Social and environmental drivers of fishers' spatial behaviour in the Northumberland lobster fishery

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Submitted for the degree of Doctor of Philosophy

September 2010

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Abstract

The current trend towards marine spatial planning (MSP) worldwide impacts marine resource users, particularly in inshore fisheries. Understanding the spatial distribution of fishing activity and complex drivers of human behaviour may help elucidate and predict responses of fishers to changes in management. This thesis characterises fishers' spatial behaviour and decision-making in the lobster (*Homarus gammarus*) fishery in Northumberland (UK).

Information on the distribution of UK inshore fisheries activity is scarce, but arguably is critical to the success of future MSP and fisheries management. Chapter 2 develops a methodology using GIS to quantitatively compare the spatial coincidence of fishing effort distribution based on two different data sources. A statistically significant similarity is demonstrated between patterns of fishing activity indicated by observational and interview data. Spatial variability in lobster landings and inferred catch rates among fishing ports is examined in Chapter 3 using linear mixed effects models. A negative relationship was identified between measures of fishing intensity and landings at port level, yet this variability in landings is minimal compared to that among individual vessels, the causes of which are discussed.

Based on quantitative and qualitative data collected through interviews with fishers, Chapters 4 and 5 investigate how the social context influences fishers' decision-making and behaviour. Chapter 4 considers fishers' perceptions in prioritising factors driving spatial decision-making. The findings are examined in light of evidence for territorial behaviour and discussed using theories of economic defendability and collective action. Social network analysis is applied in Chapter 5 to uncover information-sharing behaviour among fishers. Results highlight differences in network structure among ports, demonstrate a relationship between fishers' position in information-sharing networks and their fishing success, and point towards the existence of social-spatial groups in fishing behaviour at sea.

This thesis identifies inter-related factors driving decision-making, suggesting that an understanding of the social context shaping fishers' spatial behaviour is important for developing appropriate management measures. Taking account of a fishery's environmental and social characteristics is recommended for predicting fishers' responses to changes in them.

Acknowledgements

Numerous people have provided invaluable support throughout the three years of planning, researching and writing this thesis. Firstly, I would like to thank my supervisors, Selina Stead and Nick Polunin, who encouraged me to take on the challenge of a PhD and have provided guidance, feedback and support throughout. Thanks also to all at Northumberland Sea Fisheries Committee (NSFC) who have provided me with data, answered my frequent queries, and were a great help in the initial stages of my fieldwork. Above all, I am indebted to all the fishers that made this research possible by giving up their time to answer my questions, and whom it was a pleasure to meet and learn from. I am extremely grateful for all the information and experience they shared with me.

A number of other people have provided me with assistance in various ways. Aaron Mair, Rod Henderson, Craig Irwin and Jacqueline Reilly at the Marine and Fisheries Agency (MFA) answered many of my queries and provided additional data on lobster landings; Bob Foster-Smith (Envision Mapping Ltd). provided marine substrate data on the study area; Rob Clark (Sussex SFC), Stuart Barr, Louis Goffe and Helen Bloomfield advised on spatial analysis and many GIS queries; Steve Rushton, Aileen Mill and Andy Close gave invaluable statistical advice and introduced me to the joys of R!; Jeremy Phillipson and Tim Gray took an interest in my work and helped me develop my ideas; Neil Armstrong and Barry Pearson provided advice on my questionnaire and helped with initial contacts in local fishing communities; Colin Bannister, Mike Smith and others at Cefas have answered various queries and provided useful insights; Jim Wilson, Jim Acheson, Teresa Johnson and others hosted a visit to the University of Maine and gave me the opportunity to learn more about the Maine lobster fishery. I am sure there are many others I have neglected to name but whose help I have appreciated along the way.

Thanks to everyone in the research group who has kept me sane, made me laugh and provided coffee, cake and ideas over the last three years, including Helen Bloomfield, Natalie Bown, Alex Caveen, Pete Chaniotis, Clare Fitzsimmons, Estelle Jones, Ben Kurten, Margarita Lavides, Aileen Mill, Will Reid, Reuben Sulu, and Mike Sweet. Finally, thanks to my family and friends who have been infinitely patient and periodically dragged me away from my computer for much-needed distractions and adventures!

This thesis is the result of a three year research project funded by an ESRC/NERC Interdisciplinary studentship. Additional funding came from a project with NSFC funded by the Fisheries Challenge Fund, administered by the Marine and Fisheries Agency (Defra).

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List of acronyms

AIC	Aikike's Information Criterion
ANOSIM	Analysis of similarity
AR	Autoregressive
BIC	Bayesian Information Criterion
CBD	Convention on Biological Diversity
CEFAS	Centre for Environment, Fisheries and Aquaculture Science
CFP	Common Fisheries Policy
CL	Carapace length
CPUE	Catch per unit effort
DEFRA	Department for Environment, Food and Rural Affairs
EC	European Community
EU	European Union
GIS	Geographic information systems
GLM	General linear model
GPS	Geographic positioning system
HR	Home range
HS	Hotspot
IFD	Ideal free distribution
IPA	Inshore Potting Agreement (Devon)
JCA	Joint count analysis
KDE	Kernel density estimate
LPUE	Landings per unit effort
MA	Moving average
MCP	Minimum convex polygon
MCZ	Marine Conservation Zone
MFA	Marine and Fisheries Agency
ML	Maximum likelihood
MLS	Minimum landing size
MPA	Marine protected area
MSP	Marine spatial planning
MSY	Maximum sustainable yield
NAO	North Atlantic Oscillation
NGO	Non-governmental organisation
nmi	Nautical mile
NSFC	Northumberland Sea Fisheries Committee
OLS	Ordinary least squares
OSPAR	Convention for the Protection of the Marine Environment of the NE Atlantic
PCA	Principal component analysis
PE	Patrol effort
PVC	Percent volume contour
QAP	Quadratic assignment procedure
RDA	Redundancy analysis
REML	Restricted maximum likelihood
SFC	Sea Fisheries Committee
SNA	Social network analysis
TURFS	Territorial use rights in fisheries
VMS	Vessel monitoring system

Chapter 1.

Drivers of fishers’ spatial behaviour

1.1 Introduction

Human use of environmental goods and services can be influenced by change in both the natural environment and in socio-economic systems. For natural resource exploitation to be sustainable, appropriate management must therefore be informed by a range of disciplines including biology, economics and social science. Successful ecosystem management that reconciles sustainable livelihoods with conservation requires an understanding of the contextual factors that drive change in resource-use patterns, including an understanding of the knowledge, perceptions and motivations that determine resource use behaviour. Fisheries provide an ideal opportunity to investigate relationships between people and the environment, as their management requires human exploitation to be constrained within natural productivity limits and in complex systems that cannot easily be controlled.

This chapter will outline the rationale for the focus of this thesis on the spatial behaviour of inshore fishers. The theoretical background of approaches to understanding fishers' behaviour is reviewed with reference to current gaps in knowledge and implications for fisheries management. The importance of spatial behaviour in inshore fisheries of the UK is discussed, and the choice of study area for the research described in this thesis is outlined. Finally the main sources of data and structure of the thesis are described.

1.2 Marine resource management and fishers' behaviour

Many of the world's fisheries are perceived to be in crisis, with management failure leading to resource degradation, and related economic and social problems (Hutchings 2000; Allison 2001; Rossiter & Stead 2003; Thurstan et al. 2010). Fisheries managers, particularly in temperate commercial fisheries, strive to achieve economically efficient and profitable fleets, while concurrently attempting to sustain jobs in a politically important industry (Hilborn 2007a). Particularly in temperate waters, fisheries management has traditionally focused on single species bio-economic modelling to inform management, based on biological targets and reference points such as maximum sustainable yield (MSY) (Caddy & Cochrane 2001). More recently, a broader conception of the ocean as a dynamic and unpredictable system has led to greater consideration of multi-species fisheries, ecological interactions and alternative stable states, with increasing emphasis directed towards what is referred to as an ecosystem approach to fisheries management (Botsford et al. 1997; Symes 2001a; Wilson 2006). Recognition that target species populations are highly variable in space and time, and are affected by unpredictable environmental changes, has contributed to a developing consensus that spatially explicit management is needed to account for the patchy nature of marine systems (Caddy & Cochrane 2001; Wilen et al. 2002; Wilen 2004) .

With an increasing focus worldwide on the potential for spatial management measures (e.g. marine reserves) to benefit fisheries (Hilborn et al. 2004; Sweeting & Polunin 2005; Greenstreet et al. 2008; Roberts & Mason 2008; Jones & Carpenter 2009), there is a strong case for developing a good understanding of the spatial dynamics of fisheries systems. It is widely recognised that fisheries management pertains to the management of resource users as much as to the management of the resource itself (Gordon 1954; Hilborn & Ledbetter 1979; Bockstael & Opaluch 1983; Bene & Tewfik 2001). In considering spatial patterns in fisheries, the distribution of fishing activity is therefore as important as that of the target species, and can be useful both in assessing the impact of fishing on a resource, and in evaluating options for resource management (Pet-Soede et al. 2001, Wilen et al. 2002).

Concurrent to these developments in fisheries management, there has been increasing emphasis on the role of spatial management measures as part of a broader ecosystem-based approach to marine resource management and conservation (Botsford et al. 1997; Hughes et al. 2005; St. Martin & Hall-Arber 2008). In the last decade, marine spatial planning (MSP) has become a key element of this trend (Ehler & Douvere 2007). MSP is defined in the UK as "a strategic plan for regulating, managing and protecting the marine environment that addresses the multiple, cumulative and potentially conflicting uses of the sea" (Canning 2003). As such, it is considered a key element in an ecosystem-based approach to integrated marine resource management, providing a tool to reconcile social, economic and environmental activities that compete for space and resources (Douvere 2008; Gilliland & Laffoley 2008).

Marine protected areas (MPAs)[1] may form one component of an MSP approach to zoning marine resource use. In the field of conservation science there is support for areas of the marine environment being closed to some or all types of fishing activities to protect marine biodiversity (Kelleher 1999). In 2003, the World Parks Congress called for the establishment of a network of MPAs across 20-30% of the world's oceans by 2012 (UNEP-WCMC 2008), and the European Marine Strategy Framework Directive requires member states to establish MPA networks by 2020. In the UK, commitments under the Convention on Biological Diversity (CBD) and Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR) to develop a

[1] Defined by IUCN as, "Any area of intertidal or sub-tidal terrain, together with its overlying water and associated flora, fauna, historical and cultural features, which has been reserved by law or other effective means to protect part or all of the enclosed environment" (Kelleher 1999).

representative network of MPAs will be met in part by the designation of new marine conservation zones (MCZs) (DEFRA 2010). MCZs are a type of MPA created under the UK Marine and Coastal Access Act (2009) to protect nationally important marine wildlife, habitats, geology and geomorphology under varying levels of protection (JNCC 2010). There is support from environmental NGOs, scientists and government agencies for these to include a network of no-take MPAs, or Highly Protected Marine Reserves (HPMRs), in which extractive activities such as fishing are prohibited (Jones 2008; DEFRA 2010).

Understanding fishers' spatial behaviour and the factors driving it is important in relation to these developments for several reasons. Firstly, knowledge of the spatial distribution of fishing activity is needed to predict potential impacts of spatial management measures on fisheries, including possible loss of income for fishers or displacement of fishing effort due to spatial closures and limited access to fishing grounds (Richardson et al. 2006; Greenstreet et al. 2008; Valcic 2009). Quantifying the intensity and value of fishing activity across fishing grounds can inform planning and designation of spatial management measures or closures, giving greater potential to optimise benefits of such measures while minimising negative impacts on fishing activities and significantly reducing costs incurred by fishers that may be displaced (Richardson et al. 2005). It may also be necessary where there is a requirement to determine appropriate levels of compensation for economic losses incurred by resource users.

Secondly, an appreciation of the contextual drivers of spatial behaviour is necessary to understand and predict fishers' responses to change, which in the past have often surprised managers (e.g. by finding ways to circumvent regulations) (Hilborn 2007b). Fishers' responses to spatial displacement of fishing activity may have implications for the surrounding marine environment (e.g. increased fishing pressure and associated impacts in alternate fishing grounds), for the economic viability of fishing fleets (e.g. in terms of the availability of alternative productive fishing grounds and fishers' ability to travel to these), and for the social aspects of coastal communities (e.g. displacement of effort may disrupt customary allocation of fishing activity or lead to conflict with other gear types or other users of the marine environment). While spatial closures in offshore waters may be more easily adapted to by mobile fleets, closures inshore may have greater implications, including loss of livelihoods and social identities (Symes 2001a).

Thirdly, understanding fishers' motivations and decision-making processes in relation to their fishing practices may be important to ensure the success of spatial management measures designed for either fisheries management or conservation purposes. Different management scenarios can take into consideration likely reactions of fishers to specific measures. To illustrate, there is often strong resistance from fishers to the implementation of MPAs that restrict fishing activity, on the grounds that benefits for fisheries are scientifically unproven and may take years to accrue, while economic losses are often immediate and have long-lasting impacts (Jones 2006; Higgins et al. 2008). Enforcement of MPAs remains a major challenge, and a lack of compliance by fishers may lead to failure in achieving MPA objectives. Understanding fishers' decision-making and behaviour may help to plan management measures better suited to local conditions, increasing the perceived legitimacy of management in the eyes of resource users and engendering a higher degree of voluntary compliance (Hønneland 1999; Hønneland 2000; Raakjær Nielsen 2003). An appreciation of the relative importance of factors driving change in resource use behaviour can therefore inform the creation of appropriate incentives to achieve environmental, economic and social goals (Hilborn 2007b; Beratan 2007).

1.3 Understanding fishers' spatial behaviour

Despite a proliferation of studies on the use and application of fishers' knowledge of the marine environment to understanding fisheries and fish, comparatively less effort has been expended on understanding the factors underpinning strategies of individual fishers in deciding when, where and how to allocate their fishing effort. Consequently, managers often have simplistic conceptions of fishers' behaviour and consider the fishing effort of a stock in aggregate over fishing grounds, leading to models of behaviour that fail to reflect spatial complexity (Hart & Pitcher 1998; Hutton et al. 2004; Salas & Gaertner 2004; Salas et al. 2004). As a result there is limited understanding of the heterogeneous behaviour of fishers in responding to change in the environment and external drivers, particularly in small scale mixed-species fisheries where changes in price and abundance can lead to frequent redistribution of effort (Salas et al. 2004; Abernethy et al. 2007).

Assessing spatial dynamics of fisheries involves both describing fishers' behaviour and explaining their decision-making. Spatial allocation of fishing effort can be investigated through several means, including examination of information submitted by fishers to monitoring programmes, at-sea observation of vessels, vessel monitoring systems (VMS) and overflight data, fishers' own logbooks, and information obtained directly from fishermen through surveys or interviews (Hilborn & Ledbetter 1979; Swain & Wade 2003; Abernethy et al. 2007; Daw 2008). Cross-referencing and triangulation of information is desirable to reduce the influence of bias from different sources (Scholz et al. 2004).

Investigating spatial behaviour in small-scale inshore fisheries may be particularly problematic, for example as smaller vessels (<15m) may not be included in VMS schemes, and reported information on fishing locations may be at an insufficiently fine scale to determine short-term variation (Harrington et al. 2007). In such cases information obtained directly through interviews with fishers may provide a useful source of data for fisheries managers and marine spatial planners. However, there remain methodological questions as to how such data sources compare with those collected through more formal monitoring programmes. For instance the fishing activity distribution indicated by a particular dataset may be influenced by the underlying distribution of the resource, the spatial scale of analysis, and the quantity of data collected. Geographic information systems (GIS) provide a means to combine and present different layers of spatial information in a common format, as well as preserving links to contextual information (Caddy & Carocci 1999; Aswani & Hamilton 2004; Scholz et al. 2004; Aswani & Lauer 2006; Hall & Close 2007; Lauer & Aswani 2008; De Freitas & Tagliani 2009; Hall et al. 2009). Analysis of data sources using GIS allows an opportunity to make statistical comparisons of datasets and to visualise the information they contain. In addition, GIS enables social dimensions of marine resource use to be incorporated into spatial analysis, providing a medium for integration of data sources that otherwise may be difficult to compare (St. Martin & Hall-Arber 2008; Hall et al. 2009).

While information on the distribution of activity is important to inform management decisions, anticipating the response of fishers to potential management measures requires an understanding of the underlying motivations of their decision-making. Literature in the field of resource use behaviour and decision-making comes from many disciplines, including ecology, economics, sociology, and psychology, and no common theoretical or methodological framework exists. Fishers' decision-making can be investigated through empirical studies or through modelling, and a variety of approaches have been taken to examine the behaviour of both individuals and fishing fleets (e.g. Allen & McGlade 1986; Hilborn & Ledbetter 1979; Dorn 2001; Swain & Wade 2003; Pradhan & Leung 2004), while social and ethnographic research has contributed a deeper understanding of fishers' perceptions as well as social, economic and cultural factors underlying decision-making (e.g. Holland & Sutinen 1999; Salas et al. 2004; Wagner 2004; Acheson & Gardner 2005; Christensen & Raakjær 2006; Abernethy et al. 2007). The drivers of fishers' behaviour and spatial decision-making have been reviewed with respect to both temperate commercial fisheries (Branch et al. 2006) and small-scale fisheries (Salas & Gaertner 2004); the principal ecological, economic and social theories, and recent developments in these, are summarised in the following sections.

1.4 Environmental drivers

Fishers' knowledge of the ecological characteristics of targeted resources can be influential in determining fishing practices. Studies from both small scale tropical artisanal fishers and industrial scale fleets have found that fishing patterns and temporal and spatial variability in effort allocation in part reflect aspects of the ecological characteristics or availability of the resource (e.g. Bertrand et al. 2004; Tewfik & Bene 2004). For example, in the South Caicos spiny lobster (Palinuridae) fishery, seasonal exploitation of inshore shallows is followed by relocation to deeper areas, consistent with the movement of recently matured adults to deeper habitats (Tewfik & Bene 2004). Spatial variability in target species can be affected by the mobility and habitat dependency of the species, including seasonal and migratory movements, patterns of aggregation, and vulnerability to environmental variability such as changes in water temperature, salinity, and abundance of predators and prey (e.g. Butler et al. 2006; Rios-Lara et al. 2007).

The ideal free distribution (IFD) theory (Fretwell & Lucas 1969), which emerged from behavioural ecology, predicts that fishers will seek to maximise their catch by allocating fishing effort in proportion to available resources, leading to differential fishing pressure over space (Gillis 2003). For instance, where there is an area of greater target species abundance, sufficient vessels are expected to move to that area until it is no longer worthwhile for further vessels to move (i.e. the fishing opportunity is roughly equal to that elsewhere). Where fishers respond to variable abundance in this way, catch per unit effort (CPUE) may be consistent over large areas, despite difference in abundance (Gillis 2003; Branch et al. 2006). CPUE can be defined as CPUE = qN, where N represents total abundance, and q is a catchability coefficient, representing the proportion of a stock caught using a given unit of effort (Jennings et al. 2001). CPUE has therefore often been used as an indicator of the relative abundance of target species when assessing the state of exploited resources, assuming catchability to be constant. The spatial behaviour of fishers in response to differences in abundance presents a challenge for interpreting fisheries dynamics using data from commercial fisheries as CPUE may not reflect abundance if competition and congestion alter catchability (Gillis 2003). Understanding sources of variability in CPUE data is therefore important where it is used to inform fisheries management.

The IFD theory has been applied to investigate the relationship between spatial allocation of fishing effort and resource distribution in both commercial fleet dynamics and in small scale artisanal fisheries. Some studies have found relatively consistent catch rates over space and conclude that effort is a more reliable indicator of resource distribution than CPUE where there is high fishing intensity and interference competition (Prince & Hilborn 1998; Swain & Wade 2003). However, others have found that spatial allocation of fishing effort did not conform to the IFD, with effort not distributed in proportion to target species abundance (Abernethy et al. 2007).

Failure to conform to the predictions of the IFD may relate to violation of the theory's two key assumptions: 1) that fishers act in a rational way to maximise their utility, and 2) there is no constraint on fishers' movement. The first assumption requires that fishers have sufficient information on target species abundance to respond to changes in distribution, which may not be the case if sharing of information is limited or high variability in resource abundance makes spatial trends hard to detect (Pet-Soede et al. 2001; van Oostenbrugge et al. 2001; Gillis 2003; Daw 2008). Fishers must also have the capacity to process this information and make rational decisions in the time available. The assumption that vessels can move freely may be confounded where movement is restricted by cost, regulations, or defence of productive areas by individuals or groups (Gillis 2003). Consequently, it is important to consider the economic and social factors driving fishers' behaviour.

1.5 Economic drivers

Economic constraints (e.g. fuel costs) and incentives (e.g. high market prices) are expected to affect the allocation of fishing effort, as variable costs of fishing in different areas effectively constrain fishers' freedom of movement. Economic models therefore predict that spatial allocation of effort is driven by expected returns, and profit rates even out over the area fished (Gordon 1954). Catch rates are expected to reflect the costs of fishing, with higher costs of particular fishing grounds being balanced by a higher CPUE (Prince & Hilborn 1998; Gillis 2003).

Several empirical studies support this theory; for example, research on Tasmanian abalone (*Haliotis* spp.) fisheries suggests that rates of return are higher in areas where the cost of fishing is higher (Prince & Hilborn 1998). Similarly, a study of the British Columbia salmon (*Oncorhynchus* spp.) fishery found effort allocation was best explained by the direct (e.g. travel time, fuel) and indirect (e.g. potential conflict with other vessels, opportunity costs of time) costs associated with each fishing area, and movement of vessels maintained the ratio of catch rates in each area (Hilborn & Ledbetter 1979). Distance of fishing grounds from port is often used as a proxy for the cost of fishing, and in the Gulf of St Lawrence snow crab (*Chionoecetes opilio*) fishery a negative relationship was found between fishing effort and distance from port (Swain & Wade 2003). In artisanal fisheries of Nicaragua there was also evidence that greater catch by some fishers was associated with greater fuel costs, and that some perceived the distance they travelled to be limited by fuel costs (Daw 2008). An understanding of economic considerations is therefore important to understand spatial behaviour and a lack of appreciation of such factors can affect the success of spatial management measures, which can themselves alter the relative profitability of fishing in the surrounding area (Smith & Wilen 2003).

