2	4	4	4	2.57	2	2	3.16
Trawling	Lemon Sole	1.62	1.62	2	4	4	3	2.03	2	2	2.47
Trawling	Lesser Spotted Dogfish	4.86	4.86	2	4	4	4	2.16	2	2	3.32
Trawling	Monks/anglers	1.76	1.89	2	4	4	4	4.32	2	2	2.89

Method	Species	Value (per tonne) rank	Final economic output rank	Gross profit rank	Fuel use rank	Ecosystem damage rank	Bycatch rank	Port dependency rank	Employment rank	Wage rank	Average
Trawling	Plaice	3.65	3.78	2	4	4	5	0.95	2	2	3.04
Trawling	Pouting Bib	5.00	5.00	2	4	4	4	4.59	2	2	3.62
Trawling	Smoothhound	4.32	4.32	2	4	3	4	3.65	2	2	3.26
Trawling	Sole	1.08	1.22	2	4	4	5	0.54	2	2	2.43
Trawling	Squid	1.22	1.08	2	4	3	3	3.51	2	2	2.42
Trawling	Thornback Ray	3.38	3.38	2	4	4	5	2.70	2	2	3.16
Trawling	Turbot	0.68	0.68	2	4	4	5	2.97	2	2	2.59
Trawling	Whiting	4.19	4.19	2	4	4	3	4.19	2	2	3.29

8.5 Research ethics checklist

UNIVERSITY OF BRIGHTON

SCHOOL OF ENVIRONMENT AND TECHNOLOGY

RESEARCH ETHICS CHECKLISTS FOR UNDERGRADUATE AND MASTERS LEVEL RESEARCH PROJECTS

This Ethics Checklist is designed to help you quickly and easily identify how you should approach any ethical issues raised by your project or dissertation. If you have any concerns about completing the checklists, please see your supervisor.

An Ethics Checklist should be completed for ALL research projects and dissertations prior to the commencement of the project. Please do not approach any participants involved in the research until these checklists have been completed. The Ethics Checklist will help you identify whether you need to complete an **ethics approval form** to be considered by the School of Environment and Technology Research Ethics and Governance Committee.

The Student Ethics Checklist must be completed by the project student. Once completed, you should discuss it with your project or dissertation supervisor to ensure that you take the right follow-up actions.

If you answer 'no' to all questions in Section B of the Student Checklist you will NOT need to complete an ethics approval form. Please note that in signing the Student Checklist you accept that it is still your responsibility for your project or dissertation module to follow the University's Guidance on Good Practice in Research Ethics and Governance, available on the studentcentral pages. Any significant change in the question, design or conduct of your project or dissertation that would alter your answers to the checklist questions must be notified to your supervisor who will advise you on whether you need to complete an **ethics approval form**.

If you have answered 'yes' to *any* of the questions in Section B of the Student Checklist you will need to complete an ethics approval form prior to the commencement of research. This does not mean that you will not be able to do the research, but it will need to be approved by the School Research Ethics and Governance Committee.

Ethics approval forms and supporting guidance are available on studentcentral pages for your project or dissertation module. Please discuss completing the **ethics approval form** with your supervisor.

Signed copies of the completed Ethics Checklist must be submitted with your project or dissertation, (the project or dissertation will not be marked if the completed checklist is not included).

Further guidance on ethical issues along with Risk Assessment Forms and examples of consent and information forms for research participants are available on the studentcentral pages for your project or dissertation module.

Ethics Checklist

Section A Project details - to be completed by the project student

1. **Name of student/s:** Kathryn Nelson
2. **Name of supervisor:** Dr Niall Burnside
3. **Title of project (no more than 20 words):** Supporting marine spatial management using a multi-parameter approach to assess environmental value and fishing intensity
4. **Outline of the research (1-2 sentences):** The research aims to support evidence-based marine spatial management by using a multi-parameter approach to assess the relative value of the marine environment and the intensity of fishing activities.
5. **Timescale and date of completion:** Deadline is the end of August 2017
6. **Location of research:** Desk-based study. No field or lab work will be undertaken. Study area is Sussex coastal waters.
7. **Course module code for which research is undertaken:** GBM01 Masters Dissertation as part of MSc GIS and EM
8. **Email address**: K.Nelson1@uni.brighton.ac.uk
9. **Contact address**: 4 Park Close, Brighton BN1 9AJ
10. **Telephone number**: 07792574889

Section B Ethics Checklist questions

Please tick the appropriate box	Yes	No
1. Is this research likely to have significant negative impacts on the environment? (*For example, the release of dangerous substances or damaging intrusions into protected* ***habitats.)***		X
2. Does the study involve participants who might be considered vulnerable due to age or to a social, psychological or medical condition? (*Examples include children, people with learning disabilities or mental health problems, but participants who may be considered vulnerable are not confined to these groups.)*		X
3. Does the study require the co-operation of an individual to gain access to the participants? (*e.g. a teacher at a school or a manager of sheltered housing)*		X
4. Will the participants be asked to discuss what might be perceived as sensitive topics? (*e.g. sexual behaviour, drug use, religious belief, detailed financial matters)*		X
5. Will individual participants be involved in repetitive or prolonged testing?		X
6. Could participants experience psychological stress, anxiety or other negative consequences (beyond what would be expected to be encountered in normal life)?		X
7. Will any participants be likely to undergo vigorous physical activity, pain, or exposure to dangerous situations, environments or materials as part of the research?		X
8. Will photographic or video recordings of research participants be collected as part of the research?		X
9. Will any participants receive financial reimbursement for their time? (*excluding reasonable expenses to cover travel and other costs*)		X
10. Will members of the public be indirectly involved in the research without their knowledge at the time? (*e.g. covert observation of people in non-public places, the use of methods that will affect privacy)*		X
11. Does this research include secondary data that may carry personal or sensitive organisational information? (S*econdary data refers to any data you plan to use that you did not collect yourself. Examples of sensitive secondary data include datasets held by organisations, patient records, confidential minutes of meetings, personal diary entries. These are only examples and not an exhaustive*		X
12. Are there any other ethical concerns associated with the research that are not covered in the questions above?		X

All Undergraduate and Masters level projects or dissertations in the School of Environment and Technology must adhere to the following procedures on data storage and confidentiality:

Once a mark for the project or dissertation has been published, all data must be removed from personal computers, and original questionnaires and consent forms should be destroyed unless the research is likely to be published or data re-used.

Please sign below to confirm that you have completed the Ethics Checklist and will adhere to these procedures on data storage and confidentiality. Then give this form to your supervisor to complete their checklist.

Signed

(Student):

Date: 04/05/17

8.6 Risk survey form

University of Brighton

Stage 1 of 3

University of Brighton Risk Survey Form

Activity / area surveyed:

Surveyed by:

Date of survey:

No.	Activity / Hazard?	Type of assessment needed? (E.g. General, DSE, COSHH etc)	Priority (H/M/L)	Action by when?	Action by whom?	Done
1	The study involves computer based research and analysis, no fieldwork or lab work is proposed. Could develop muscular aches from sitting at the computer too long. Will need to take regular breaks and find a work position with least strain.	General	Low	Throughout study	Kathryn Nelson	Yes