Models of the behaviour of individual fishers and fishing fleets commonly assume an economic profit-maximising strategy based on rational choice theory, in which decisions reflect rational calculations to maximize their utility in the short-term (Branch et al. 2006; Hilborn 2007). However, the underlying assumptions of this approach are often questioned for a number of reasons. As individuals often have imperfect information and limited cognitive capacity to process all available information in a short time frame, it has been suggested that they may use heuristics, or rules of thumb, to make decisions based on previous experience (Axelrod 1984). Developments in cognitive psychology suggest decision-making starts with the activation of neural connections representing the desired outcome, and heuristics may therefore represent patterns of connections regularly encountered in past experiences (Beratan 2007). The view of resource users as rational decision makers may therefore be inappropriate in predicting behaviour (Beratan 2007).

While it is commonly asserted that fishers pursue self-interest, it is widely recognised in social science disciplines that utility maximisation relates not only to economic well-being but also to happiness, independence, maintaining a way of life, gaining social acceptance, and many other factors shaped by social influences (Hart & Pitcher 1998; Jentoft et al. 1998; Salas & Gaertner 2004). Agent based models[2] such as random utility models (RUMs) attempt to account for this by modelling heterogeneity in the utility of individuals (Wilen et al. 2002; Hutton et al. 2004; Pradhan & Leung 2004). Others have suggested that individuals aim to satisfy non-economic goals as long as a minimal level of profit is achieved (Simon 1982, cited in Gigerenzer 2001). This explanation is seen to be more congruent with actual behaviour than a profit-maximisation strategy, but is not easily incorporated into behavioural models (Robinson & Pascoe 1997).

Despite recognition that fishers' behaviour is heterogeneous, few studies explicitly assess the degree of profit-maximising behaviour in individuals. Abernethy et al. (2007) used an index based on motivation to fish, use of catch and time spent fishing to categorise fishers as high, medium or low profit-maximisers. Empirical research suggests that fishers may make decisions based on long-term economic well-being rather than short-term economic goals (Robinson & Pascoe 1997). For instance, where there is competition for space there may be an incentive to leave fishing gear in place when not in use, to maintain occupation of an area for longer-term economic benefits (Blyth et al. 2002; Wagner 2004). In addition, the economic rationality of fishers' motivations can be complicated by the wider economic context, which is often not considered in sectoral management policies (Allison & Ellis 2001). Where fishers are engaged in other livelihood activities, market conditions and opportunity costs of time may be important in decision-making.

In addition to direct economic factors such as expected costs and catches, several empirical studies have found factors such as tradition, risk perception, regulations, conflict with other vessels, preferences for fishing close to home, and value of time to be important in determining fishers'

[2] Defined as "the computational study of social agents as evolving systems of autonomous interacting agents" (Janssen & Ostrom 2006). In studies of fishers' behaviour social agents would represent individual fishers.

decisions about where to fish (Prince & Hilborn 1998; Bene & Tewfik 2001; Pet-Soede et al. 2001; Abernethy et al. 2007; Daw 2008). For instance, risk-averse fishers may stick to grounds they know well, while others may explore new areas and opportunities, resulting in differing behaviour and responses to change (Hutton et al. 2004; Salas & Gaertner 2004; Gelcich et al. 2007). In the Turks and Caicos, switching between target species was found to be driven by both bioeconomic and socio-anthropological factors, including social pressure (higher social status associated with targeting some species) and individual incentives to fish for particular species based on the labour intensiveness of fishing (Bene & Tewfik 2001). These studies support the view that fishers' decisions are shaped by the social and cultural context in which they operate.

Importantly, rational choice approaches treat society as a product of interactions between individual agents, and are consequently criticised for failing to account for social processes (e.g. norms, culture and power) that also influence behaviour (Wilson & Jentoft 1999). There is debate over the degree to which such social complexity can be captured in models, since the lack of a common measure of social values makes algorithmic solutions for decision-making in social situations questionable (Paavola & Adger 2005). Furthermore, it is argued that approaches to fisheries management that fail to consider social aspects of fishing communities have contributed to the failure of fisheries management to date (McCay & Jentoft 1998; Jentoft 2000). Alternative methods of researching fishers' decision-making and motivations, including ethnographic research and approaches that focus on the links between individuals and recognise that economic behaviour is embedded in social relations, may therefore help inform the future development of both models of fishers' behaviour and approaches to fisheries management.

1.6 Social drivers

A purely economic model assumes that individuals' decisions are independent of those of other fishers (Knight 1992), yet in practice fishers' decisions are influenced by the behaviour, attitudes and expectations of others, and by the social structure of fishing communities (Hart 1998; Raakjær Nielsen & Mathiesen 2003). Agent based models of fishing behaviour attempt to represent decisions of individual vessels, but seldom include social interactions between vessels. Alternative approaches increasingly recognise the social context of behaviour, which is rarely incorporated into fisheries management models (Rudd 2000). In recognising the social context of decision-making, individuals are seen to be embedded in systems of interactions with others and are influenced by norms and social responsibilities (Wilson & Jentoft 1999). These social influences can have implications for fishing practices by determining behaviour that is socially acceptable, and exerting influence through peer pressure or conflict (Jentoft 1998; Maurstad 2002). Two areas in which social processes are important in influencing spatial behaviour are information-sharing among fishers, and systems of informal property rights or territoriality among fishers.

1.6.1 Information sharing

Availability of information can have a direct bearing on fishers' spatial behaviour, as the extent to which fishers can target areas of high abundance or profitability depends upon their knowledge. Despite this, few studies quantify the effects of information on fishers' effort allocation and success rates (Gillis 2003). Fishers' knowledge may come from personal experience, or through active or passive transfer of information, i.e. communication between fishers or observation of others (Branch et al. 2006; Wilson et al. 2007). Fishers are often characterised as secretive, as knowledge about the resource and local environment can be used to gain a competitive advantage, for instance to set fishing gear in a prime location, particularly where occupation allows continued use for the season (Anderson et al. 1972; Maurstad 2002; Wilson 2006; Gezelius 2007).

However, others suggest that in a competitive fishery models suggesting secrecy have a short-sighted economic view, and that long-term benefits can be achieved through cooperation with others (Palmer 1991). Engaging in information-sharing relationships with other fishers may provide an opportunity to increase individual knowledge, reducing the costs incurred through individual search for productive fishing areas, and thus increasing the efficiency of fishing. While sharing information may seem to contradict rational economic interest, it may prove to be rational in the long-term as maintaining a good reputation and building social relationships can confer social advantages that extend beyond immediate benefits. Observation of others' behaviour and sharing of information are therefore key processes, making social relationships fundamental to understanding fishers' behaviour.

Much of the work to date investigating the influence of information and decision-making on spatial behaviour has been based on modelling. Recent studies have increasingly modelled the behaviour of individual vessels, allowing heterogeneity in decision-making to be incorporated. Dorn (2001) modelled the influence of knowledge gained from individual search and fishing experience on spatial decision-making, but did not model interactions between vessels. Other studies have included the exchange of information between vessels using information on the location of other vessels to model fishers' observation of others vessels' behaviour (e.g. Little et al. 2004), or used information on fleet-wide average catch rate or revenue as a proxy for observation or information sharing (e.g. Hilborn & Ledbetter 1979; Holland & Sutinen 1999; Vignaux 1996). A study of the British Columbia salmon fleet found evidence to support the hypothesis that individual fishers moved fishing grounds in response to overall catch rate of fleet, although were constrained by costs of movement (e.g. fuel) and imperfect information concerning the opportunities available in alternative fishing grounds

(Hilborn & Ledbetter 1979). In contrast, in New England trawl fisheries a large increase in average revenue was needed before fishers responded by changing fishing grounds, perhaps because fishers were unaware of average revenue for the whole fleet (Holland & Sutinen 1999). Similarly, Vignaux (1996) modelled strategies and movements of individual vessels based on standardised catch rates and found fishers' movements responded in a rational way to their own catch rates, but did not respond to fleet-wide average catch rates on a daily timescale, suggesting fishers were unaware of mean catch rates or that they were not considered important in daily decisions. Finally, some studies have attempted to explicitly model information sharing between vessels, exploring the implications of information exchange between fishers with different strategies (Allen & McGlade 1986).

Many analyses of the social dynamics of information use draw on foraging models or game theory to look at the behaviour of individuals in situations where others are also harvesting the resource (Aswani 1998; Little & McDonald 2007). Game theory assumes individuals will pursue rational self interest and consider all options before deciding whether or not to cooperate with others. Although game theory allows precise predictions to be made, model assumptions may overlook individual preferences that confound rational behaviour, and collective aspects of action such as social norms (Gezelius 2007). A modified form of game theory has been applied where alternate strategies were based on social norms determined through ethnographic fieldwork (Gezelius 2007). In Norwegian pelagic fisheries, fishers' motivations were considered to be both economic profit and social status, as despite incentives for secrecy, fishers faced moral norms of reciprocity and norms against lying that led to a high degree of cooperation (Gezelius 2007). Wilson et al. (2007) modelled interactions leading to cooperation in a competitive fishery; individual agents developed decision rules based on biophysical conditions and encounters with others, and several persistent patterns of behaviour were found, including individual search for productive areas, and imitation of successful neighbours, which led to repeated encounters and group formation. A mixture of group and autonomous behaviour was considered advantageous to maintain a balance between shared information and exploration.

Modelling work has also found that the structure of social networks among fishers may affect resource use behaviour; for instance, random social networks in which agents were highly connected led to lower harvests as agents shared a similar view of the resource and made similar choices (Little & McDonald 2007). Where variable harvesting abilities were modelled, network type again affected performance, as skilled harvesters out-performed others in the absence of a network, and a hierarchy developed under social networks as the success of those closer to the skilled agent improved (Little & McDonald 2007).

Informal networks of information exchange are based on social relationships, which may vary in strength. Common theories are that information is shared though relationships based on kinship or reciprocal altruism (Palmer 1991; Ruttan 1998). Sharing of information among kin has been observed in fishing communities and may be independent of fishing experience or success (Acheson 1981), while in reciprocal relationships fishers share information with those whom they expect to provide equally valuable information in return (Palmer 1991). In Maine, fishers in one harbour shared information by radio along lines of kinship and reciprocity, but patterns of information exchange in another were complicated by a high degree of intertwined social relationships within a smaller community, resulting in significant economic consequences (e.g. potential loss of future information exchange) and social consequences (e.g. affecting friendships or ties that cross into aspects of life outside fishing) of secrecy or deceit (Palmer 1991). In Norway, various strengths of social networks were identified, with links closest among fishers sharing kinship or friendship bonds; both cooperation and competition were found to be greater where social bonds were strongest, and bonds were more significant in times of scarcity, when fishers shared only with their closest neighbours (Gezelius 2007).

The influence of the structure of social networks and dynamics of information sharing between individuals has implications for the information that is available to fishers, and consequently their ability to make informed decisions about the relative desirability of alternative fishing locations. Social network analysis (SNA) provides a tool to begin to examine these theories empirically by quantifying properties of networks and the position of individuals within networks. SNA has been used in a number of studies relating to resource users and fisheries management (Johnson et al. 1988; Johnson & Orbach 1990; Crona & Bodin 2006; Bodin & Crona 2008; Ramirez-Sanchez & Pinkerton 2009; Marín & Berkes 2010), but to date its potential to shed light on relationships between social networks, individual fishers' performance and fishers' spatial behaviour has been under-explored.

1.6.2 Territoriality

The social context of fishing activity can influence spatial behaviour through systems of informal property rights or territoriality among fishers. Fishers' behaviour is commonly examined in the context of fisheries as an open access resource, in which each fisher's catch may be affected by the catch of others, and a lack of private property rights makes excluding others difficult. These conditions are thought to create competition between fishers and lead to prioritisation of short-term economic gain over long-term sustainability, which ultimately may lead to depletion of the resource (Gordon 1954; Hardin 1968). This perspective has contributed to a view that without intervention, resource users will compete in a race for fish, leading to inevitable overexploitation.

Fisheries management has been historically influenced by these theories in much of the western world. Property rights are one solution commonly put forward to address this problem, as secure individual or community rights to resources can provide incentives to invest in long-term sustainability of resources by allowing resource users to exclude outsiders and reducing the uncertainty associated with competing for a resource (Ensminger & Rutten 1991; Begossi 2006; Hilborn 2007b). However, while in some circumstances areas of the marine environment may be formally owned as property, other forms of appropriation are possible. Fishers may control an area for a period of time (for example by setting fishing gear or defending an area) without legally owning it, and long-term use of an area is often seen as signifying a right to permanent occupation (Acheson 1972; Durrenberger & Palsson 1987; Wagner 2004).

The term territory is used to refer to a range of formal and informal systems, from legally recognised territorial use rights in fisheries (TURFs) (Christy 1982) to uncodified agreements at a local level such as informal allocation of fishing grounds (e.g. Woodhatch & Crean 1999). Systems of territorial use rights are common in traditional marine resource management; for example, in many Pacific Islands terrestrial boundaries are extended to areas of the marine environment where social groups have exclusive use rights (Ruddle et al. 1992). The informal and flexible nature of such arrangements means that more is known about formal than informal systems of territoriality (Acheson & Gardner 2005). The remainder of this section focuses on informal systems of territory, defined as "an area occupied more or less exclusively by an individual or group by means of repulsion through overt defence or some form of communication" (Dyson-Hudson & Smith 1978: 22).

Ideas from human ecology have been used to study the relationship between ecological characteristics and the social organisation surrounding resource exploitation. The theory of economic defendability (Dyson-Hudson & Smith 1978) relates to the abundance and predictability of resources in relation to the foraging population and degree of competition for the resource. It predicts that where resources are abundant and predictable then territoriality will be high (unless resources are so abundant that they are not limiting), whereas alternative strategies such as large home ranges or greater mobility may be more advantageous if resources are scarce or unpredictable. The theory of economic defendability sees development of territoriality as resulting from the rational choice of individuals in response to the costs (e.g. time, energy and risks involved in defence) and benefits (e.g. increased availability of resources) involved in territorial behaviour.

A commonly cited example of territoriality in fisheries is the Maine lobster fishery, where benefits of exclusive access are thought to outweigh the costs of defence (Acheson & Gardner 2005). Geographical and ecological factors such as the relatively restricted geographic range of the fishery and low target species mobility are considered to be conducive to territorial behaviour (Wilson et al.

2007). There is also some evidence that holding and defending a territory is economically rewarding, with highly defended areas in Maine found to have a lower density of fishing vessels, and a greater proportion of large lobsters and mature females than less strongly defended areas; these factors led to a greater number of large lobsters caught with less effort expended, yielding direct economic benefits to fishers (Acheson 1975).

While ecological and economic factors are important in the development of territorial behaviour, informal territories are commonly regulated by social norms and rules (Blyth et al. 2002; Wagner 2004; Acheson 2006). Acceptance into local fishing grounds is strongly regulated by social factors in Maine; new fishers often experience hostility and the biggest factor determining acceptance is willingness to abide by local rules (Acheson 1972). Similarly, in the Nova Scotia lobster fishery, variations of informal territories or "berths" control access along the coast, regulated by social norms (Wagner 2004). Those that fail to abide by norms (e.g. by violating territorial boundaries) can face sanctions leading to short-term economic losses through destruction of fishing gear and reduced cooperation from others (e.g. withholding information), and longer-term impacts as a result of social factors such as gossip, which can damage a fisher's reputation and jeopardise social relationships (Gezelius 2007). Territories are dynamic and boundaries may change; however, while many fishers explore new areas and may tentatively encroach on others' grounds, most try to avoid conflict due to its negative economic and social consequences (Anderson et al. 1972; Wagner 2004; Acheson 2006). Territoriality therefore requires individuals to overcome problems of collective action and cooperate to achieve the benefits of maintaining a territory.

The ability of groups to create rules and local institutions is important in determining whether systems of territorial behaviour arise, and requires resource users to act in a way that benefits the collective good rather than individual motivations. Much research has investigated the circumstances under which resource users will cooperate to achieve this (e.g. Acheson 1998; Agrawal 2001; Cárdenas & Ostrom 2004; Biel & Thogersen 2007). Informal agreements and cooperation norms are generally thought to be easier to achieve in small groups where resource users interact frequently and are able to monitor each other, resources are relatively sedentary, boundaries are clearly defined, and outsiders can be excluded (Ostrom et al. 1999; Dietz et al. 2003). In Maine the lobster conservation laws are thought to be "virtually self-enforcing", as fishermen do not tolerate those that break the rules; this is partly attributed to the fact that the lobster industry is organised into small groups by harbour, shares small territories, uses similar boats and fishing gear, and fishers are often longstanding members of the community who interact frequently, resulting in a greater social solidarity and increased likelihood of compliance with informally devised rules and norms (Acheson 1998; Acheson 2006). The social context of the fishery and development of social relationships are therefore important in determining a sense of social responsibility and willingness to cooperate (Hart 1998).

The existence of systems of territory can be expected to affect the distribution of fishing activity. For instance, interference competition, in which individuals or groups defend a fishing territory through practices such as trap cutting, serves to reduce the success of encroaching fishers (Wilson et al. 2007). Such practices are therefore expected to influence the predictions of the IFD by constraining fishers' movement through risk of increased costs associated with fishing in a particular area. The extent to which such behaviour is a deterrent to fishers may depend on their assessment of the risk of being caught, but may also relate to a moral commitment to a socially-accepted course of behaviour. While the existence of territoriality is affected by environmental characteristics and economic costs and benefits, it is also a system that reinforces social relationships and community spatial boundaries by linking resource exploitation to social history and identity (Anderson et al. 1972; Wagner 2004). The costs of defending a resource can therefore vary depending on the strength of common social values and beliefs, which are difficult to measure (Dyson-Hudson & Smith 1978). In this sense, rational choice theory can only go so far in explaining systems of territorial behaviour. Further understanding is needed of the social and cultural context to obtain an insight into how fishers' decision-making and spatial behaviour are influenced by informal rules and social relationships.

The presence of social relationships and cooperation in fishing communities may be conducive to improved fisheries management by building social capital. The concept of social capital is based on the idea that social relationships are a resource that individuals can use to increase their well-being (Rudd 2000). Broadly, social capital is used to refer to the norms and networks that exist within and between groups, including norms of trust, reciprocity and exchange, rules and sanctions, and connecting networks and institutional infrastructure (Rudd 2000; Pretty 2003; Grafton 2005). The presence of social capital, particularly trust, lowers the transaction costs of individuals working together (i.e. costs related to monitoring, specification of the terms of interactions, and enforcement that are required in interactions with others (Rudd 2000)). This facilitates cooperation, and high levels of social capital may be associated with greater economic and social well-being (Pretty 2003). Cooperation can also help conflict resolution, information sharing and collective action, which can contribute to improved management of common pool resources and long-term economic benefits (Grafton 2005; Ostrom 2009).

While social capital has benefits for individuals, it can only exist at a group level, highlighting the fact that communities are more than groups of individuals (Ostrom 1999; Rudd 2000; Grafton 2005). In this sense, sustainable communities are essential for sustainable fisheries as well as vice versa, as social ties, moral values and communication networks enhance capacity for collective action (Jentoft 2000). Although fishing communities are subject to the conflicts, inequalities and power struggles found in all communities, fishers in a community can be mutually dependent and supportive as well as competitive (Jentoft 2000). To date, top down management measures have been seen to depersonalise relationships between fishers, weakening social bonds and a sense of social responsibility by emphasising individual rights (Jentoft 1998; Jentoft 2000). A shift towards the more encompassing concept of governance recognises that fisheries management often requires social, political and institutional solutions as well as natural science (Degnbol et al. 2006; Jentoft 2006; Symes 2006). Governance can be defined as, "the whole body of public as well as private interactions taken to solve problems and create societal opportunities. It includes the formulation of principles guiding those interactions and care for institutions that enable them" (Kooiman & Bavinck 2005 p.17). Understanding the social context and recognising rules and norms that influence decision-making acknowledges the capacity of fishers to regulate their own behaviour and may be helpful in developing governance systems that are more inclusive of resource users.

1.7. Thesis outline and study site

As outlined in the preceding sections, complex social arrangements interact with environmental and economic factors to influence fishers' behaviour. Furthermore, fisheries management is more likely to be successful if it reflects the socio-economic as well as the biological conditions of the fishery (Cinner 2007). While ecological and economic factors are important in fishers' decision-making relating to spatial allocation of fishing effort, many approaches to understanding fishers' behaviour pay insufficient attention to social interactions, norms, relationships and behaviour (Rudd 2000). In order to fully understand fishers' spatial behaviour and decision-making an interdisciplinary approach is therefore needed that recognises the social context of fisheries. An interdisciplinary approach is defined as one which draws on a range of disciplinary perspectives, the contributions of which are integrated to give a holistic outcome to inform complex problems that cannot be solved through a single discipline (Bruce et al. 2004). This thesis takes an interdisciplinary approach in that it draws on, and attempts to integrate, qualitative and quantitative methods from both social and natural science disciplines to characterise the links between fishers' decision-making, their spatial behaviour and the social and ecological context in the inshore lobster (*Homarus gammarus*) fishery in Northumberland (UK).

1.7.1 Inshore fisheries in the UK

There is no widely accepted definition of what constitutes inshore fisheries, and the term may be used to refer to a combination of criteria including vessel size, trip length, activity patterns, fishing gear and target species (Symes 20012). In the UK the term inshore fisheries is commonly used to refer to UK territorial waters (0-12 nautical miles (nmi)), within which fishing access rights are restricted to UK vessels (0-6 nmi) and European vessels with historic rights (6-12 nmi). Inshore fisheries in this thesis refers to fishing activity within 6 nmi of the coast, where fisheries management is not complicated by historical rights of other nations' fishing fleets, and some aspects of fisheries management and enforcement are devolved to local Sea Fisheries Committees (SFCs) in England and Wales. However, it is acknowledged that many of the inshore fisheries that historically may have been restricted to this area (including European lobster potting fisheries; Symes 2001b) now extend well beyond 6 nmi, and even beyond the limit of UK territorial waters (12 nmi) (Phillipson & Symes 2001; Symes 2001b). Given high levels of competition for space and resources in inshore waters throughout the UK, management of these fisheries faces the difficulty of managing resource exploitation, conserving wider habitats and biodiversity, and optimising socio-economic benefits from resources.

With <10 m vessels comprising over 75% of the UK fishing fleet, inshore fisheries are of considerable value to the UK economy and society (MFA 2008), although estimating their contribution is difficult as national statistics do not differentiate landings within and outside of the 0-6 nmi zone (Phillipson & Symes 2001). Many inshore fishers are restricted in the distance they can travel by the nature of their vessels (typically small size and low engine power), and may rely on expert knowledge of local fishing grounds that is often passed on through several generations. Thus, while <10 m vessels account for only 9% of UK fleet capacity (MFA 2008), inshore fishing sustains many livelihoods and represents a way of life vital to the coastal economy of the UK (Jones 2009). However, in the UK there is a lack of information on the spatial distribution of inshore fishing activity, in particular for <10 m vessels (Woolmer 2009). In the light of increased emphasis on marine spatial planning, and given that spatial management measures are likely to impact primarily on the inshore sector where demand for space and resources is high, it is important that this knowledge gap is addressed. Knowledge elicited through interviews with fishers has been used where other sources of data on distribution of <10m vessel activity are lacking, however efforts are needed to assess the comparability of such data with other sources.

Inshore fisheries in the UK have historically consisted largely of shellfisheries, although increasingly this is less so as improved technology allows "inshore" vessels (e.g. prawn trawlers and potting vessels) to fish much further offshore (Symes & Phillipson 1998; Phillipson & Symes 2001). The value of shellfisheries landings in the UK, and in particular the contribution of <10m vessels, is often underestimated, yet shellfish represent a significant source of revenue and employment (Bannister 2006). It is estimated that inshore fisheries account for between a fifth to a quarter of the total value of UK shellfish landings (Phillipson & Symes 2001), and the contribution of shellfish to the total value of landings by UK vessels has risen from 31% in 1999 to 42% in 2008 (MFA 2008). Many shellfish represent high value species with market demand in mainland Europe, therefore increasing importance of shellfisheries in the UK, particularly *Nephrops* sp. but also crabs and lobsters, may be related to market drivers. However, the increasing importance of shellfisheries could be symptomatic of the decline in viability of finfish fisheries (e.g. "fishing down food webs", (Pauly et al. 1998); as such, sustaining shellfisheries could help avoid further crisis in the fishing industry. For most shellfish however, there are no explicit European or UK management plans or objectives. Shellfish management measures in the UK are often locally specific and enforced under SFC byelaws, but stocks of several species, including European Lobster (*Homarus gammarus*), are considered to be fully exploited, and the UK government is seeking improved management of key shellfish resources (Bannister 2006; Lake & Utting 2007).

Legislative developments such as the UK Marine and Coastal Access Act (2009) and EU Common Fisheries Policy review have implications for the management of inshore fisheries. The diverse habitats, biological complexity, and multiple anthropogenic uses of inshore marine areas, combined with the relative simplicity of inshore fisheries management (i.e. uncomplicated by shared access with other EU fleets within 6 nmi), has meant that designation of European MPAs to date has been concentrated in inshore areas (Jones 2009). Moreover, the often small-scale economies of inshore fisheries may be first to feel the social and economic impacts of marine resource management policies (Hall et al. 2009). For example, displacement of fishing activity may incur additional costs for small-scale fishers, and may disrupt informal social arrangements concerning use of fishing grounds by failing to take account of how fishing grounds are linked to communities (Ehler & Douvere 2007). The concern that the costs of spatial management are likely to be borne disproportionately by inshore fishers is supported by claims that spatial management is likely to have greater effect on less mobile fishers (Hilborn & Ledbetter 1979; Branch et al. 2006); these may include those confined to limited fishing grounds by the nature of their vessels (i.e. smaller, less powerful vessels), and those targeting species that are less mobile (e.g. shellfish) or have particular habitat requirements common to inshore areas. Assessing potential impacts of spatial management or conservation measures on fisheries can be difficult given the limited information available on the spatial distribution of current activity, in particular for <10 m vessels (Woolmer 2009). The significance of shellfisheries and their potential to be affected by spatial management measures means that understanding drivers of spatial distribution of fishing activity is essential.

Current research on European fisheries is neglectful of the social context, yet this is crucial for the viability of management to reverse long-term declines in catches. The history of the Common

Fisheries Policy (CFP) in Europe has contributed to a lack of legitimacy in fisheries management, as rules are not perceived to ensure a fair distribution of resources (Woodhatch & Crean 1999). Fisheries management has tended to overlook existing informal rules for resource management, yet given the problems associated with the CFP, increasing attention is warranted to local management systems that have been successful (Blyth et al. 2002). While most attention to voluntary agreements is focused on those that are verbalised or codified (written or formalised), it is also important to investigate informal and uncodified rules and norms that regulate fishing practices, as spatial management measures may disrupt customary arrangements based on such rules (Jones 2008).

1.7.2 Northumberland lobster (*Homarus gammarus*) fishery

With landings of 204 tonnes of lobsters in 2008 valued at an estimated £2.9 million (MFA data), lobster fishing in the NSFC district forms the most economically valuable part of the catch for the 132 permit holders (NSFC data, 2008), and is of increasing value to the local industry (Bannister 2006). The NSFC is working to improve the basis for managing local lobster stocks, however information on the spatial distribution of inshore fishing effort is lacking and there remains a need to understand how fishing effort is distributed by the fleet.

The NSFC district comprises the area from the River Tyne to the northern boundary of Northumberland, and out to 6 nmi from the coast (Fig. 1.1). Several fisheries are targeted in the district by a variety of fishing gears (including trawling, potting, netting and some dredging) (NSFC 2008). The pot fishery targets four main species: European lobster (*Homarus gammarus*), brown crab (*Cancer pagurus*), velvet swimming crab (*Necora puber*) and prawns (*Nephrops norvegicus*), with a number of vessels also using other fishing gears (e.g. t-nets for salmon, handlines for mackerel, or trawling gear for prawns and white fish) at certain times of year. A variety of pots (or creels) are deployed in the district with variable entry design, dimensions and mesh sizes, and many fishers use more than one type of pot (Garside et al. 2003). The majority of pots worked are multi-purpose, and are deployed on different ground types at different times of year to target particular species. Some pot types exclude certain species (e.g. some hard-eyed pots do not allow entry of mature crabs, and prawn creels preclude entry of large lobsters), but most can be used to catch lobster if deployed in appropriate locations with suitable bait. While landings of lobster are lower in volume that those of brown crab, lobster is the most economically valuable target species in the NSFC potting fishery, fetching prices at over £10 per kilo, compared to under £3 per kilo for brown crab (Bannister 2006).

Potting vessels in the district are between 4m and 12m in length, ranging from traditional cobles to keels, fast workers and catamarans. Individual vessels work up to 1200 lobster and crab pots, although a recent byelaw means pots in excess of 800 must be deployed outside the NSFC district. The majority of vessels work within the 12 nmi limit, although a small number of faster, more modern vessels work beyond this. Crab and lobster potting is to some extent geographically restricted by the available habitat for target species and potential conflict with other gear types such as trawlers. A number of potting vessels operate pots seasonally or part time, with some skippers also using other fishing gear or employed in other occupations.

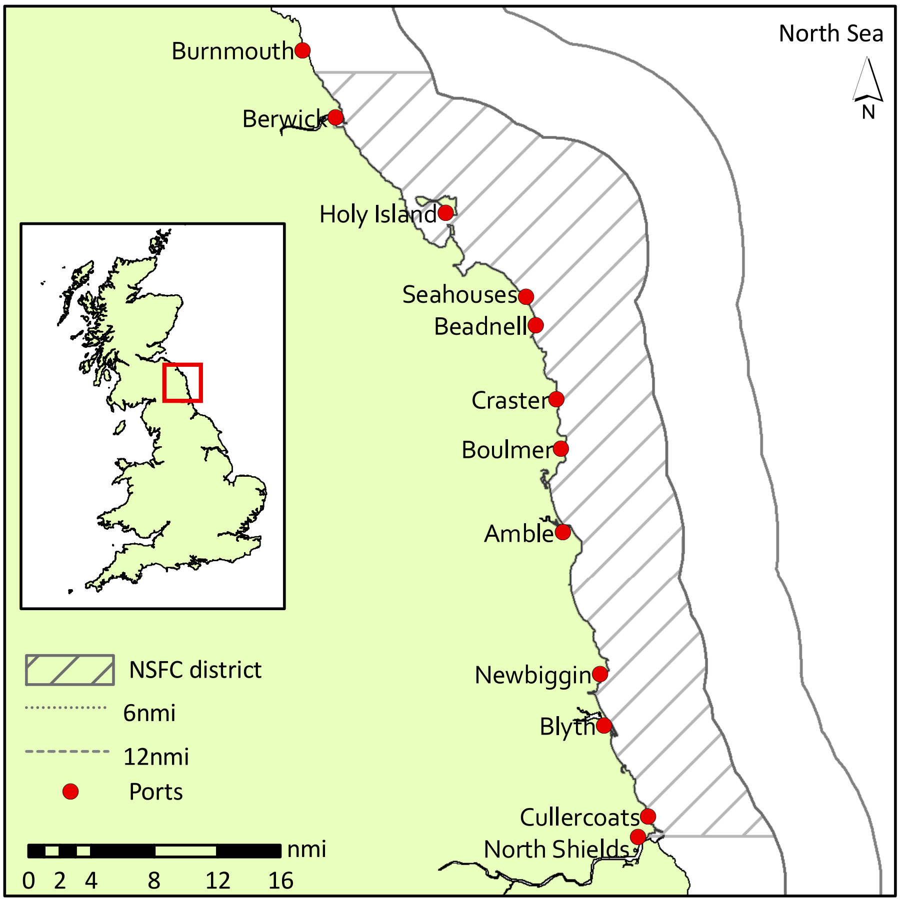

Figure 1.1. Map of the Northumberland SFC district and local shellfish ports

All vessels fishing commercially for shellfish within the district must hold a permit from the NSFC, and a national shellfish entitlement on a fishing licence is a prerequisite for a permit application. Vessels and hobby fishers without a permit are restricted to fishing 5 pots, with a maximum landing of 1 lobster and 5 crabs per day. Recent indications from the issuing of pot tags to recreational fishers suggest that just under 200 recreational fishers are working up to 5 pots each within the district (NSFC *pers. comm*. 2009). Other regulations applying to NSFC permit holders include an EU-set minimum landing size (MLS) of 87 mm carapace length (CL), a ban on landing soft or V-notched lobsters (the tail sections of 1,000 egg-bearing lobsters per year are notched by NSFC as a conservation measure aiming to protect breeding population), and a pot limitation (Table 1).

Table 1.1. Regulations applying to the Northumberland lobster fishery

Management measure	Legislation
Minimum landings size (87 mm carapace length)	SI 2000 NO. 1503 (The Undersized Lobster Order 2000)
Protection of "V" notched lobsters	NSFC Byelaw 6
Protection of soft shelled lobster	NSFC Byelaw 7
Prohibition on landing parts of shellfish	NSFC Byelaw 8
Redepositing of prohibited shellfish	NSFC Byelaw 10
Permit to fish for and sell lobsters and other shellfish	NSFC Byelaw 13
Pot limitation (800 permit holders, 5 non-permit holders)	NSFC Byelaw 15

While a typical <10m vessel would historically have been engaged in a number of fisheries throughout the year (e.g. crab and lobster March-October, salmon May-August and netting or lining for white fish over winter), there is an increasing tendency for specialisation in potting all year round (Phillipson & Symes 2001). Although lobster fishing has traditionally been a seasonal activity, increases in efficiency of both vessels and gear (e.g. steel pots rather than wooden) have enabled fishers to work further offshore and in less favourable weather conditions. There is anecdotal evidence that quantities of fishing gear worked by potting vessels have increased with the availability of improved hauling technology and increasing use of larger, faster vessels. Recent years have seen a decline in local trawl fleets and anecdotal evidence also suggests that former trawlers are increasingly turning to potting, which is less stringently regulated than trawling and perceived to offer a more stable livelihood. In recent years several skippers in the district have decommissioned trawling vessels and bought specialised potting vessels (NSFC, *pers. comm*. 2008).

In comparison to other commercial fisheries (particularly finfish but also prawns (*Nephrops norvegicus*)), there is limited management in place for UK lobster fisheries, but there is a demand for increased knowledge that can be applied to improving management of the fishery (Northumberland Sea Fisheries Committee, *pers. comm*. 2008). Given the current lack of spatial restrictions on static gear fisheries within the district, the NSFC district represents a useful case study to assess the value of different data sources in providing information on the distribution of fishing activity. The ecological characteristics such as the restricted range of the fishery and relatively low target species mobility are considered to be conducive to territorial behaviour among fishers (Wilson et al. 2007), providing an opportunity to explore differences in fishers' motivations and decision-making that underpin their spatial behaviour. In addition, information on resource distribution may be key to fishing success, and in fisheries targeting species with low mobility, knowledge of productive areas is valuable for longer (Palmer 1991; Acheson 1981). The relatively sedentary nature of European lobster is expected to lead to information having a high value to resource users, providing an ideal context in which to investigate information-sharing behaviour among fishers.

1.7.3 Thesis structure

This thesis empirically investigates the social and ecological drivers of fishers' decision-making and behaviour in the inshore lobster fishery in Northumberland using a number of primary and secondary data sources (Fig. 1.2). Current gaps in the literature are addressed through the following objectives:

1) To develop a methodology to compare different existing sources of data on the distribution of inshore potting activity in the NSFC district;
2) To investigate sources of variability in lobster landings in relation to fishing effort and environmental variables, and in relation to both shellfish ports and individual vessels;
3) To explore fishers' perceptions of the factors motivating their spatial behaviour, and the factors influencing territorial behaviour;
4) To investigate the relationships between information sharing among fishers, spatial behaviour, and fishing success.

The rationale for each chapter and links between chapters are summarised below.

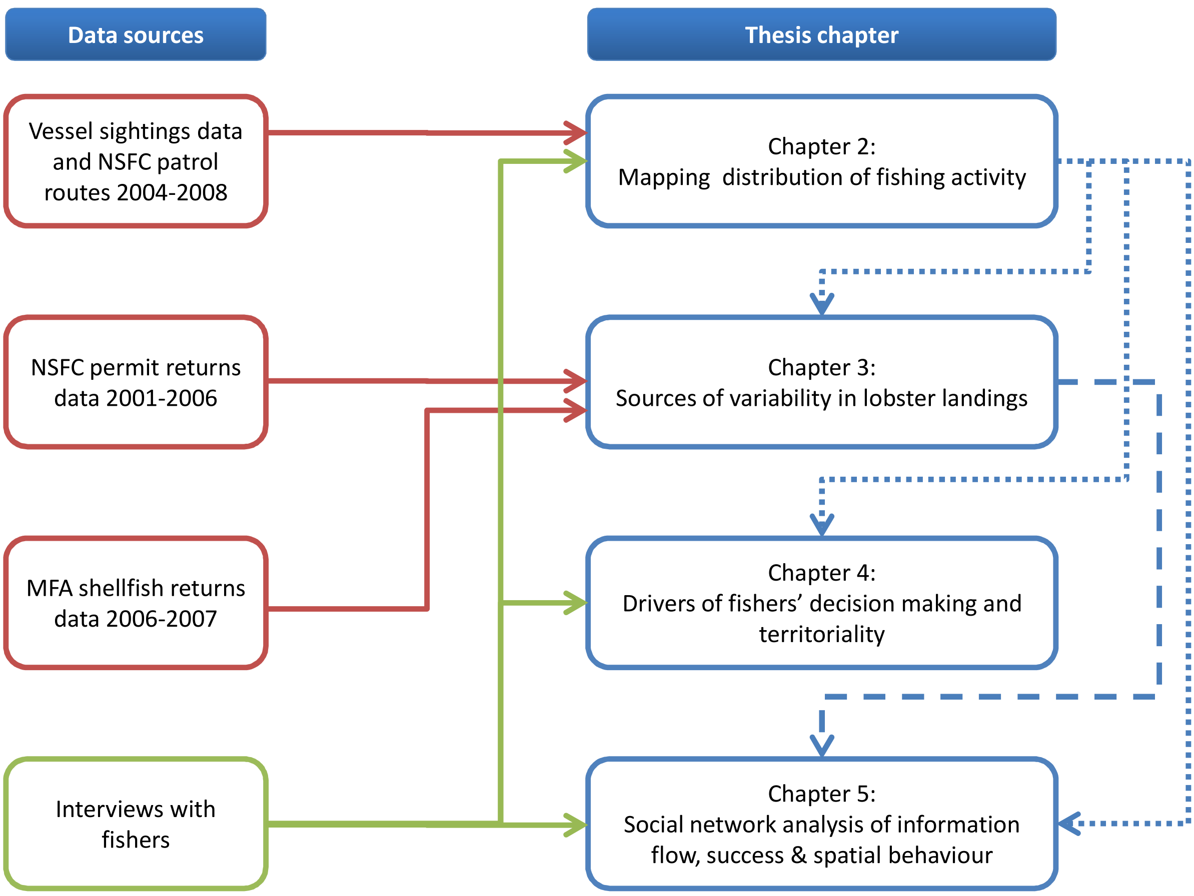

Figure 1.2. Summary of primary (green) and secondary (red) data sources used in this thesis, and the chapters in which they are used (blue). Solid lines represent initial analysis of data sources in relevant chapters. Additional lines (blue) represent outputs of Chapters 2 (dotted) and 3 (dashed) which feed into analysis in Chapters 4 and 5.

Chapter 2

Information on the distribution of UK inshore fisheries activity is scarce, but arguably is critical to the success of future MSP and fisheries management, particularly in light of UK commitments to create a network of MPAs by 2012. Chapter 2 develops a methodology using geographic information systems (GIS) to quantitatively compare the spatial coincidence of fishing effort distribution based on two different data sources: vessel sightings data collected by NSFC and information elicited through face-to-face interviews with local fishers. The comparability of the data sources is assessed with respect to the underlying distribution of fishing activity, the sampling intensity of interview data, and the spatial scale of data analysis. While the principal objective of this chapter is methodological, the outputs are employed in analysis in subsequent data chapters.

Chapter 3

Variability in catch rates across fishing grounds can influence the decision-making of fishers and be altered by responses in fishers' spatial behaviour. Spatial variability in lobster landings and inferred catch rates among fishing ports are explored in Chapter 3 using linear mixed effects models. Monthly returns from shellfishers in Northumberland are examined to investigate effects of measures of fishing effort, seasonality and environmental conditions on lobster landings. In particular the analysis considers whether spatial differences in landings were evident among ports during 2001-2007. The factors that may cause spatial differences are explored, and the relative magnitude of variability in landings among Northumberland ports is compared to that among individual vessels.

Chapter 4

Based on quantitative and qualitative data collected through interviews with fishers, Chapter 4 begins to investigate how the social context influences fishers' decision-making and behaviour. Quantitative data on fishers' perceptions of the importance of factors driving spatial decision-making are analysed. Qualitative data on fishers perceptions of rights of access to and ownership of resources are discussed in relation to the social, economic and ecological drivers that may influence the development of territoriality, and the findings are examined in light of theories of economic defendability and collective action.

Chapter 5

Social network analysis is applied in Chapter 5, using data from interviews with fishers in four Northumberland ports to investigate information-sharing behaviour using quantitative and qualitative analysis. The structure of fishers' communication networks is compared among ports, and relationships between social and spatial networks, and between fishers' network positions and their fishing success are tested. The implications of information-sharing behaviour for both individual fishers and wider resource management are explored in relation to the findings.

Chapter 6

Chapter 6 draws together the inter-related factors driving fishers' decision-making and underpinning their spatial behaviour identified in Chapters 2-5. The implications of the findings for individual fishers, fisheries management, and broader spatial management of the marine environment are discussed. Specific implications of the findings are outlined in the context of the NSFC case study. While a local case study approach is adopted, this chapter also highlights the generic lessons of the research with a view to informing fisheries policy development at a broader scale.

Chapter 2.

Comparing fishers' knowledge and vessel sightings data to assess the distribution of inshore potting activity in the Northumberland lobster fishery

Abstract

Information on the distribution of UK inshore fisheries activity is scarce, but is critical to the success of future marine spatial planning (MSP) and fisheries management. A methodology is developed in this chapter using geographic information systems (GIS) to quantitatively compare the spatial coincidence of fishing effort distribution based on two data sources on the distribution of potting activity at four ports in the Northumberland lobster (*Homarus gammarus*) fishery: vessel sightings data (2004-2008) and information elicited through interviews with local fishers (2009). The comparability of the data sources is assessed with respect to the underlying distribution of fishing activity, the sampling intensity of interview data, and the spatial scale of data analysis. There was a statistically significant positive correlation between spatial patterns of fishing activity indicated by the two datasets, with greater correlation strength identified at ports where fishing activity showed a higher degree of spatial aggregation. Analysis of the same data at different spatial scales (1x1,2x2 and 3x3 km grids) showed that the correlation between the datasets was also stronger at broader spatial scales. Both correlation strength and area of fishing grounds mapped increased with greater sampling intensity in interview data. Vessel sightings data may better reflect the variable intensity of fishing activity over fishing grounds, while interview data may give a better indication of both the absolute extent of fishing grounds and contextual information on temporal variability and drivers of behaviour. It is therefore recommended that both data sources are used to inform designation of spatial management measures, and that triangulation with additional data and validation with resource users are undertaken to support integration of different datasets.

2.1 Introduction

Traditionally, fisheries management has focused on managing stocks at the level of whole target species populations or over areas defined by political boundaries (Wilen 2004). Improved understanding of ecological processes and technological ability to detect and monitor patchy species distributions has led to a tendency towards more spatially explicit management measures (Wilen 2004). For instance, spatial closures to particular fishing activities may be implemented to protect spawning grounds or nursery areas of commercially important species. At the same time, there has been increasing recognition of the importance of fishers' spatial behaviour in understanding fishery dynamics. Monitoring the distribution of fishing effort may be vital to interpret trends in catch per unit effort (CPUE), since vessels' search for target species means that the spatial distribution of fishing activity may be related to patterns of resource abundance (Vignaux 1996; Salthaug & Aanes 2003). Furthermore, the success of spatial management measures may depend on taking into account fishers' behaviour in response to such measures, since the degree of compliance and patterns of effort re-allocation may have implications for achieving the objectives of spatial management measures (Wilen et al. 2002). Consequently, there is a demand for data on the spatial distribution of fishing activity to inform fisheries management.

Information on the distribution of fishing activity is also needed to inform broader management of marine resource use and conservation planning. There is increasing emphasis on spatial management of the marine environment as part of an ecosystem-based approach to management of marine resources (Botsford et al. 1997; Hughes et al. 2005). In the UK, commitments under the Convention on the Protection of the Marine Environment in the North East Atlantic (OSPAR) to develop a network of marine protected areas (MPAs)[3] by 2012 will be met in part by the designation of new MCZs[4] (DEFRA 2010), which as a tool for the conservation of marine species and habitats, forms one component of marine spatial planning (MSP)[5]. The designation of MCZs will require spatial information on the distribution of different activities at sea. Data on the distribution of fishing activity are needed to identify areas of economic importance to the fishing industry as well as sites of potential impacts from fishing activities. Such data can aid in assessing the potential impacts

[3] Defined by IUCN as, "Any area of intertidal or sub-tidal terrain, together with its overlying water and associated flora, fauna, historical and cultural features, which has been reserved by law or other effective means to protect part or all of the enclosed environment" (Kelleher 1999).

[4] MCZs are a type of MPA created under the UK Marine and Coastal Access Act (2009) to protect nationally important marine wildlife, habitats, geology and geomorphology under varying protection levels (JNCC 2010).

[5] Defined as, "A process of analyzing and allocating parts of three-dimensional marine spaces to specific uses, to achieve ecological, economic, and social objectives that are usually specified through the political process; the MSP process usually results in a comprehensive plan or vision for a marine region" (Ehler & Douvere 2007)

of MSP and MCZs on fisheries, including possible loss of income for fishers or displacement of fishing effort due to spatial closures (Richardson et al. 2006; Valcic 2009).

A variety of methods have been used to map the spatial distribution of fishing activity (summarised in Woolmer 2009). These include reporting schemes relying on information submitted by fishers in the form of logbooks, active data collection by enforcement agencies, and passive data collection through the transmission of satellite data from vessel monitoring systems (VMS). Analysis of spatial patterns in temperate European fisheries has made extensive use of information from European Community (EC) logbooks (and associated observer data), in which fishing activity is reported by individual vessels on the basis of 30 x 30 nautical mile (nmi) ICES statistical rectangles (Rijnsdorp et al. 1998; Jennings et al. 1999; Hutton et al. 2004; Anderson & Christensen 2006; Greenstreet et al. 2009). These data allow for analysis of spatial information alongside information on fishing effort and landings, but without supplementary information (e.g. positions of individual trawls) are restricted to use for broad-scale analysis due to the low spatial resolution of the data, and may be subject to bias as a result of mis-reporting by fishers (Witt & Godley 2007).

Active recording of vessel sightings data by enforcement agencies (e.g. overflight data collected by the Marine and Fisheries Agency (MFA), and vessel sightings recorded by Royal Navy and Sea Fisheries Committee (SFC) sea-based patrol vessels) is carried out on an opportunistic basis during routine enforcement patrols, often resulting in limited spatial or temporal coverage (Witt & Godley 2007). The development of automated recording of vessel positions has enabled finer scale analysis of fishing effort distribution through the passive collection of large volumes of data on fishing vessel location (Rijnsdorp et al. 1998). Since 2005, fishing vessels of 15 m or more in length in the EU have been required to carry VMS, which transmit data on vessel positions, speeds and bearings at regular intervals. While this requirement was driven by the need for fishery regulation enforcement, the data have also been used to analyse spatial distribution of fishing activity, by inferring the activity of vessels using rules based on speed of travel (Hutton et al. 2004; Deng et al. 2005; Mills et al. 2006; Harrington et al. 2007; Witt & Godley 2007). However, the requirement for only larger vessels to carry this technology means that VMS cannot provide data on all fishing fleets, particularly the <12m vessels operating in inshore areas (within 6 nmi) that are the focus of this thesis, which have historically have been subject to less consistent data reporting schemes than larger vessels (Jennings et al. 1999).

Recent UK initiatives to increase data collection on the spatial distribution of inshore fleets' activities have attempted to standardise collection of vessel sightings data by Sea Fisheries Committees (SFCs), which are responsible for aspects of inshore fisheries management and enforcement in England and Wales (Eastwood 2006). These initiatives aim to build up more comprehensive coverage of inshore fishing grounds which can be analysed in combination with data from shellfish activity returns to the MFA (Clark 2008; Woolmer 2009; Turner et al. 2009). Collection of sightings data relies on active data collection by patrol vessels (e.g. SFC or Royal Navy), therefore limited resources and patrol vessel activity mean that the temporal resolution of the data remains less comprehensive and more opportunistic than continuous passive collection of VMS data. Furthermore, both spatial and temporal bias may result from patterns of patrol activity, which are driven by local enforcement needs. Nevertheless, these data currently represent the most extensive source of formal data on the distribution of <10 m vessels.

The lack of fine-scale data on the distribution of inshore activities has led to increasing use of interviews with fishers to elicit spatial data needed to inform management decisions (Scholz 2004; Ardron et al. 2005; Des Clers et al. 2008). This development acknowledges the role of local knowledge and expertise to corroborate or supplement scientific knowledge (Schneider et al. 1999; Bergmann et al. 2004; Brown 2004; Stead et al. 2006). Furthermore, involvement of fishers in this way has potential to demonstrate the value of fishers' contextual knowledge for decision-making. Interaction between fishers and scientists can encourage the engagement of fishers in the planning processes by improving relationships between resource users, scientists and managers, leading to increased legitimacy of decision-making and incorporating local values into scientific assessment (Neis et al. 1999; Johannes et al. 2000; Scholz et al. 2004; Scholz et al. 2006; Hall & Close 2007; Hall et al. 2009).

Despite these positive aspects, several limitations of interview data have been recognised. Firstly, the collection of interview data relies on the willingness of fishers to take part, and organisation of times and locations to minimise costs to participants. Reticence to agree to interviews may be linked to a broader distrust of scientists (particularly where research may be used to inform controversial management measures such as MCZs) and establishing good relations with fishing communities can be a time consuming process (Maurstad 2002; Woolmer 2009). Consultation fatigue among fishermen may also be a problem when there is heavy reliance on interview data. The time-consuming and voluntary nature of the process means that obtaining large sample sizes is often difficult. Interviewees may be reluctant to reveal preferred fishing grounds, as the value of this knowledge to fishers is greatest when kept secret from competitors (Maurstad 2002; Scholz 2004; St. Martin & Hall-Arber 2008). Furthermore, where fishers are willing to share such information, the ability of individuals to accurately recall and chart their knowledge may be variable. Finally, there are practical challenges entailed in the collection and analysis of such data, including methods of representation on charts (e.g. point, lines or polygons), methods of attributing value (e.g. fishing effort or economic value) to the mapped data, and methods of representing uncertainty and variability.

Geographic information systems (GIS) provide a means to combine and present different layers of spatial information in a common format, as well as preserving links to contextual information (Caddy & Carocci 1999; Aswani & Hamilton 2004; Scholz et al. 2004; Aswani & Lauer 2006; Hall & Close 2007; Lauer & Aswani 2008; De Freitas & Tagliani 2009; Hall et al. 2009). In combination with interviews, GIS enables social dimensions of marine resource use (e.g. relating fishing grounds to particular fishing communities) to be incorporated into spatial analysis, recognising that local knowledge relates to social relations and communities as well as to the natural environment (St. Martin & Hall-Arber 2008; Hall et al. 2009) .

While local knowledge and interview data are generally not subject to scientific peer review, they can be triangulated through comparison with other data sources (Scholz et al. 2004). Work is increasingly undertaken on the development of methods to integrate local and scientific knowledge into policy making and management (e.g. Hall et al. 2009). The recognition that different types of knowledge have varying values and limitations makes it difficult to measure one directly against another. As a result there is instead a focus on assessing the mutual consistency of local knowledge and scientific data (Brown et al. 2004; Alessa et al. 2008; Rochet et al. 2008; Ban et al. 2009; Hall et al. 2009). In cases where interview data are focused on mapping areas of perceived value or importance to stakeholders, scientific and resource user opinions may be expected to differ as a result of different values attributed to the marine environment by scientists and resource users, thus the combined use of both datasets adds valuable information. Furthermore, it allows those from different backgrounds to visualise areas of value or importance from others' perspectives. Where more than one dataset is available, combining multiple sources of information may provide opportunities for cross-referencing and allow greater confidence in data. However, map-based interviews are commonly used to provide spatial information in situations where fine scale scientific data is unavailable (Des Clers et al. 2008). Consequently it is often not possible to compare the outputs produced from two data types at the same scale, yet it is important to assess the comparability of the patterns observed by different data sources. The need for such triangulation has been recognised (Scholz et al. 2004), but limited work has been undertaken in this area so far (Woolmer 2009). Important questions remain relating to the implications of the underlying distribution of fishing activity, sampling methods, and spatial scale of analysis when comparing data sources.

The goal of this chapter is to compare two sources of spatial information on inshore fisheries, from SFC patrol vessel sightings and map-based interviews with local fishers. These datasets are illustrative of those currently available to inform fisheries management and marine conservation planning in the UK. This study focuses on four major shellfish ports (Blyth, Amble, Seahouses and Holy Island) within the Northumberland SFC (NSFC) district (comprising the area north from the River Tyne to the northern boundary of Northumberland, and out to 6 nautical miles from the coast) in north east England. Specifically, the focus is on the potting fishery in this area, which targets predominantly European lobster (*Homarus gammarus*), brown crab (*Cancer pagurus*), velvet swimming crab (*Necora puber*) and prawns (*Nephrops norvegicus*). Potting vessels in the district are 4-12 m in length and the majority of vessels work within the 12 nmi limit, highlighting the importance of smaller vessels in inshore fishing fleets to this region. The Northumberland coast is home to a wide range of ecologically important habitats (Bennett & Foster-Smith 1998), and forms part of the area currently considered by a regional project (Net Gain[6]) working towards the designation of an MCZ network for conservation of marine habitats and species in the UK. Given the current lack of spatial restrictions on static gear fisheries within the district, the NSFC district represents a useful case study to assess the value of different data sources in providing information on the distribution of fishing activity. Specifically, the questions addressed in this chapter are:

1. Is there a relationship between observations (vessels sightings) and perceptions (interview data) of the spatial distribution of potting activity?
2. What effect does the level of aggregation or dispersion of observed and perceived fishing activity have when comparing the two datasets?
3. What effect does spatial scale have when comparing the datasets, and what level of spatial resolution is possible while maintaining a relationship between the two datasets?
4. What effect does interview sampling intensity (i.e. proportion of fishers interviewed) have on the level of agreement between observations and perceptions data?
5. How does any agreement between the two datasets vary at the level of individual fishers and over time?

[6] www.netgainmcz.org

2.2 Methods

The methods used to map fishing activity involved integrating and comparing data on observed fishing vessel sightings recorded by NSFC fishery officers on routine patrols, and perceived use of the marine environment elicited through face-to-face interviews with local fishers. This approach builds on work undertaken by others who have explored methods to map fishing activity (e.g. Scholz 2004; Eastwood 2006; Hall & Close 2007; Clark 2008; Des Clers et al. 2008; St. Martin & Hall-Arber 2008) and to integrate spatial information drawn from scientific knowledge and resource users' local knowledge or values (Alessa et al. 2008; Ban et al. 2009; Hall et al. 2009; Woolmer 2009).

2.2.1 Observed fishing activity

The NSFC collects data on fishing vessel sightings during routine enforcement patrols. Since 2004, recorded sightings have included the name, registration and home port of fishing vessels, their geographic position and observed activity (although no distinction is made between potting vessels actively fishing or steaming). Vessel sightings are recorded when they are first observed, their position recorded using geographic positioning system (GPS) or plotter equipment onboard the patrol vessel, and their activity determined through observation from a distance or from boarding of the vessel.

Vessel sightings recorded during 2004-2008 (Table 2.1, e.g. Fig. 2.1a) were verified by cross-referencing with Marine and Fisheries Agency (MFA) fishing vessel lists (MFA 2004-7), NSFC permit databases and communication with NSFC Fishery Officers to identify inconsistencies in vessel details, ports or fishing activities. Sightings of crab and lobster potting activity (recorded as one activity; prawn potting is recorded separately) were extracted for the ports studied (n = 1982, 58% of all sightings of lobster and crab potting) and mapped using ArcView GIS version 9.2 (ESRI 2006). As prawn potting is carried out by a minority of potters and utilises habitat types different from crab and lobster potting, spatial data on this activity was excluded. Collection of data is limited to the NSFC district, and points outside NSFC boundaries were removed.

Table 2.2. Sightings data and patrol route information 2004-2007, obtained from NSFC

Year	Vessel sightings by port					NSFC Patrols	Patrol routes available (%)
	Blyth	Amble	Seahouses	Holy Island	Total		
2004	119	201	230	46	596	104	90 (87)
2005	120	167	144	33	464	99	47 (47)
2006	137	167	113	21	438	86	0 (0)
2007	106	94	65	9	274	85	49 (58)
2008	109	73	28	0	210	75	56 (75)
Total	591	702	580	109	1982	449	242 (54)

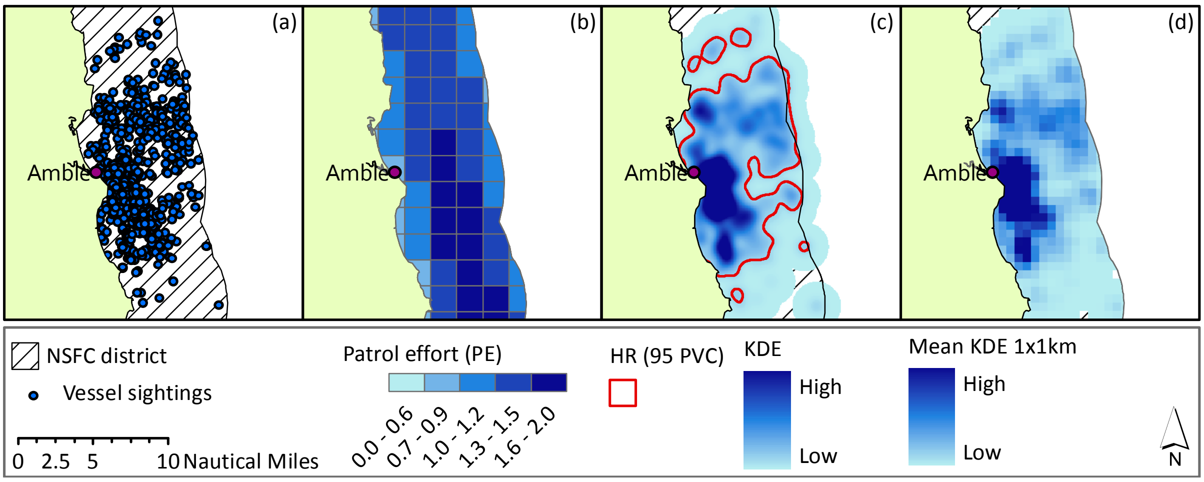

Figure 2.3. Illustration of vessel sightings data processing and analysis: a) point data representing individual sightings, b) 3 x 3 nmi grid cells weighted by patrol effort, c) example of port kernel density estimate (KDE) with 95 percent volume contour (PVC) d) zonal statistics (1 x 1 km grid)

Recorded sightings of fishing activity may be influenced by the timing and routes of patrols, and may be biased by seasonal patterns in patrol activity, which is driven by enforcement priorities. During summer, patrols are focused largely inshore when potting activity is high, while in winter there is more extensive coverage of grounds towards the 6 nmi line in the south of the district where trawlers commonly operate (NSFC *pers. comm*., 2008). A substantial bias in patrol effort was evident towards the south of the district due to the location of the NSFC patrol vessel mooring in the Tyne. Patrol route information for 54% of patrol routes during 2004-2008 (n = 242) was obtained from the NSFC vessel and geo-referenced using GIS. The quantity of information available differed between years (Table 2.1), but no change in pattern over time was apparent from visual inspection of the patrol routes. The information was therefore considered to be representative of patrol effort distribution during the study period, and patrol effort data from all years were pooled.

A 3 nmi^2 grid was superimposed on the NSFC district (Clark 2008), assuming that visibility would be sufficient for any fishing vessel within the same grid square to be seen by the patrol vessel. Patrol effort (PE) was estimated using a combination of the number of patrols passing through each grid cell, and the distance of each grid cell to the nearest mapped patrol route (Equation 2.1, Fig. 2.2). Vessel sightings in grid squares containing no patrol routes implied a degree of patrol effort in these areas unaccounted for by patrols passing through the cell. It was therefore assumed that patrol effort decreases linearly with distance from patrol routes.

$$PE = \left(1 - \frac{n}{N}\right) + \left(1 - \frac{D_{max} - D_g}{D_{max} - D_{min}}\right)$$

Equation 2.1. Calculation of patrol effort (PE) weighting. The first part of the equation is based on proportion of patrols passing through each grid cell, where n = number of patrols passing through a grid cell and N = total number of patrols. The second part is based on a linear distance decay function in which the inverse Euclidean distance of each cell to patrol points is normalised as a proportion of the maximum possible distance; D_{max} = maximum distance to patrol route, D_g = grid square distance from patrol route, and D_{min} = minimum distance to patrol route.

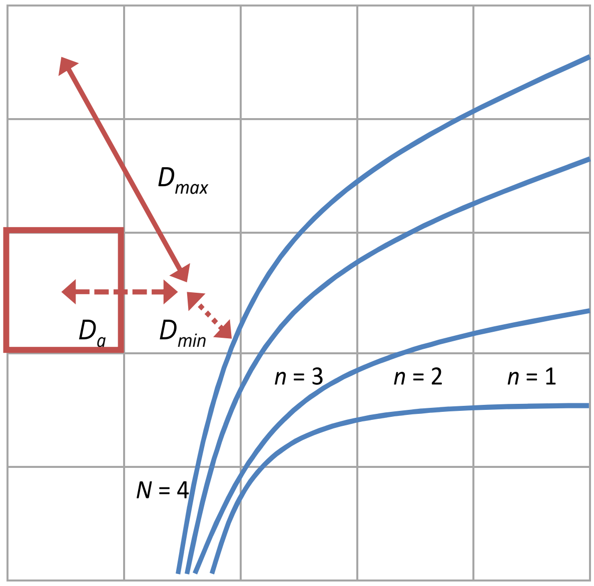

Figure 2.4. Example of parameters used in calculation of patrol effort (Equation 2.1) for grid cell outlined in red. Blue lines represent patrol routes (*N* = 4; *n* = 1-3 illustrated). Red lines represent distances between grid cells and grid cells containing patrol routes.

The combined measure of patrol effort was used to weight sightings in each grid square, negatively weighting those in areas of high patrol effort and positively weighting those in areas of low patrol effort (Fig. 2.1b).

Transforming point data to a continuous surface provides more information on the relative intensity of fishing activity in different areas (De Freitas & Tagliani 2009). In producing a continuous surface, density methods such as kernel density estimation (KDE) have been identified as more suitable than either raw point data, or interpolation methods in instances where continuous spatial coverage of a variable cannot be assumed (Alessa et al. 2008). The probability distribution of fishing activity was therefore assessed from the sample of weighted vessel locations using a fixed KDE tool in Hawth's Tools (Beyer 2004) to produce a raster image of cell size 100 m x 100 m from which zonal statistics (e.g. mean values for 1 x 1 km cells) were derived (Fig. 1c-d). The smoothing factor for the KDE is important, as it determines the area around a given location within which data points contribute to the probability estimate for that point (Bailey & Gatrell 1995). A range of smoothing factors was tested and resulting maps discussed with local fishers and NSFC Fishery Officers. A smoothing factor of 1000 m (approximately 0.5 nmi) was perceived to give the most accurate representation of fishing activity.

Due to the limited number of vessel sightings per port per year (Table 2.1), owing partly to the small number of vessels operating from some ports, sightings over the period 2004-2008 were pooled to enable analysis at port level. Pooling data from several years assumes no change over time in the distribution of activity. This assumption was tested prior to pooling data by comparing the distribution of sightings during each year across a 3 nmi^2 grid. Autocorrelation in spatial data can confound the assumption of parametric statistical tests that data points are independent of one another. Observed fishing activity distributions among years were therefore compared using the Mantel test, a correlation between two distance matrices summarising pairwise similarities among grid cells (Goslee & Urban 2007). The hypothesis of the test is that the degree of similarity in one matrix corresponds to degree of similarity in the other. Where standardised values are used, values of the Mantel statistic (called r_M) fall between -1 and +1, and behave like a correlation coefficient (Legendre & Legendre 1998). The significance of the Mantel statistic is determined by a permutation test that produces a reference distribution of r_M values obtained under H_o, against which the obtained value of r_M is compared (Legendre & Legendre 1998). Distance matrices were calculated using Euclidean distances for each year on the basis of vessel sightings per grid cell. Mantel tests were performed using the Vegan library in the statistical package R, version 2.10 (Oksanen et al. 2009; R Development Core Team 2009). Significant correlations between distance matrices were found between distribution of vessel sightings between all years ($r_{M\,=}$ 0.590 – 0.766, significance ≤ 0.001), suggesting similar inter-annual spatial patterns of observed fishing activity. This assumption was tested further through comparison of the datasets on the basis of individual fishers over time (as described in section 2.3.4).

Percent volume contours (PVCs), which delineate contours containing a specific proportion of the probability density distribution, were used to estimate the home range of each port. Home range is defined in this context as the smallest area accounting for a specified proportion of the distribution of vessel activity from each port (following Van Winkle 1975). To minimise the influence of possible positional errors or vessel mis-identification in outlying data points, the 95 PVC (delineating the area in which 95% of vessel sightings are expected to occur based on the sample data) was calculated for each port using Hawth's Tools (Beyer 2004), and used as an estimate of the port home range. All polygons produced were clipped to the extent of the NSFC district (Fig. 2.1c).

2.2.2 Perceived fishing activity

Interviews were conducted between March and September 2009 with 41 fishers (95% of active fishers) at 4 ports (Table 2.2). The target population comprised skippers of registered fishing vessels holding NSFC shellfish permits, who were considered by NSFC fishery officers to be actively targeting shellfish (potting within the last 12 months). Lists of active fishing vessels were corroborated by cross-checking fishing vessel lists obtained from NSFC with interviewees at each port. Due to the small number of fishers at each port (Table 2.2) an attempt was made to interview all those identified. Initial contact with a number of fishers was made through introductions by NSFC officers. Subsequent interviewees were contacted via snowballing methods (i.e. interviewees provided contact details or introductions to others), or by approaching fishers on the quayside. While the initial method of sampling may lead to bias in interviewee characteristics in a small sample, over 90% of active fishers were interviewed in each port (Table 2.2), and are therefore considered to be representative of the target fishing communities. All fishers approached agreed in principle to interviews; however one interview was cut short due to ill health, and despite several attempts it was not possible to arrange a convenient time to interview two further fishers. Interviews were carried out at times and places convenient to fishers, and the purpose of data collection and intended use of data were discussed before each interview.

Table 3.2. Interviewee characteristics (percentages given as percentage of respondents who replied)

	Port			
Port characteristics	Blyth	Amble	Seahouses	Holy Island
Active potting vessels	11	17	9	6
% interviewed (n)	91 (10)	94 (16)*	100 (9)	100 (6)
Mean age (SE)	47 (3)	52 (3)	42 (4)	56 (5)
Mean years experience fishing (SE)	23 (3)	29 (4)	25 (3)	40 (5)
Mean years experience potting (SE)	19 (4)	18 (3)	19 (3)	32 (6)
Mean vessel length (m) (SE)	9.0 (0.56)	7.8 (0.47)	9.9 (0.35)	8.5 (0.51)
Mean engine size (kW) (SE)	106 (28)	56 (11)	187 (43)	119 (39)
Mean number lobster pots (SE)	410 (60)	388 (55)	636 (74)	575 (101)
Mean total pots (inc. prawn) (SE)	540 (112)	458 (67)	813 (166)	575 (101)
% using other gear (n)	40 (4)	56 (9)	33 (3)	0 (0)
% targeting lobster (n)	100 (10)	100 (16)	100 (9)	100 (6)
% targeting brown crab (n)	90 (9)	82 (14)	100 (9)	100 (6)
% targeting velvet crab (n)	70 (7)	82 (14)	100 (7)	100 (6)
% targeting prawns (n)	70 (7)	29 (5)	100 (3)	0 (0)
Mean months worked yr^{-1} (n)	8.2 (10)	10.6 (16)	11.3 (9)	12 (5)
Mean % time outside 6nm (n)	2 (9)	21 (14)	34 (9)	10 (6)
Mean max distance travelled (nmi) (n)	8.3 (6)	9.4 (11)	7.5 (4)	17.7 (9)

* One respondent did not provide map-based data and is excluded from the analysis in this chapter

Interviews were conducted face to face and were semi-structured, lasting between 30 minutes and 3 hours. Questions relevant to addressing the objectives for this chapter included enquiries about historical and current fishing activity, current gear use, details of fishing vessels, and a map-based component (sections A, B, C, G; Appendix 1). The approach taken followed that of previous studies designed to elicit fishers' spatial knowledge (Scholz et al. 2004; Ardron et al. 2005; Hall & Close 2007; Des Clers et al. 2008; St. Martin & Hall-Arber 2008; Hall et al. 2009; Woolmer 2009). Interview questions were piloted with one current fisher from a different port and two ex-fishers to determine suitable wording and an appropriate style and scale of charts.

Interviewees were first shown an example map to illustrate the types of responses sought and help initiate the process of eliciting spatial information, which can be difficult (Hall et al. 2009). This served two purposes: firstly to make interviewees more comfortable with drawing on the charts, and secondly to encourage respondents to draw polygons surrounding specific fishing grounds, rather than points or lines marking fishing spots. Initially using an unstructured approach, fishers were asked to illustrate on charts any features or areas they considered important to fishing locally. Responses were recorded on colour copies of local admiralty charts (with which local fishers are familiar) at scales of between 1:115,000 and 1:125,000. To elicit comparable responses, interviewees were prompted to indicate areas that they fish, including areas specifically targeted in different seasons or for different species, and any seasonal or temporal changes in fishing area (e.g. Fig. 2.3a). Different types of information (e.g. relating to different target species) were recorded using different colours and additional information such as type of ground or seasonality of use was noted.

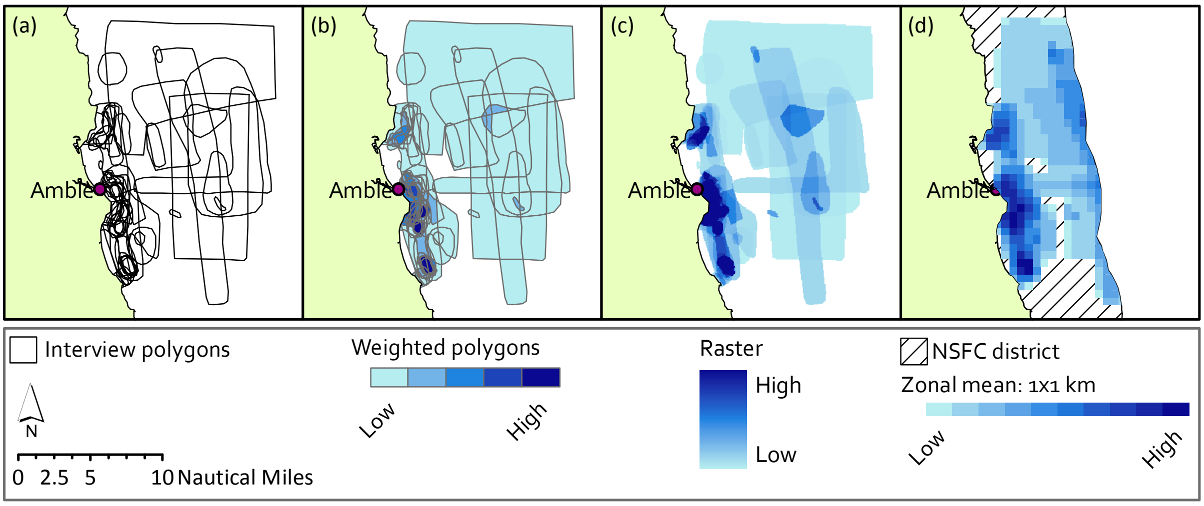

Figure 2.5. Illustration of interview data processing: a) individual polygons overlaid, b) weighted polygons overlaid, c) sum overlapping polygon values and convert to raster, d) zonal statistics (1 x 1 km grid) clipped to NSFC district

Individual maps were scanned and saved as georeferenced shapefiles. Each polygon was given an identification number linking it to the interviewee and to any additional information provided. Using data on the seasonal use of each mapped polygon and the total quantity of gear worked by each fisher, fishing effort (pot months km^{-2} yr^{-1}, where one pot month is equal to one pot worked for one month, i.e. one vessel working 100 pots for 6 months equates to 600 pot months) was estimated for each polygon (Fig. 2.3b). If fishers indicated that an area was fished during summer or winter, this was interpreted as equating to half their annual fishing time (i.e. 6 months if fishing all year round). For each month, the number of pots worked by each fisher was distributed evenly across the total area of polygons worked each month (i.e. greater total fishing effort was attributed to larger polygons). Polygons of individual fishers were then overlaid at each port, and fishing effort summed in areas where polygons overlapped. In a number of cases mapped fishing grounds extended beyond the limit of the map; to enable direct comparison of interview and sightings data, polygons were clipped to the extent of the NSFC district before converting the shapefile to a raster of 100 m x 100 m cell size (Fig. 2.3c), from which zonal statistics were derived (Fig. 2.3d).

2.2.3 Data integration and analysis

Data from vessel sightings and interviews were converted to the same projection and coordinate system in order to integrate and compare data sources (Fig. 2.4). Using a 1 x 1 km grid covering the maximum extent of both datasets at each port, zonal statistics were derived from each dataset, resulting in a measure of both observed and perceived fishing activity for each grid cell. This scale was considered the most detailed level of analysis possible given the potential inaccuracies of interview maps and the unknown level of error resulting from choice of smoothing factor in KDE analysis.

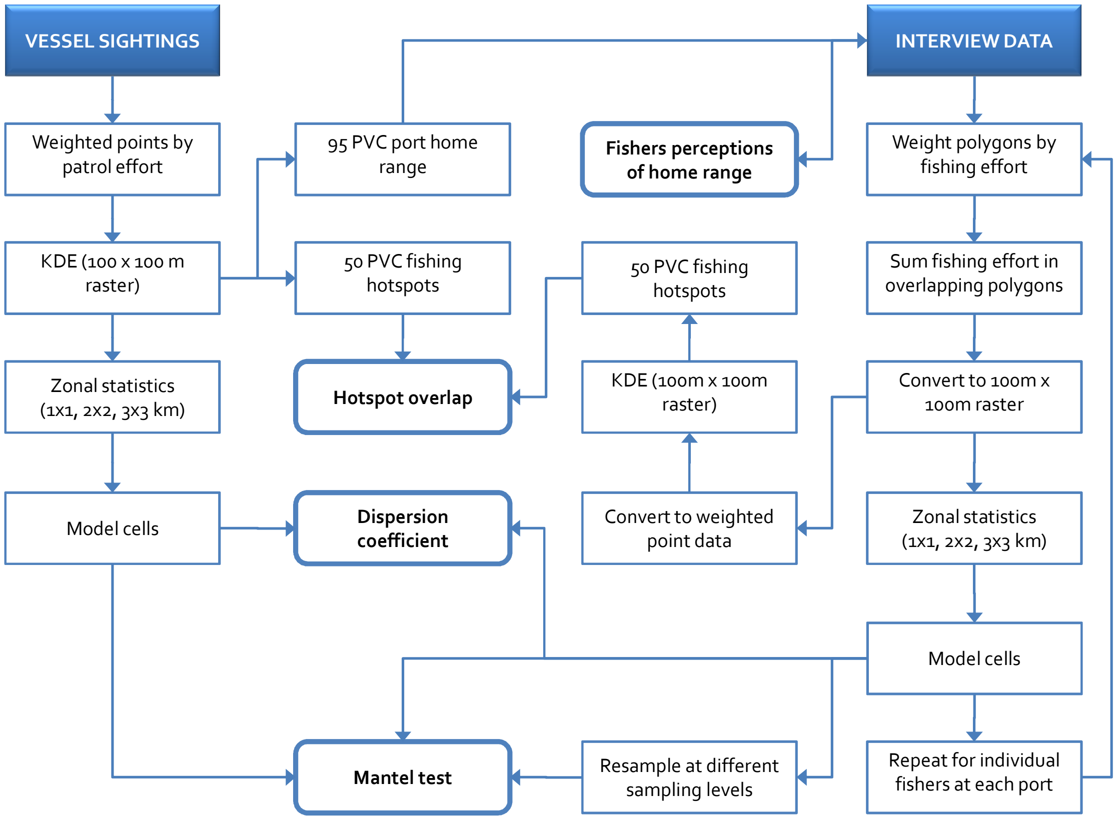

Figure 2.6. Overview of data conversion and analysis. Shaded boxes indicate data sources, unshaded represent processes in data analysis and conversion, boxes in bold indicate outcomes presented in results. Acronyms: KDE = kernel density estimate; PVC = percent volume contour. For more detail on the following see sections listed in parentheses: analysis of sightings data (2.2), analysis of interview data (2.3), dispersion coefficient (2.3), Mantel tests (2.3.1), fishing hotspots (2.3.2), fishers' perceptions of home range (2.3.3).

Map comparison

Methods such as the Kappa statistic compare the spatial distribution of variables in terms of their presence or absence, or other categorical classifications (Hagen-Zanker 2006; Ban et al. 2009). However, there are fewer established methods for statistically comparing the distribution of variables with numerical values, such as the intensity of fishing activity (Hagen-Zanker 2006). Perceived and observed fishing activity distribution among grid cells were compared using the

Mantel test (see Section 2.1). To compare the distribution of perceived and observed fishing activity, two distance matrices were calculated for each port based on the modelled 1 x 1 km grid cells, using Euclidean distances between standardised values of the datasets.

Fishing hotspots

While the overall pattern of fishing activity can be visually compared to identify fishing hotspots, mapping areas of consistently high fishing activity using KDE and PVCs takes account of the statistical spatial distribution of the dataset (Alessa et al. 2008). To enable a direct comparison of hotspots, the initial raster produced using interview data was converted to weighted point data, and a KDE calculated. Fifty percent volume contours were then plotted for each port using KDEs derived from interview and sightings data. The total area mapped by observed and perceived hotspots was calculated, and the area over which the two data sets coincided was expressed as a percentage of the total area.

Fishers' responses to maps

Studies mapping fishing activity commonly include a validation phase during which data aggregated at port level (to ensure anonymity of individual fishing grounds) are discussed with fishers, particularly when data are based on a small sample (Scholz et al. 2004; Des Clers et al. 2008; St. Martin & Hall-Arber 2008). This was not carried out here due to limited time and a near-complete sample of fishers. However, at the end of interviews individual fishers were invited to comment on the maps produced using the sightings data, and to make any amendments they thought necessary.

Aggregation of fishing activity

Values from modelled grid cells were standardised (by subtracting the mean from each value and dividing by the standard deviation) for each dataset and the dispersion coefficient (variance:mean ratio), denoted as C (Pet-Soede et al. 2001) was calculated for each port to assess whether the distribution of fishing effort differed from a random distribution. A random distribution was indicated by a value of $C = 1$, while increasing values above one indicated a greater degree of aggregation or patchiness. Measures of dispersion for both observed and perceived distributions of fishing activity at each port were compared to measures of consistency between the two datasets (Mantel statistics and hotspot overlap).

Scale

Analysis attempted to address the question of how spatial coincidence of the two datasets differed with varying spatial resolution. Zonal statistics for sightings and interview data were calculated at three spatial scales: 1 x 1 km, 2 x 2 km, and 3 x 3 km. As noted above, the lowest scale bound was considered the most detailed level of analysis possible, while the upper scale bound was chosen as a more conservative estimate of the accuracy of the data, which still illustrated variation in the NSFC district. Dispersion coefficients were calculated, and Mantel statistics used to compare the datasets at each resolution.

Sampling intensity

Given the time needed to collect interview data and possibility that fishers may be unwilling to take part, the effect of sampling intensity on the consistency between the two datasets was assessed. For each port, individual fishers' mapped polygons were processed separately and zonal statistics at 1 x 1 km resolution calculated for each fisher. Data from one fisher were removed at random, before summing the fishing effort values for each grid cell and standardising the resulting values. A distance matrix was then calculated and a Mantel test carried out to compare the sightings and interview distance matrices. This was repeated, each time removing one more fisher at random. One hundred replications of this process were carried out to produce mean estimates for the Mantel statistic at each level of sampling.

Sources of variability

To investigate variability in individual fishers, the comparability of sightings and interview data were assessed on the basis of 15 skippers for whom >50 vessel sightings had been recorded. For this purpose, minimum convex polygons (MCPs) were created around the fishing grounds mapped by individual fishers to account for the possibility that vessel sightings may include those of vessels travelling from one potting ground to another, or to and from port. The distance of each sighting to the respective MCP was measured. Differences among fishers in the distances from vessel sightings to MCPs were assessed using the Kruskal-Wallis test, a non-parametric analysis of variance.

As interview data and vessel sightings data were collected over different time periods (interviews in 2009, sightings in 2004-2008), the inter-annual variability between location of sightings and interview data was assessed by comparing distances between vessel sightings and MCPs among years, using the Kruskal-Wallis test.

Combining data

Maps illustrating the combined distribution of fishing activity shown by the sightings and interview data were produced by summing standardised values of both variables for each grid cell. Similarly, maps highlighting areas of disparity between the spatial distributions were displayed using the differences between standardised values.

2.3 Results

2.3.1 Spatial coincidence of observational and perceptions data

Maps of observed (sightings data) and perceived (interview data) distributions of potting activity showed similar overall patterns, with highest potting activity located largely in inshore areas in close proximity to vessels' home ports, and much activity within 3 nmi of shore (Fig. 2.5 a-h). Port home ranges estimated from vessel sightings ranged from a minimum of 78 km^2 at Holy Island to a maximum of 265 km^2 at Amble (Table 2.3). In contrast, the largest area of fishing ground mapped by fishers was at Holy Island. Fishers each drew on average 5 polygons representing the areas they fished, with individual polygons having a mean area of 21 km^2 and total fishing grounds of individual fishers covering a mean area of 110 km^2 before coverage was cropped to the 6 nmi limit. At all ports, perceived fishing grounds within 6 nmi were more extensive than home ranges estimated using sightings data.

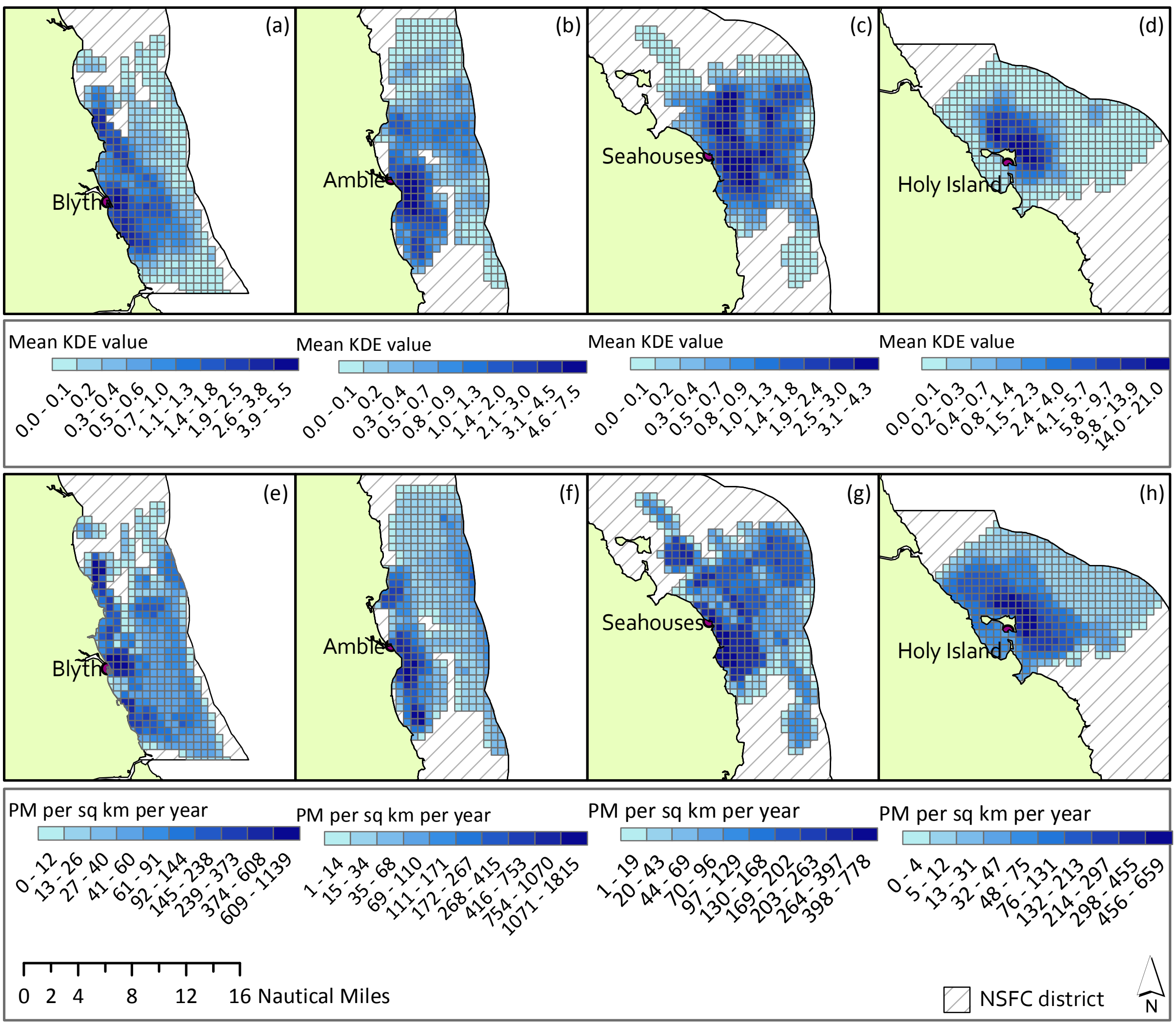

Figure 2.7. Estimated distribution of fishing activity based on: a-d) observed fishing activity (vessel sightings, based on kernel density estimates (KDE)), and e-h) perceived fishing activity (interviews, estimated pot months (PM) km^{-2} yr^{-1}) at Blyth (a,e), Amble (b,f), Seahouses (c,g) and Holy Island (d,h).

Distance matrices (see 2.2.1) of the two datasets at each port were correlated to each other, suggesting that grid cells similar in terms of perceived fishing activity were also similar in terms of observed fishing activity. This indicates that the two datasets show a similar pattern of fishing activity distribution. However, the strength of correlation varied between ports, being lowest at Seahouses and highest at Holy Island (Table 2.3).

Table 2.4. Summary of interview and sightings data (to 6 nmi only). Mantel statistics based on Pearson's product-moment correlation between dissimilarity matrices of standardised sightings data and interview data. All calculations are based on 999 permutations. C= dispersion coefficient, HR = home range.

Port	Sightings data (2004-2008)			Interview data (2009)				Comparison	
	Vessel sightings	HR (km^2)	C	No. interviews	Total polygons	Total area (km^2)	C	Mantel statistic r_M	Significance
Blyth	591	193	1.60	10 (91%)	83	284	1.96	0.528	0.001
Amble	701	265	1.80	15 (88%)	56	336	2.31	0.676	0.001
Seahouses	580	260	1.48	9 (100%)	48	341	1.39	0.384	0.001
Holy Island	109	78	2.97	6 (100%)	23	350	1.94	0.832	0.001

Dispersion coefficients suggested fishing activity at all ports tended towards an aggregated or patchy distribution, with fishing activity concentrated in particular areas rather than evenly or randomly distributed across possible fishing grounds. Both sightings and interview data produced the lowest dispersion coefficient at Seahouses, while the highest aggregation in the vessel sightings data was identified at Holy Island, and highest aggregation in the interview data at Amble.

Fishing hotspots

Sightings data and interview data both suggest that hotspots of high potting activity by vessels at each port were located in inshore areas and in close proximity to ports (Fig. 2.6a-d); 50% of sightings-inferred fishing activity occurred over 20-75 km^2 at each port, representing 18-29% of the home range of each potting fleet. Similarly, interview data suggested 50% of activity occurred within 12-35 km^2 at each port, representing 11-31% of the total mapped fishing grounds within 6nmi at each port.

Table 2.5. Estimated hotspots (HS) of fishing activity based on observed fishing activity (OHS, based on vessel sightings) and perceived fishing activity (PHS, based on interview data), and area of overlap between the two hotspots at each port.

Port	Perceived hotspots (PHS)				Observed hotspots (OHS)				Overlap		
	No.	Mean area (km^2)	Total area (km^2)	% of fishing grounds	No.	Mean area (km^2)	Total area (km^2)	% of home range	Total HS area (km^2)	Area of overlap (km^2)	% Overlap
Blyth	4	14.4	57.8	20	5	10.5	52.5	27	81.1	29.3	36
Amble	3	12.2	36.6	11	3	15.5	46.4	18	53.7	29.2	54
Seahouses	3	34.9	104.8	31	4	18.6	74.4	29	138.9	40.3	29
Holy Island	1	48.6	48.6	14	1	20.0	20.0	26	48.6	20.0	41
Total	10	18.6	242.1		13	14.9	193.3		322.3	118.8	37

At Amble and Holy Island no polygons were identified in which there was no overlap between datasets (Fig. 2.6 b,d). However, at Blyth and Seahouses smaller hotspots were identified by either sightings or interview data, with no overlap, suggesting differences between the two datasets in identifying hotspots (Fig. 2.6 a,c).

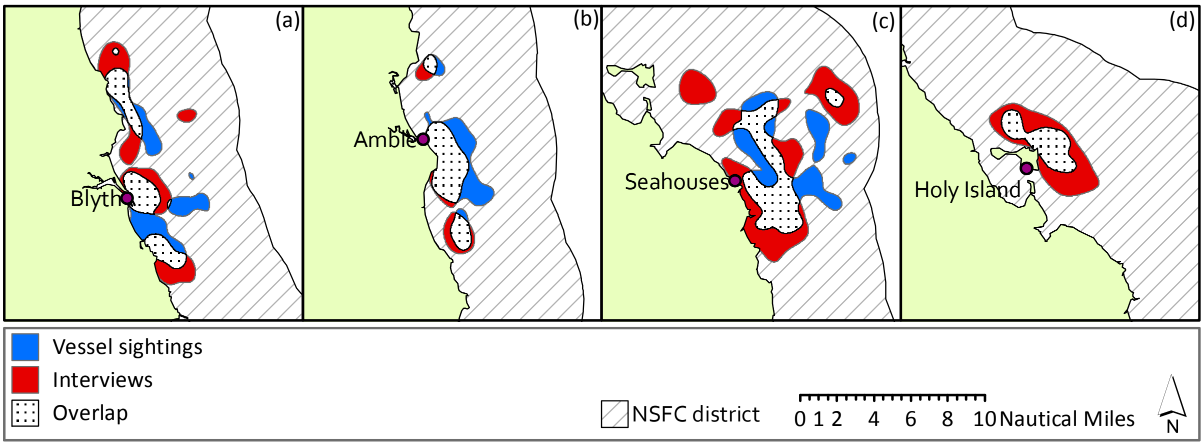

Figure 2.8. Hotspot overlap (based on 50 percent volume contour) for observed (blue) and perceived (red) fishing activity, and the overlap between hotspots (cross-hatch) at a) Blyth, b) Amble, c) Seahouses and d) Holy Island (hotspot indicated by sightings data at Holy Island is completely contained within area of overlap)

Fishers' responses to maps

All fishers agreed that the KDE and port home range were a good representation of local fishing activity. Amendments to port home ranges focused primarily on extensions to the area covered, with a small number of fishermen noting a minority of vessels within the port that worked further than the home range suggested, although fishers agreed that the home range represented the main fishing area for their peer group as a whole. However, skippers at Amble and Blyth noted some areas of likely mis-identification of vessel activity, including areas unsuitable for lobster and crab potting where vessels may have been prawn potting or fishing for salmon using T-nets. Fishers at Holy Island also noted that NSFC patrols in the vicinity are usually close inshore and are therefore unlikely to see vessels fishing further offshore.

2.3.2 Effect of fishing activity aggregation on data comparison

The greatest spatial coincidence between fishing hotspots mapped by the two datasets was at Amble. Lowest overlap was at Seahouses (Table 2.4), where hotspots extend further offshore than in other ports and both interview and sightings data showed the least spatially aggregated distribution (Table 2.3). At Holy Island, the spatial distribution of sightings data was highly aggregated (dispersion coefficient of 3.0), and the hotspot identified through analysis of sightings data was completely contained within the hotspot identified through interview data (Fig. 2.6d). In general, agreement between the datasets appeared to be higher where there was greater aggregation in mapped fishing activity (Fig. 2.7).

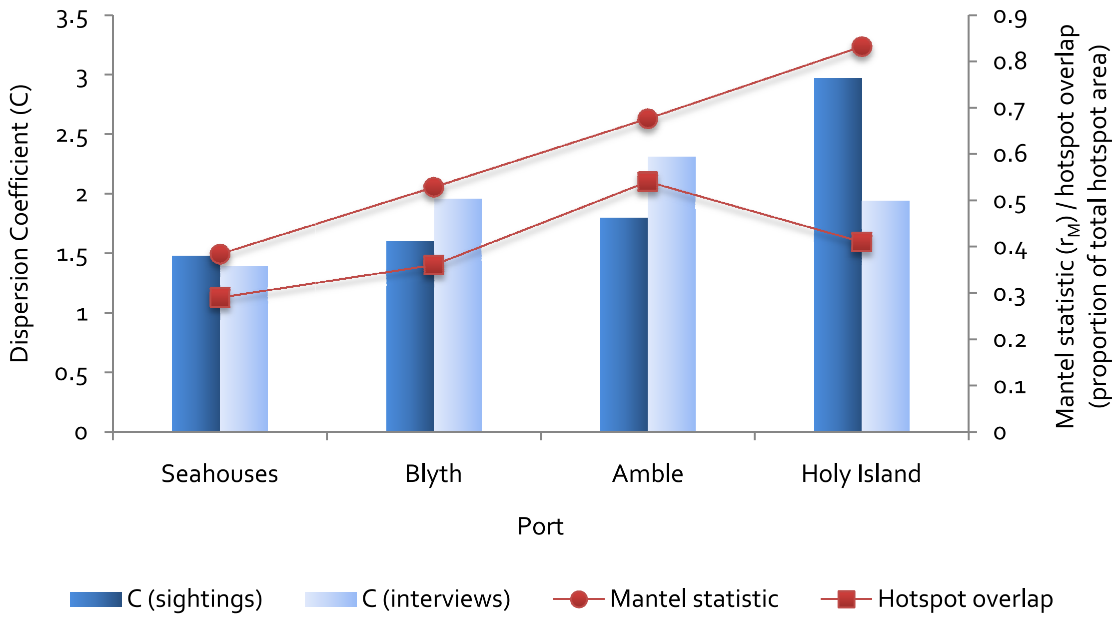

Figure 2.9. Relationship between aggregation of fishing activity (dispersion coefficient, C) and measures of consistency between observed and perceived fishing activity distribution (Mantel statistic, r_M, and hotspot overlap, as proportion of total mapped hotspot areas).

2.3.3 Effect of spatial scale on data comparison

A consistent pattern was observed in the level of agreement between sightings and interview data at different scales, with a higher Mantel statistic occurring at all ports with increasing spatial resolution (Table 2.5). However, variability in the level of agreement at different scales was greater between ports than between different spatial scales. There were significant differences in the Mantel statistics at different ports (one way ANOVA, $F_{(3,8)}$=18.256, p<0.001), but no difference in Mantel statistics among spatial resolutions ($F_{(2,9)}$=1.333, p=0.275).

Table 2.6. Effect of spatial scale on Mantel statistic (r_M) and dispersion coefficient (C)

Port	Spatial Resolution	r_M	Significance	C (sightings)	C (interviews)
Blyth	1 km x 1 km	0.5277	0.001	1.60	1.96
	2 km x 2 km	0.6354	0.001	1.59	1.99
	3 km x 3 km	0.6937	0.001	1.40	2.03
Amble	1 km x 1 km	0.6758	0.001	1.80	2.31
	2 km x 2 km	0.7457	0.001	1.81	1.99
	3 km x 3 km	0.8063	0.001	1.78	1.74
Seahouses	1 km x 1 km	0.3835	0.001	1.48	1.39
	2 km x 2 km	0.4795	0.001	1.52	1.31
	3 km x 3 km	0.5345	0.042	1.54	1.27
Holy Island	1 km x 1 km	0.8318	0.001	3.00	1.94
	2 km x 2 km	0.8486	0.001	2.92	1.92
	3 km x 3 km	0.9177	0.001	2.89	1.94

2.3.4 Effect of interviews sampling intensity on data comparison

The level of agreement between the two datasets increased with increasing interview numbers (Fig. 2.8a). An increase in the extent of coverage of fishing grounds was observed with increased interview data at each port. While the relationship between sampling levels and the Mantel statistic were variable among ports (Fig. 2.8a), similar patterns were observed at each port in the relationship between sampling levels and areas extent of fishing grounds (Fig. 2.8b).

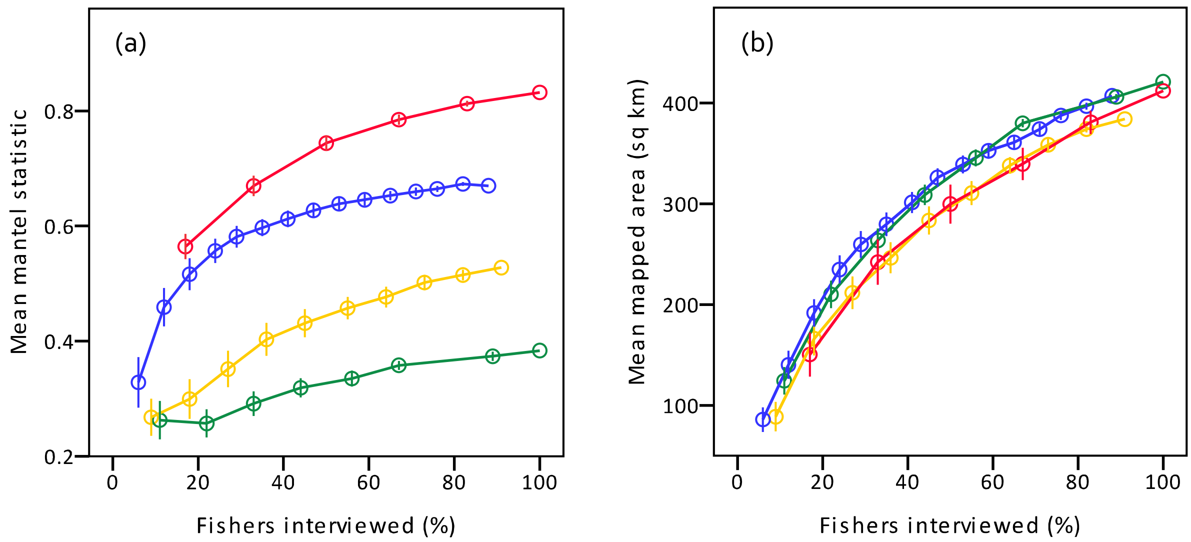

Figure 2.10. Plots of a) mean Mantel statistic (r_M) and b) area fished (number of 1 x 1 km grid cells with fishing effort >0) against numbers of interviews at Blyth (yellow), Amble (blue), Seahouses (green) and Holy Island (red) within 6 nmi. Based on 100 replications at each sampling level. Error bars represent 95% CI of mean. Note that in (b) the maximum mapped area exceeds the total mapped area recorded in Table 2.3; this is a result of the analysis being undertaken using a 1 x 1 km grid (i.e. a grid cell was considered part of mapped fishing grounds if it contained any mapped fishing activity).

2.3.5 Variation among individual fishers and over time

Investigation of 15 individual fishers revealed no difference in the distance of sightings to minimum convex polygons (MCPs) surrounding mapped polygons between years (KW χ^2=8.120, *df*=4, *p*=0.087). The majority of fishers (87%, n=13) stated that distance travelled to fishing grounds had either remained the same or had increased in recent years. None of these fishers mentioned having abandoned previous fishing grounds, therefore it is expected that vessel sightings during 2004-8 would in most cases be encompassed by the MCP enclosing the area fished currently. The two remaining fishers stated that the distance they travelled to fishing grounds had decreased, and this is reflected in the sightings data: the mean distance of sightings of fisher B to the mapped MCP was greater than that of other fishers in all years, and the mean distance of fisher L was greater than that of other fishers in 2004, but comparable to those of other fishers in subsequent years (Table 2.6).

Table 2.7. Summary of distances from vessel sightings to MCPs for 15 fishers (A-O), and changes in distance travelled to fishing grounds over time.

Fisher	Port	No. vessel sightings	Mean distance of sightings to MCPs (km)							Change in distance travelled	Reason for change
			2004	2005	2006	2007	2008	Mean	SD		
A	Amble	50	0.1	0.0	0.0	0.0	0.0	0.0	0.1	Increased	Larger vessel
B	Amble	77	9.3	11.4	9.4	7.5	3.0	9.1	5.4	Decreased	Vessel getting old
C	Amble	66	0.0	0.0	0.2	0.0	0.0	0.1	0.5	Same	-
D	Amble	69	0.1	0.0	0.1	0.0	0.0	0.1	0.3	Increased	Fewer trawlers (less conflict)
E	Blyth	65	0.0	0.0	2.5	0.9	0.3	0.8	1.4	Increased	Larger vessel
F	Blyth	69	0.0	0.0	0.0	0.0	0.0	0.0	0	Increased	Larger vessel
G	Blyth	101	0.1	0.0	0.0	0.0	0.0	0.0	0.2	Increased	Try less heavily fished areas
H	Blyth	53		0.4	2.1	0.8	1.1	1.3	1.9	Same	-
I	Blyth	127	0.2	0.1	0.5	0.0	0.0	0.2	0.6	Increased	New vessel
J	Seahouses	69	0.1	0.1	0.0	0.0	0.0	0.1	0.4	Increased	Larger vessel
K	Seahouses	56	0.0	0.0	0.0	0.0	0.0	0.0	0.1	Increased	-
L	Seahouses	65	2.4	0.6	0.4	0.1	0.4	1.1	2.4	Decreased	Now working alone (no crew)
M	Seahouses	81	0.2	0.6	0.1	1.2	0.0	0.4	1	Same	-
N	Seahouses	52	0.0	0.0	0.0	0.0	0.0	0.0	0	Increased	-
O	Seahouses	63	0.9	0.6	0.1	0.5	0.0	0.6	0.9	Same	-

Distance of vessel sightings to MCPs surrounding mapped fishing grounds was found to be variable among fishers (KW χ^2= 518.885, *df*=14, *p*<0.001). In particular, in 2008, sightings of fisher B remained on average 3.0 km from the respective MCP, compared to the mean distance of all fishers of 0.3 km (Table 2.6). Variation remained however when fisher B was excluded from the analysis (KW χ^2 = 191.474, *df*=13, *p*<0.001), suggesting variability among individuals in the agreement between observed and perceived fishing activity. This suggests that the mismatch between observed and perceived fishing activity by fishers may result from inaccurate recall or mapping as well as temporal change in fishing area.

2.3.6 Combining data

The combined map of potting distribution highlights areas of spatial coincidence between high perceived fishing activity and high observed fishing activity, and modifies the extent of fishing activity to account for both datasets (Fig. 2.9 a-d). The difference between standardised values illustrates geographic areas of particular disagreement between the datasets, a potentially useful tool for further validation of the maps produced (Fig. 2.9 e-h).

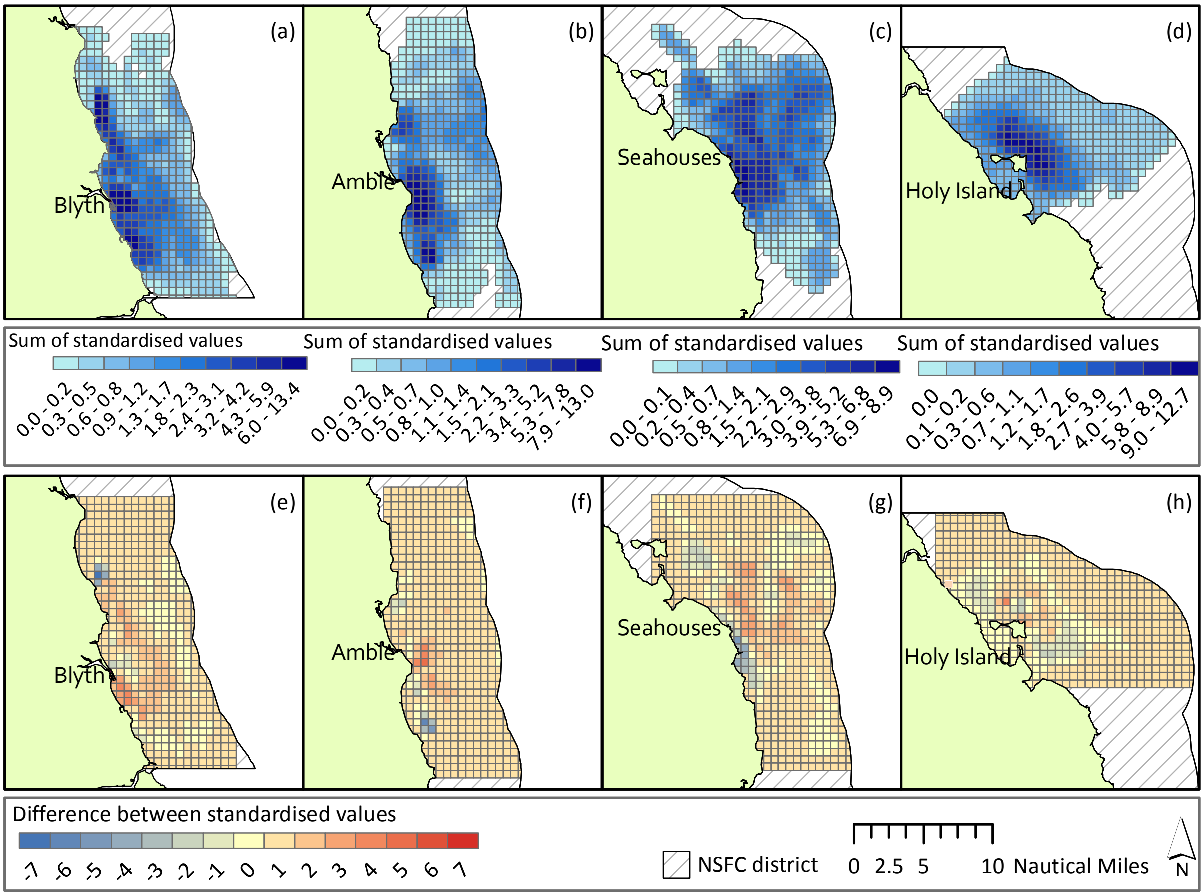

Figure 2.11. a-d) combined standardised values of observed and perceived fishing activity and e-h) differences between standardised values of observed and perceived fishing activity (positive values represent higher fishing activity indicated by vessel sightings data, negative values indicate higher values indicated by interview data)

2.4 Discussion

This research highlights some of the relative merits and limitations of two available data sources currently used in the UK to inform fisheries management and marine conservation planning. The methods used here illustrate one approach to assessing the consistency of two datasets in describing the spatial distribution of activity and identifying hotspots.

2.4.1 Consistency among data sources

Investigating the level of consistency among datasets is important to identify potential limitations of the independent use of such data sources before considering applications to inform decision-making. Both datasets presented here showed similar patterns of distribution in potting activity, with high concentrations of fishing activity in inshore areas near vessel home ports. Home range estimates from sightings data were significantly lower than those produced by interview data in all cases, and the percentage of overlap was variable between ports. However, home ranges were estimated using the 95 percent volume contour, therefore are likely to exclude the more peripheral fishing grounds of a minority of individuals.

The sizes and shapes of hotspots partly resulted from the choice of parameters in the kernel density estimation, and as such should not be seen as representing definite boundaries (Alessa et al. 2008), as different choices of smoothing factor and PVC would give different results. Nevertheless, the use of identical parameters among data analysed here allows the two sets of hotspots to be directly compared. A significant degree of overlap occurred between perceived and observed hotspots, particularly in the case of the larger hotspots identified. Similar findings have emerged from studies comparing hotspots of perceived and scientifically measured ecological values in the marine environment, with consistent identification of major hotspots, but greater inconsistencies in the case of minor hotspots (Alessa et al. 2008).

Differences between hotspots identified by sightings and interview data may be related to methods of data collection and analysis. For instance, spatial or temporal bias in the distribution of patrol activity and the inclusion of vessels steaming as well as actively potting may result in a skewed distribution of sightings data. Furthermore, while the KDE from the sightings point data represents the probability distribution based on the sample of vessel sightings, the KDE from the interview data is based on weighted points derived from the mapped polygons of fishers (under the assumption that the fishing activity of each fisher is distributed evenly across the areas fished at any point in time).

There are very few studies that compare interview-based data on the distribution of fishing activity with other sources of spatial information. While one recent report has compared fishers' interview data with SFC vessel sightings on a presence-absence basis (Woolmer 2009), there has not been a statistical comparison of these datasets which takes into account variable intensity of fishing activity across fishing grounds. Mantel statistics at each port indicated consistency between distribution of observed and perceived fishing activity, although the strength of correlation between distance matrices varied between ports.

Analyses attempted to account for the trend in declining patrol coverage observed from the south to the north of the district when analysing the sightings data, and there was no evidence of a corresponding geographical pattern in the strength of the agreement between the two datasets. For instance, Holy Island has the lowest frequency of patrols, yet the correlation between sightings data and interview data was strongest at this port, and the hotspot identified by sightings activity was completely contained within the hotspot identified through interview data, suggesting a high degree of spatial congruity. However, lower patrol effort in the vicinity of Holy Island may account for the smaller home range and highly aggregated pattern of vessel sightings at this port.

2.4.2 Aggregation of fishing activity

Differences in the strength of correlation between sightings and interview data at different ports may be related to differences in the underlying spatial pattern of fishing effort distribution at each port. Fishing activity at all ports was found to display an aggregated pattern, as is commonly found in studies of fishing effort distribution (Jennings 1999; Pet-Soede et al. 2001; Daw 2007). However, in ports where the dispersion coefficient indicates a higher degree of aggregation, the Mantel statistic shows a greater degree of similarity in the distribution of fishing activity indicated by the two data sources.

At Holy Island, where the highest Mantel statistic is observed, a single hotspot of fishing activity can be clearly identified in both interview and sightings data in the area immediately adjacent to the island. In contrast, while the total area mapped by fishers from Seahouses is comparable to that of other ports, hotspots cover a larger area and extend further out to sea than at other ports, and the dispersion index of both sightings and interview data indicates less aggregation in fishing activity. Information from local fishers suggests that this is related to the distribution of suitable habitat in this area, which is more extensive and reaches further out to sea than in areas further south in the NSFC district. With increasing distance from port, available fishing areas increase more than linearly, assuming that suitable habitat is available (Caddy & Carocci 1999), therefore fishing activity further offshore may be expected to be less aggregated than in areas close inshore. Potting activity around Seahouses may also be fragmented in distribution due to the presence of the Farne Islands (a group of up to 28 small islands 2.5-7.5 km from the mainland (Bennett & Foster-Smith 1998)).

Further south towards Amble and particularly Blyth, suitable potting habitat is less prevalent and more limited to areas close inshore (local fishers, *pers. comm*., 2009). In these areas trawl vessels are able to work further inshore, further restricting the movement of potting vessels offshore due to the risk of gear damage. These findings are consistent with other studies that have found different spatial patterns of fishing effort within different fishing communities (e.g. St. Martin & Hall-Arber 2008). The size, shape and frequency of use of individual fishing grounds may be affected by the distribution of suitable habitat and distance from port, as well as other factors such as seasonal variation in target species and fishing conditions, vessel capabilities, and skippers' knowledge.

The apparent relationship between the strength of agreement between the two datasets and level of aggregation in fishing activity suggests that one or both methods of data collection and analysis may be less effective at capturing the spatial distribution of fishing activity where there is a greater degree of dispersion. Several factors relating to the methods of data collection and analysis of the datasets may explain this.

Firstly, with regard to vessel sightings, concentration of patrol effort in areas of high fishing activity or persistent byelaw infringements may mean that activity in ports where fishing activity is more dispersed is more difficult to capture than in areas where there is greater aggregation. Patterns of patrol effort are shown to vary within the NSFC district, and are likely to vary among SFCs, which may be an important factor in determining data reliability. Secondly, the probability of fishing activity estimated from vessel sightings data using KDE is calculated by considering activity in the neighbourhood of each location, and the resulting pattern may therefore be influenced by the choice of smoothing factor, the optimum value for which may depend on the underlying spatial pattern of the data. In this case, the method used to determine the smoothing factor was somewhat arbitrary, and further work could include a sensitivity analysis to investigate the effect of varying this parameter.

Thirdly, estimates of fishing effort attributed to polygons may be influenced by differences in representation of fishing grounds by individual fishers. This may lead to overestimates of fishing effort, for example where fishers highlight particularly important fishing grounds but omit other less frequented areas. In other cases it may lead to underestimates of fishing effort, for example where fishers draw polygons covering large areas to avoid revealing detailed information, or in instances where fishers marked large areas on charts to indicate areas of "patchy" ground fished further offshore, where suitable habitat is more dispersed and behaviour may be exploratory or variable.

Finally, attributing measures of fishing effort to polygons mapped by fishers presents a challenge, particularly where there is a high degree of variability in fishing behaviour arising due to the opportunistic nature of fishing and highly variable environmental factors (e.g. weather conditions) and socio-economic conditions (e.g. changes in fuel costs). Anomalies may therefore result from the assumption that fishing gear of an individual is distributed evenly across marked fishing grounds at any particular time of year. Furthermore, it was assumed here that where grounds of individuals overlap, fishing effort is the sum of that of the individuals in that area. This may be unrealistic, as overlap of fishing grounds may result in either higher fishing effort (fishers attracted to particularly good fishing grounds) or lower fishing effort (due to competition between vessels and conflict avoidance) than indicated by summing individuals' fishing effort. This study considered the fishing activity of individual ports, and overlap with the fishing grounds of adjacent ports adds further complications. The distribution of individuals' fishing effort among fishing grounds could be further informed through the use of logbooks, voluntary GPS recordings, or access to records kept by fishers on electronic plotters. Analysis of additional data sources would provide further opportunities for triangulation and develop further understanding of the advantages and limitations of each data collection method.

2.4.3 Scale of analysis

Prior studies have noted the importance of the scale of analysis for capturing patterns in spatial data (e.g. Turner et al. 1989; Mac Nally 1997; Tian et al. 2009). At increasingly fine scales fishing effort is likely to become more randomly distributed (Rijnsdorp 1998; Harrington et al. 2007). For example, in the Tasmanian scallop (*Pecten fumatus*) fishery, fishing was found to be more randomly distributed at the scale of individual scallop beds (Harrington et al. 2007), while in the Bluff oyster (*Ostrea chilensis*) fishery the distribution of fishing activity was found to vary both with the distribution of habitat and with the distribution of oysters over individual oyster beds (Hall et al. 2009). The spatial scale of analysis should therefore be meaningful in relation to the distribution of habitats. These studies emphasise the importance of using fine scale spatial data to inform management decisions, although often this may be constrained by the costs of data collection and precision and accuracy of resulting datasets. In temperate commercial fisheries, studies have highlighted patchy distributions of fishing activity, and warned against basing both fishing effort estimates and socio-economic data relating to fisheries on mean values over large areas (Rijnsdorp 1998; Jennings 1999; Richardson et al. 2006).

However, the agreement between the two data sources revealed a consistent increase in the Mantel statistic at each port with decreasing spatial resolution of data analysis considered. The process of rescaling datasets to a broader spatial resolution may therefore reduce the influence of positional and other errors in representing fine scale variability, yet this must be balanced with the need for fine scale information to inform management. A statistically significant correlation was found between distance matrices of the two datasets at all scales, and there was greater variability in the Mantel statistic between ports than at different scales of analysis within ports, suggesting that factors other than spatial resolution (such as level of aggregation or dispersion) may be more important in determining the level of agreement. Ultimately however, the spatial resolution that is feasible remains constrained by the limitations of the original data collection methods, including both the volume of vessel sightings data and the accuracy of interview-based methods. Further work should be undertaken to explore the use of maps at different scales, the degree of variability among fishers, and the framing of interview questions.

2.4.4 Sampling and the use of interview data

The samples of fishers interviewed in Northumberland comprise small numbers of respondents, despite the ports studied representing four of the larger potting fleets in the NSFC district. While 95% of active fishers at each port were interviewed here, often studies requiring input from fishers have smaller samples as a result of limited time, resources or cooperation from the fishing industry. Where this is the case, it is therefore essential to assess the implications of sample size for estimating the distribution of fishing activity.

The results suggest that the level of agreement in the spatial pattern of fishing activity between interview and sightings data rises with increases in the percentage of fishers interviewed, although the relationship between the sample size and Mantel statistic appears to vary in nature between ports. For example, in Amble a rapid increase in the Mantel statistic is observed with initial increases in sample sizes, while in Seahouses there is a much more gradual increase. In contrast, the relationship between sample size and total area of fishing grounds mapped is similar between ports, and mapped fishing grounds continue to increase at high levels of sampling, suggesting that there may be limited overlap between fishing grounds of individual fishers. It has been noted that where territoriality exists among fishers it may be more difficult to fully map fishing grounds through interview methods (Woolmer 2009). However, while the absolute extent of fishing grounds continues to increase, in the lobster fishery the location of hotspots is likely to be highly dependent on availability of suitable habitat, with peak season lobster fishing often bringing competition amongst fishers for rocky substrate close inshore. Such areas are therefore likely to be relatively consistent over time and information from a small number of fishers may suffice to identify key hotspots. In contrast, fisheries that are more mobile or dispersed are likely to require a higher level of sampling to identify patterns of activity distribution, although in North Sea trawling a large proportion of activity was found to be concentrated in a relatively small number of ICES rectangles (Jennings et al. 1999).

2.4.5 Sources of variability over time and among individuals

In producing kernel density estimates from sightings data, pooling data from several years allows analysis of data from smaller ports with fewer vessels. However, this may mask both seasonal variability and inter-annual change in the distribution of fishing activity. Significant correlations between patterns of observed fishing activity between years suggested that inter-annual variability was low. The data presented suggest that fishers perceived the maps produced using sightings data to be representative of the distribution of their peer group's fishing activity. Further investigation of interview data suggested that the agreement between vessel sightings and mapped fishing grounds has not varied significantly over the period 2004-2008, supporting the case for grouping together the available data for analysis. It is possible that in fisheries operating more mobile gear types, temporal variability in the distribution of fishing activity is more likely, although several studies have found the spatial distribution of fishing activity to remain similar over time (Rijnsdorp et al. 1998; St. Martin & Hall-Arber 2008; Hall et al. 2009).

Agreement between mapped fishing grounds and vessel sightings varied among individual skippers. This may point to limitations of map-based interview methods, suggesting variation in fishers' abilities to accurately recall and map fishing grounds on the charts provided. Further work would be useful to investigate how fishers recall spatial information and how this can be used to inform methodologies for collecting spatial data. Representation of fishers' activity in both data sources may also be influenced by vessel characteristics and behaviour. For instance, smaller vessels fishing close inshore may be more likely to be seen by patrol vessels than those that fish towards and beyond the limits of the NSFC district. Furthermore, vessels with more regular fishing habits may find it easier to represent their activities on a chart than those who are more exploratory and variable in their behaviour. This issue has also been raised in the context of mapping different types of fisheries; for example it has been noted that mapping extensive and variable activities such as trawling may present a greater challenge than mapping inshore potting activities where fishing grounds are relatively small and defined (Des Clers et al. 2008). Developing methods to incorporate variability and uncertainty is important to inform decision-making and identify potential implications of spatial management measures for fisheries.

2.4.6 Combining data

The potential limitations and biases in both vessel sightings and interview data make it difficult to assess which of the two datasets best represents the reality of the distribution of fishing effort. Studies of fishers' knowledge emphasise the value of bringing together scientific and local knowledge to support management decisions (Brown et al. 2004; Alessa et al. 2008; St. Martin & Hall-Arber 2008; Ban et al. 2009; Hall et al. 2009). In particular it is argued that fishers' knowledge and perceptions add value to scientific data and have potential to fill gaps. While the purpose of this study was to assess the comparability of these data sources on the basis that interview data are often used as a substitute where fine scale scientific data are lacking, the two data sources both have unique limitations and merits. Sightings data have the potential to provide a better understanding of the fine-scale density of fishing activity, but may fail to capture the extremes of fishers' spatial behaviour. Conversely, interpreting the distribution of fishing effort across interview-based mapped fishing grounds presents a major challenge, but interview data may be more effective at capturing the absolute extent of grounds important to fishers.

While more peripheral areas may not be used as frequently or as intensively as fishing hotspots, their availability may be vital to sustaining the adaptive capacity of fishers to respond to change and make a living throughout the year. For instance, the highest fishing intensity and most frequented fishing grounds are likely to be in inshore areas during late summer where abundance of lobsters is high and both full time and seasonal fishers are engaged in the fishery. During the winter however, the number of fishers is lower and fishers move further offshore to avoid gear damage in bad weather. Offshore grounds in winter are described by fishers as more variable and patchy therefore the ability of fishers to cover their costs and make a profit during winter may depend on the ability to move frequently in response to localised abundances. This has important implications for the use of such data in informing spatial management measures such as MCZs, which need to take account of variability as well as simply the economic value of fishing grounds. Combining the two data sources based on standardised values for each grid square therefore incorporates the relative merits of both approaches, and combined maps, along with maps highlighting areas of differences, can provide a useful point of reference for further validation with the fishing community.

2.5 Conclusion

This chapter focused on developing a method to quantitatively compare the spatial coincidence of fishing effort distribution as indicated by two different data sources. The findings support other studies that have demonstrated the value of low-technology, cost-effective interview based methods to indicate the distribution of fishing activity, and the utility of GIS systems to integrate and compare different datasets. Furthermore, the results demonstrate a statistically significant relationship between patterns of fishing effort distribution identified by the different sources.

These findings represent a starting point for an improved understanding of the spatial distribution of inshore fisheries, which is of importance for the current process of MCZ designation in the UK. However the study also raises further questions surrounding the implications of chosen methods of data collection and analysis (e.g. sampling intensity and choice of scale), and influence of underlying spatial patterns of fishing effort distribution. While there are many possible approaches to the analysis of the interview data and vessel sightings data presented here, key questions for further research include the implications of the strength of relationship between the data sources for the degree of confidence held by managers in using such data for marine spatial planning. Furthermore, the variability of responses among fishers, difficulties in representing uncertainty, and assumptions regarding the distribution of activity over mapped areas mean that where independent data sources are unavailable, validation of the maps produced in consultation with the fishing community is imperative.

Information on the distribution of inshore fishing activity will be critical to the success of future marine spatial planning and fisheries management. Given the current lack of coverage by VMS data for inshore fleets, data from vessel sightings and interview methods are the primary sources of data available for information on the distribution of inshore fleet activity in the UK. Interview data is likely to be particularly valuable in areas where SFC observations are particularly sparse, patchy or biased in their spatial or temporal coverage. Both datasets provide an opportunity for fine scale analysis to enhance planning through integration with biological and ecological data, and to minimise economic costs and conflict associated with marine spatial planning. Given the strengths and weaknesses of both datasets it is recommended that triangulation of both datasets is undertaken to inform marine spatial management measures. While vessel sightings may provide greater detail of the intensity of fishing activity, engagement with resource users is essential to gain an understanding of the drivers of resource distribution patterns.

Chapter 3.

Analysis of variability in landings of European lobster (*Homarus gammarus*) in Northumberland, 2001-2007

Abstract

Knowledge of the distribution of fishing activity and its relationship to catch rates is important to understand fishery dynamics and potential implications of different management measures. Monthly returns from shellfishers in Northumberland were examined over an 8 year time series (2001-2007) for 183 vessels operating from 12 ports. The main objective was to examine factors affecting variability in landings of European lobster (*Homarus gammarus*), and in particular to identify any spatial differences in landings among ports. Monthly lobster landings were modelled using linear mixed-effects models, with nested random effects to allow for unmeasured variation in vessel type and skipper, and in port characteristics. A parsimonious model suggested that key predictors of lobster landings were season and number of pot haul days per month, representing seasonal changes (e.g. in lobster activity and catchability) and fishing effort respectively. Other predictors included number of pots worked, year, and North Atlantic Oscillation (NAO) index. A relationship between random intercepts and vessel density within port home range suggested that landings were generally higher at ports with lower fishing intensity, and baseline landings were positively correlated with mean engine size at each port. Random intercepts at port level were related to geographic position of ports with landings generally higher in more northerly than in southerly ports. While a broad-scale spatial effect was thus indicated, the model showed a much higher degree of variability in landings among vessels than among ports. The causes of this variation may be related to a number of factors including differences in fishing gear and fishing practices, technological equipment aboard the vessel, knowledge and experience of individual skippers, and fine-scale spatial behaviour of individual vessels. The results presented highlight the relative magnitude of sources of variability in Northumberland lobster landings, and may be useful in developing indicators of relative lobster abundance. Further study of sources of variability among individual vessels, and fine-scale patterns of behaviour are recommended.

3.1 Introduction

Fisheries management seeks to balance conservation of target species against economic profitability of fisheries, and is often informed by biological stock assessment, which estimates parameters of fishery dynamics. Stock assessments may utilise data from fishery-independent surveys or from commercial fisheries; however fishery-independent data are often difficult or expensive to obtain (Steneck & Wilson 2001; Maunder & Punt 2004). Consequently, catch rate (catch per unit effort (CPUE)) data from commercial fisheries are often used as an indicator of the relative abundance of target species to inform fisheries models (Campbell 2004; Maunder & Punt 2004). However, it is widely recognised that a positive relationship between catch rates and abundance may be confounded by a variety of factors, including the behaviour of fishers (Branch et al. 2006; Maunder et al. 2006). While a decline in CPUE may in some cases indicate a decline in target species abundance, in other cases changes in fishers' behaviour may lead to different responses in CPUE. For instance, spatial expansion of a fishery over time may lead to non-linear relationships between CPUE and resource abundance (Campbell 2004; Maunder et al. 2006).

Characterising spatial variation in catch rates is important to inform fisheries management, as the movements and strategies of fishing vessels in response to catch rates can have implications for the relationship between CPUE and target species abundance. The dynamic nature of fishers' decision-making means that when costs of different fishing grounds are equal, vessels may respond to localised variability in resource abundance by allocating fishing effort in proportion to the availability of target species, resulting in catch rates that may be consistent over large areas and do not necessarily reflect resource abundance (Gillis 2003; Swain & Wade 2003). This theory, based on the ecological theory of the ideal free distribution (Fretwell & Lucas 1969), assumes that a) fishers have sufficient information to respond to localised differences, and b) fishers are free to move in response to changes in catch rates. In reality these assumptions may not be met; studies suggest that high levels of variability in catch rates may limit the ability of fishers to detect and respond to trends, and movement may be restricted by factors such as vessel capabilities, operating costs, and risk of conflict with other vessels or gear types (Pet-Soede et al. 2001; Abernethy et al. 2007).

The importance of fishers' spatial behaviour in influencing the relationship between catch rate and abundance is increasingly recognised in modern approaches to fisheries management, and knowledge of the distribution of fishing activity and its relationship to catch rates is considered important to understand fishery dynamics and to monitor changes over time (Hilborn & Kennedy 1992; Hilborn & Ledbetter 1979; Gillis 2003; Wilson 2006). Investigating the magnitude of variability in fisheries landings at different scales (e.g. variability among ports compared to among individual vessels) is also important to understand the degree to which fishers may respond to spatial variability by altering their behaviour (Pet-Soede et al. 2001).

The relationship between catch rates and target species abundance may also be influenced by a number of environmental variables. Catch rates can be described as a function of both target species abundance and catchability, which represents the proportion of a stock that is caught using a given unit of fishing effort (Jennings et al. 2001). Catchability may vary over space and time with changes in environmental factors such as habitat availability, water quality and temperature, and biological changes such as moulting, foraging and migration patterns (Bigelow et al. 1999; Tremblay & Smith 2001; Drinkwater et al. 2006). In addition to fishers' spatial behaviour, other characteristics of fishing activity may also influence catchability, including gear design, fishers' knowledge and experience, and long-term changes in fishing power relating to factors such as improvements in the technological sophistication of vessels and their equipment (Punt 2000; Frusher et al. 2003; Branch et al. 2006; Marchal et al. 2006a; Marchal et al. 2006b).

Understanding factors affecting catch rates has been the focus of work to inform standardisation of CPUE data and develop more reliable indices of relative abundance of target species to inform fisheries assessment and management decisions (e.g. Bigelow et al. 1999; Goñi 1999; Tremblay & Smith 2001; Srisurichan et al. 2005; Dobby et al. 2008). Much of this work has been undertaken using general (or generalised) linear modelling (GLM) approaches (e.g. Goñi 1999; Maynou et al. 2003; Sbrana et al. 2003), which allow for heterogeneity of variances and non-normal distribution of data (Venables & Dichmont 2004). However, a limitation of the GLM approach is the difficulty in accounting for the potential correlation of observations resulting from hierarchical datasets, which is common in data from commercial fisheries. Characteristics of vessels and skippers mean that intra-vessel correlation is likely to result between multiple observations from each vessel as skippers make decisions about future fishing locations based on past experience, as well as among observations over time and space (Mikkonen et al. 2008). In addition, accounting for the effect of spatial structure using GLMs tends to increase the complexity of the analysis by increasing the number of parameters required in the model (Punt et al. 2000). Similarly, accounting for variability in landings or catch rates related to individual vessels requires a large number of parameters unless vessel effects on catch rates can be characterised effectively using attributes such as gross tonnage, vessel length or engine power. The inclusion of vessel as a random effect in mixed effects models is one alternative approach to these problems and is particularly useful in longitudinal datasets where previous experience can influence future choices of where to fish; however this method of analysis has not been widely applied in fisheries literature (Venables & Dichmont 2004). Linear mixed effects models allow for the serial correlation and dependency resulting from the hierarchical nature of fisheries dependent data to be taken into account (e.g. Mikkonen et al. 2008), and the inclusion of spatial factors and vessels as random effects allows the variability of these to be explored without over-parameterisation of the model. Furthermore, linear mixed models accommodate unbalanced data (e.g. resulting from changes in vessels within a fleet over time).

This chapter investigates the contribution of different sources of variability to landings of European lobster (*Homarus gammarus*), the main target species in the Northumberland potting fishery, northeast England. Shellfisheries are of increasing economic importance in the UK following declines in demersal and pelagic fish landings; in 2008 shellfish contributed 42% of the value of UK landings, an increase from 31% in 1999 (MFA 2008). Lobster is one of the top five shellfish species by value landed in the UK and is targeted predominantly by inshore vessels (Bannister 2006). The Northumberland lobster fishery in 2008 comprised 135 registered vessels (all <12m in length) operating from 12 ports, with lobster landings valued at an estimated £2.9 million (MFA data). While the potting fishery is multispecies (most vessels targeting European lobster (*Homarus gammarus*), brown crab (*Cancer pagurus*) and velvet crab (*Necora puber*)), lobster is the most economically valuable species (fetching prices at over £10 per kilo, compared to under £3 per kilo for brown crab (Bannister 2006)) and is the target of the majority of fishing effort.

In comparison to other commercial fisheries (particularly finfish but also prawns (*Nephrops norvegicus*)), there is limited management in place for UK lobster fisheries, but there is a demand for increased knowledge that can be applied to improving management of the fishery (NSFC, *pers. comm*., 2007). A variety of models are used for stock assessments of lobster fisheries, which are often informed by data derived from commercial fisheries, including catch and effort data to indicate changes in relative abundance (Breen 1994; Hilborn 1997; Frusher et al. 2003; Smith & Addison 2003). Past stock assessments (based on commercial data, length-based and per recruit analyses) suggest that the Northumberland lobster fishery is dependent on small lobsters, leading to high estimates of fishing mortality; however these analyses may be influenced by effects of habitat and gear selectivity on the size composition of catches among other factors (Mike Smith, Centre for Environment, Fisheries and Aquaculture Science (CEFAS), *pers. comm*. 2010). Furthermore, nationally reported statistics on which analyses are based have been subject to variable reporting procedures over time, making interpretation of trends difficult. This study represents a first step in analysing the sources of variability in Northumberland lobster landings at different scales, using a combination of nationally and locally collected data. The specific objectives of this study are to address the following questions:

1. How are lobster landings affected by measures of fishing effort (pot number, pot haul days), environmental factors (season, North Atlantic Oscillation (NAO) index), vessel capacity (vessel length and engine size) and time (year)?
2. Do lobster landings vary between ports, and if so is there a relationship between catch rates and fishing activity?
3. What is the relative importance of variability in lobster landings among ports versus among fishing vessels?

3.2 Methods

3.2.1 Data sources

Data on the Northumberland lobster fishery were obtained for the period 2001-2007 from mandatory reporting schemes implemented by the Northumberland Sea Fisheries Committee (NSFC) (2001-2006), and the Marine and Fisheries Agency (MFA) (2006-2007). Under the NSFC scheme registered fishing vessels targeting shellfish were required to submit monthly returns detailing the vessel name and registration, number of pots worked, number of days when pots were hauled (equivalent to days at sea), and the total weight of lobsters (kg) landed during the month. Under the MFA scheme monthly returns included daily information on the number of pots set and pots hauled, and weight of lobster landed each day. NSFC collate data collected by the MFA to correspond to their existing records (i.e. pot haul days is analagous to number of trips recorded, total lobster landings calculated as the sum of individual trips, and the number of pots worked recorded as the maximum either set or hauled). Since 2006 information on vessels > 10 m and Scottish vessels has been collected separately, and could not be included here. This is not expected to have significant implications for the results presented here, as the inclusion of vessel random effects in the model mean that changes in fleet structure over time are taken into account. Data on fishing vessel length (m) and engine size (kW) was appended to the monthly records from NSFC permit registration records.

Spatial information

The geographical location of fishing activity for the lobster fishery is not well recorded. During 2001-2006 vessels were required to list which sub-area they fished within the NSFC district, however the classification of sub-areas was inconsistent throughout this period. Since 2006 fishers have recorded a code combining information on the ICES sub-rectangle in which they worked and the distance offshore. However, ICES sub-rectangles represent a relatively large area (dimensions of 0.25° latitude by 0.5° longitude; approximately 10 x 10 nautical miles (nmi)), and fishers generally record only one area for each trip, even if fishing gear was distributed across more than one area. Given these limitations, landing port represented the most consistent and detailed spatial information on vessels' fishing location. The home range of vessels from each port was estimated using kernel density estimation in Hawth's tools (Beyer 2004) based on sightings of fishing vessels from 2004-2008 (see Chapter 2 for methods). Port home range was defined as the area in which 95% of potting vessel sightings from each port was expected to occur based on the sample data. Sightings data were collected by NSFC, whose jurisdiction extends to 6 nmi from shore, therefore fishing activity outside 6 nmi is not included in home range estimates.

Data accuracy

Mis-reporting of fisheries data may be a problem for data analysis, particularly where fishers are legally required to discard undersized catch, or where management of the fishery through quotas provide economic incentives for discarding over-quota or low-grade catch (Pascoe et al. 2001). During 2001-2007 lobster fisheries in the NSFC district were managed primarily through a minimum landing size (87 mm carapace length)[7], and no quotas were in place for the main target species (European lobster, brown crab, velvet crab). Consequently there was no obvious incentive for misreporting, and data on lobster landings were considered to be reliable.

While there are some problems with non-reporting that may affect estimates of total landings in the district (Turner et al. 2009), it was assumed that records submitted by individuals were appropriate for comparative purposes between vessels. It is also possible that misreporting may occur when fishers seek to maintain a historical record for vessels owned that are not actively fishing, yet as management in the lobster fishery is not currently based on track record incentives for mis-reporting on this basis were assumed to be minimal. Comparison with scientific catch sampling programmes in the New Zealand lobster fishery suggests that self-reported data such as voluntary logbooks can provide useful data on catch rates (Starr & Vignaux 1997).

Data transformation

Modelling of factors affecting catch rates in fisheries often involves transformation of response variables to meet the assumptions of particular statistical models. The response variable here, lobster landings (kg vessel^{-1} month^{-1}), showed a skewed distribution (Fig. 3.1a).

Fisheries data often contain many zero values, particularly in multispecies fisheries where targeting of one species may lead to zero catch in others. The presence of zero values in fisheries catch records poses a problem for logarithmic transformation of the data. Historically an arbitrary value has been added to all values to allow data transformation, but the choice of this value can affect the outcome of the model (Venables & Dichmont 2004) , and a more common approach now is to model zero values and non-zero values separately (Punt 2000; Maunder & Punt 2004).

In the dataset considered here only 3% (n=156 of 5187) of records of vessels actively fishing (working >0 pots) recorded zero landings, therefore these were removed from the dataset and the response variable was $\log_e$ transformed (Fig. 3.1b). A further 5.4% (n=279) of records were removed due to

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[7] National legislation: The Undersized Lobsters Order 1993, Statutory Instrument 1993 No. 1178 (www.opsi.gov.uk/si/si1993/Uksi_19931178_en_1.htm [accessed July 2010]); Local legislation: NSFC Byelaw 8 (www.nsfc.org.uk/byelaws.html [accessed July 2010])

missing values in model covariates, and 0.2% (n=12) of records were removed due to only one record being available for the vessel. The final dataset comprised 4740 records.

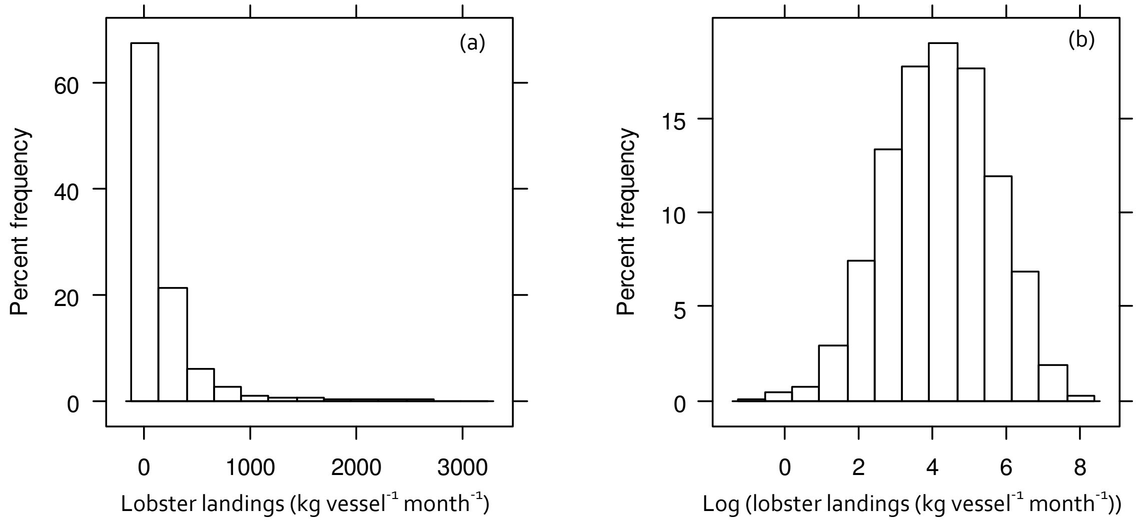

Figure 3.12. Response variable, lobster landings (kg vessel^{-1} month^{-1}): a) untransformed data, b) log transformed

3.2.2 Statistical analysis

A statistical modelling approach using linear mixed effects models was used to investigate factors affecting variability in landings. A progressive model building strategy (following Pinheiro & Bates, 2000) was used to determine the most parsimonious model. Analyses were carried out in the nlme package (Pinheiro & Bates 2009) in R (R Development Core Team 2009).

The nested structure of the data, with individual vessels working from different ports and repeated measures on individual vessels over time, would violate the assumptions inherent in many statistical tests that individual data points are independent. A random effects structure of vessels nested within ports was therefore included in the model to account for unmeasured variables relating to differences among individual ports and vessels. Port and vessel effects were included as random intercepts in the model, assuming that baseline lobster landings may differ as a result of the unmeasured variables associated with these groups. The inclusion of random slope effects was also tested for individual covariates, assuming that the response of lobster landings to the covariates may differ among vessels or ports.

Covariate selection

A number of variables representing fishing effort, vessel capacity, environmental and temporal changes were selected *a priori* for inclusion in the model (Table 3.1). Log_e-transformed lobster landings (kg vessel^{-1} month^{-1}) was included as the dependent variable, and available measures of fishing effort (number of pots and number of pot haul days) were included as covariates in the model. This removed the need to choose between the various measures of landings per unit effort (LPUE) that could be calculated from these variables, allowing the most appropriate measure to be determined by the data (Maunder & Punt 2004). Vessel length and engine size were included as indicators of vessel capacity.

Table 3.8. Model response and covariates

Variable	Name	Description
Response	Landings	Lobster landings (kg vessel^{-1} month^{-1}) – $\log_e$ transformed
Fishing effort	Pot number	Number of pots worked by vessel during month
	Pot haul days	Number of days during the month on which pots were hauled
Vessel capacity	Length	Length (m)
	Engine size	Engine size (kW)
Environmental	Season	Harmonic covariates: *cos(month*π*2/12)* and *sin(month*π*2/12)*
	NAO	Monthly NAO index
Temporal	Year	Year
Interactions	Year x NAO	Reflects change in NAO index over time
	Length x Engine	Reflects combined effect of length and engine size on vessel capacity
	Pot number x Pot haul days	Reflects soak time - effect of pot number depends on pot haul days
	Season x Pot haul days	Reflects seasonal difference in fishing practices and soak time

Harmonic covariates (allowing periodic variation in landings over a 12 month period) were included in the model to account for seasonal changes in lobster abundance and catchability, for example changes related to the moult cycle and activity levels of lobster relating to water temperature and other environmental variables such as salinity. As lobster activity is influenced by weather conditions (including temperature and sea state), data from the North Atlantic Oscillation (NAO) Index[8] were also included to account for broad patterns in regional weather conditions over time. The NAO affects weather of the North Atlantic region, influencing wind speed and direction, temperature, precipitation and storm frequency. Positive NAO index values represent increased westerly winds, cooler summers and milder winters with higher precipitation, and negative values reflecting drier conditions and colder winters. The NAO index represents an integrated measure of weather and therefore may explain more variability than single variables such as water temperature (Hurrell & Deser 2009). In addition it has been suggested that the NAO may influence patterns of abundance observed in the American lobster (*H. Americanus*) (Steneck & Wilson 2001). Year was included to investigate inter-annual changes in landings. Selected interactions between these variables were also included in the model (Table 3.1).

[8] Obtained from Climatic Research Unit, UEA: www.cru.uea.ac.uk/~timo/datapages/naoi.htm [accessed Oct 2009]

Random effects

Initially a full model of lobster landings including all covariates and interactions (Table 3.1) was considered. This model was used to determine a suitable random effects structure by comparing a model with no random effects (fitted using generalised least squares, which does not assume equal variances and allows for correlation among observations), to models with varying random effects structures (fitted using linear mixed effects) (Zuur et al. 2009).

Three models were considered with random intercepts (allowing variation in baseline landings): 1) vessel nested within port, 2) port only, and 3) vessel only. To confirm that both port and vessel random effects contributed to explaining variation in lobster catches, these models were compared against a model with no random intercept effects, and against each other.

Once the optimal grouping structure was established, random effects for the slope of the model were considered for selected covariates (pot number, pot haul days, year, and NAO Index), allowing the effect of the covariate to vary among the groups. Resulting models were compared with models containing only random intercept effects.

Nested models were compared using likelihood ratio tests on models fitted with restricted maximum likelihood (REML) (Zuur et al. 2009). The Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC) were also used to compare models. Models explaining a greater proportion of the variance in the response variable have lower AIC and BIC values (although the absolute value is not meaningful) and penalties are given for inclusion of extra terms in the model to avoid over-parameterisation (Pinheiro & Bates 2000).

Correlation structures

The extent of temporal autocorrelation in the data resulting from repeated measures over time was assessed using a plot of the autocorrelation function (Pinheiro & Bates 2000). Temporal correlation in the data suggests dependence of monthly landings on past catches, and may reflect temporal patterns in abundance or catchability as well as fishers' decision-making behaviour based on prior experience (Mikkonen et al. 2008). The model was refitted with alternate correlation structures to account for the dependence; correlation structures considered included autoregressive (AR) models, moving average (MA) models, and a combined autoregressive and moving average model (ARMA).

AR models express the response variable as a linear function of past values, with the correlation between current and past catches exponentially declining at successive lags. The order of the AR term determines the number of lagged values included as predictors. Autocorrelation may alternatively be accounted for by a moving average (MA) model, which includes zero correlations beyond the specified number of lags. An ARMA(1,1) model includes both AR and MA correlations in the first lag, but behaves in the same way as AR(1) for lags greater than one (Pinheiro & Bates 2000). Each of these correlation structures were fitted and resulting models compared using likelihood ratio tests to assess which provided the best fit (Zuur et al. 2009).

Fixed effects

The initial model considered contained fixed effects for pot number, pot haul days, vessel length, engine size, two harmonic covariates modelling season, NAO index, and year. Interactions between year and NAO, length and engine, pot number and pot haul days, and season and pot haul days were also included. After fitting an appropriate random effects structure and autocorrelation structure, non-significant fixed effects were sequentially removed to determine the most parsimonious model.

Non-nested models with different fixed factors were compared using likelihood ratio tests on models fitted with maximum likelihood (ML) as opposed to restricted maximum likelihood (REML). ML estimation of log-likelihood does not account for the fact that model intercept and slope are estimated; therefore REML is used to fit linear mixed effects models. ML is used to fit models with different fixed effects as these cannot be statistically compared if fitted using REML. ML and REML estimates tend to be similar where the number of fixed covariates is small relative to the number of observations (Zuur et al. 2009). After determining the final set of fixed effects the model was refitted using REML (Zuur et al. 2009). The multiple correlation coefficient r^2 between the log-transformed observed values and fitted values was calculated to assess goodness of fit. The assumptions of linear mixed models were checked by examination of the model residuals for the final model.

Variability among ports and vessels

Random effects in the model represent unmeasured variation relating to differences among ports and vessels. Random effects at port level may relate to differences among ports themselves (e.g. size, facilities and access) or spatial effects relating to the fishing grounds within reach of individual ports (e.g. variation in habitat availability, bathymetry and target species abundance). At vessel level, variability may be related to factors such as skipper experience and knowledge, differences in gear types and bait used, differences in man-power and technology aboard the vessel (e.g. number of crew members, navigation and ground plotter systems, and mechanical aids such as automatic hauling machinery), and variation in patterns of behaviour, including typical soak time, choice of fishing grounds and distance travelled to fishing grounds.

Random effect intercepts were extracted from the final model and correlated with variables relating to ports and vessels (Table 3.2) to further investigate the causes of variability at each level. At port level relationships between random effect intercepts and port attributes, including geographic location, were assessed using Mantel tests, a correlation between two distance matrices summarising pairwise similarities among data points (Legendre & Legendre 1998; Goslee & Urban 2007). The use of distance matrices accounts for the possible non-independence of data points resulting from spatial autocorrelation, and the hypothesis is that the degree of similarity between two points in one matrix corresponds to degree of similarity in the other. Distance matrices were calculated using Euclidean distances, and the Mantel test performed using the Vegan library (Oksanen et al. 2009) in the statistical package R (R Development Core Team 2009). At vessel level the association between random effect intercepts and vessel attributes was tested using Pearson's correlation coefficient.

Table 3.9. Port and vessel attributes analysed with respect to random effect intercepts

Scale	Variable
Port	Geographic position (latitude and longitude)
	Area of hard and patchy ground [b] within port home range (HR) [a] (km^2)
	Area of port HR (km^2) per active vessel
	Area of hard and patchy substrate within port HR (km^2) per active vessel (based on mean vessels yr^{-1})
	Gear density (mean annual pot months km^{-2}) [c]
	Mean observed probability of fishing activity [d] within port home range
	Mean vessel engine size (kW)
	Mean vessel length (m)
Vessel	Length (m)
	Engine size (kW)
	Fishing frequency (mean months fished yr^{-1})

[a] Port home range derived from kernel density estimate based on vessel sightings (see Chapter 2 for methods).
[b] Data on marine substrates obtained from habitat surveys (Foster-Smith 1998), and categorised into hard, patchy and smooth; hard and patchy ground assumed to indicate preferred lobster habitat and potting grounds (Bannister & Addison 1998; Turner et al. 2009)
[c] Pot months calculated on the basis of reported number of ports worked and number of monthly returns submitted by each vessel at each port. One pot month is equal to one pot worked for one month (i.e. one vessel working 100 pots for 12 months = 1200 pot months). Gear density calculated as mean annual pot months per km^2 port HR.
[d] Probability of fishing activity derived from kernel density estimate based on vessel sightings (see Chapter 2 for methods).

The relative importance of spatial variability compared to variability among vessels was assessed by comparing the final model to a version in which the random effect of port was removed. Models were compared using a likelihood ratio test and the multiple correlation coefficient r^2 between the log-transformed observed values and fitted values in both models calculated to allow comparison of goodness of fit.

3.3 Results

3.3.1 Variation in lobster landings

The final dataset included records from 183 fishing vessels engaged in the Northumberland potting fishery during 2001-2007 (Table 3.3). The unbalanced and grouped nature of the data (Table 3.3, Table 3.4) meant mixed-effects models were the most suitable tool for analysis (Pinheiro & Bates 2000; Crawley 2009). Data for 2006-2007 underestimate actual fishing activity, as records for vessels over 10 m in length and those registered in Scottish ports were not required to submit returns from January 2006 onwards. Despite this, both the number of active vessels and returns submitted appeared to decline during 2001-2005. However, the mean number of pots worked per vessel each month increased over time, therefore there has not necessarily been a reduction in fishing effort.

Table 3.10. Active vessels, monthly records and fishing effort, 2001-2007

Year	Active vessels	Number of returns	Mean pot number	Mean pot haul days month^{-1}
2001	102	825	282	11
2002	101	800	287	11
2003	100	798	275	13
2004	90	701	302	12
2005	89	680	331	12
2006*	70	468	359	11
2007*	63	468	349	11

* Data from > 10 m vessels and Scottish vessels not included 2006-2007

Active vessels within the district operated from 12 ports which varied in fleet size, with only four ports having on average more than 10 active vessels per year (Table 3.4). The proportion of full time and part time vessels varied considerably between ports, as did the mean number of pots worked by each vessel, which ranged from <100 in Cullercoats to >500 in Burnmouth. There was less difference among ports in mean numbers of times pots were hauled per month, with vessels in all ports hauling on average 10-14 times per month.

Table 3.11. Summary of fishing activity by port, 2001-2007

Port	Mean active vessels per year	Total active vessels 2001-2007 (% full time*)	Mean pot number	Mean pot haul days
Amble	22	43 (58)	240	11
Beadnell	6	15 (47)	265	11
Berwick	5	8 (63)	230	11
Blyth	10	27 (48)	278	11
Boulmer	3	5 (80)	370	10
Burnmouth	4	9 (78)	532	14
Craster	3	4 (50)	452	13
Cullercoats	2	5 (60)	53	10
Holy Island	5	9 (100)	325	13
N Shields	11	28 (43)	214	11
Newbiggin	6	8 (100)	223	10
Seahouses	12	22 (82)	467	12

* refers to vessels working > 6 months per year on average

There was a marked seasonal pattern in lobster landings, with median landings peaking in August, and declining during winter and spring months (Fig. 3.2). Median lobster landings were 70 kg vessel^{-1} month^{-1} (inter-quartile range 25 - 185 kg vessel^{-1} month^{-1}).

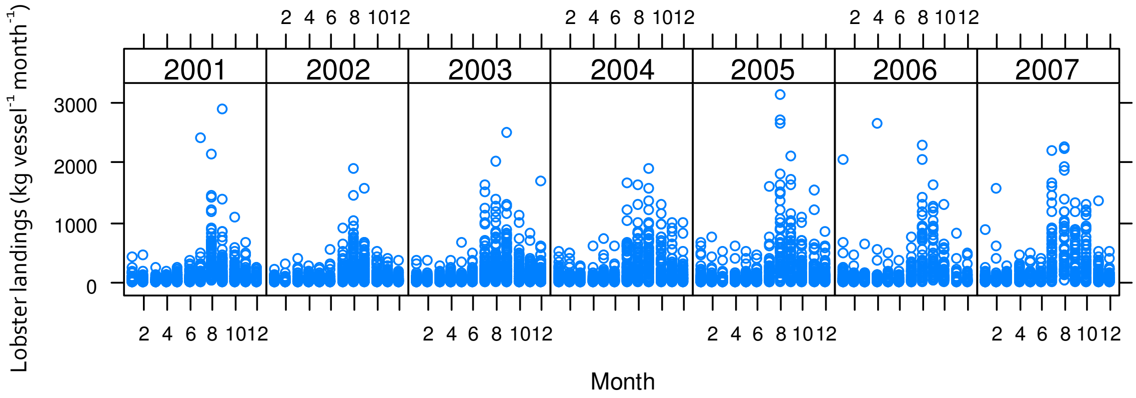

Figure 3.13. Seasonal pattern in lobster landings (kg vessel^{-1} month^{-1}) 2001-2007

Differences in median landings and degree of variability in landings between ports (Fig. 3.3) may be related to heterogeneity of vessels in different ports, differences in fishing effort, or to spatial differences in the abundance or catchability of lobsters throughout the district.

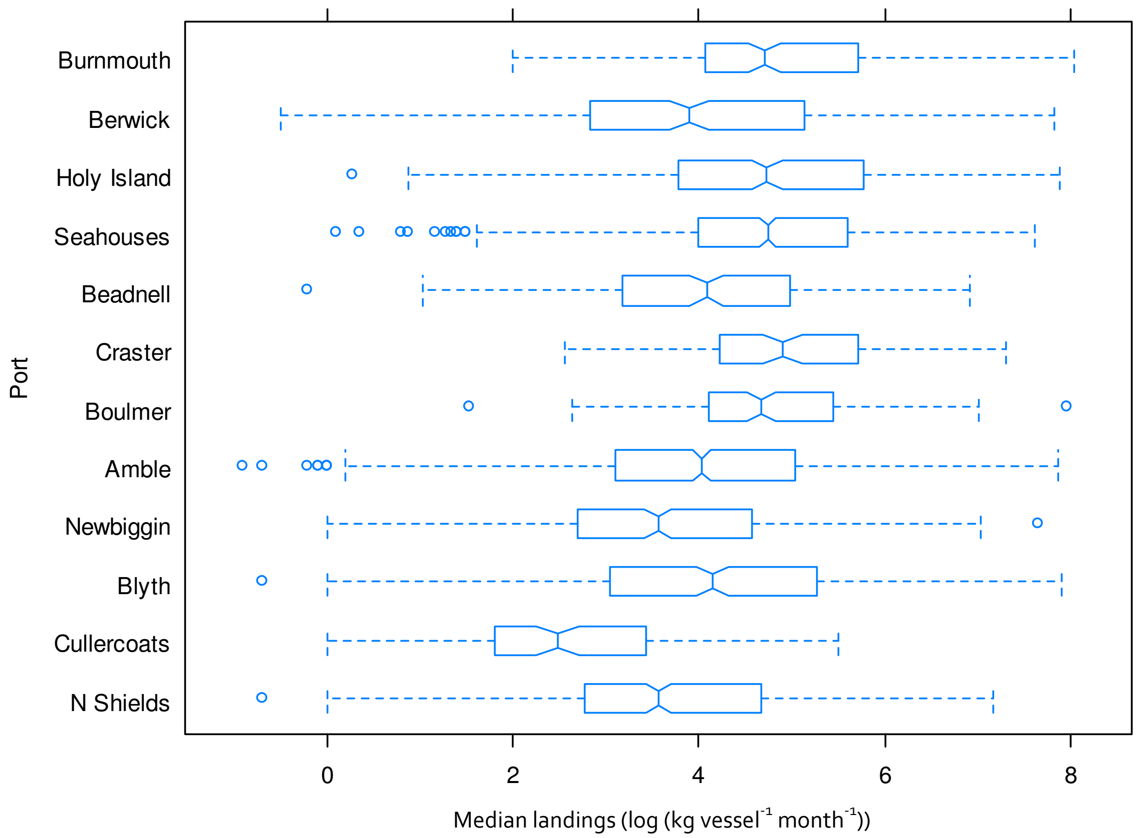

Figure 14.3. Boxplot of median landings at individual ports (log$_e$ (kg vessel^{-1} month^{-1})); box represents inter-quartile range (IQR), notch indicates median, whiskers show values within1.5 times the IQR, circles indicate outliers.

Lobster landings appeared to be positively related to vessel length (Fig. 3.4a), although the relationship of landings to engine size was unclear (Fig. 3.4b). Both measures of fishing effort, number of pots worked and number of pot haul days, were positively related to lobster landings (Fig. 3.4 c-d).

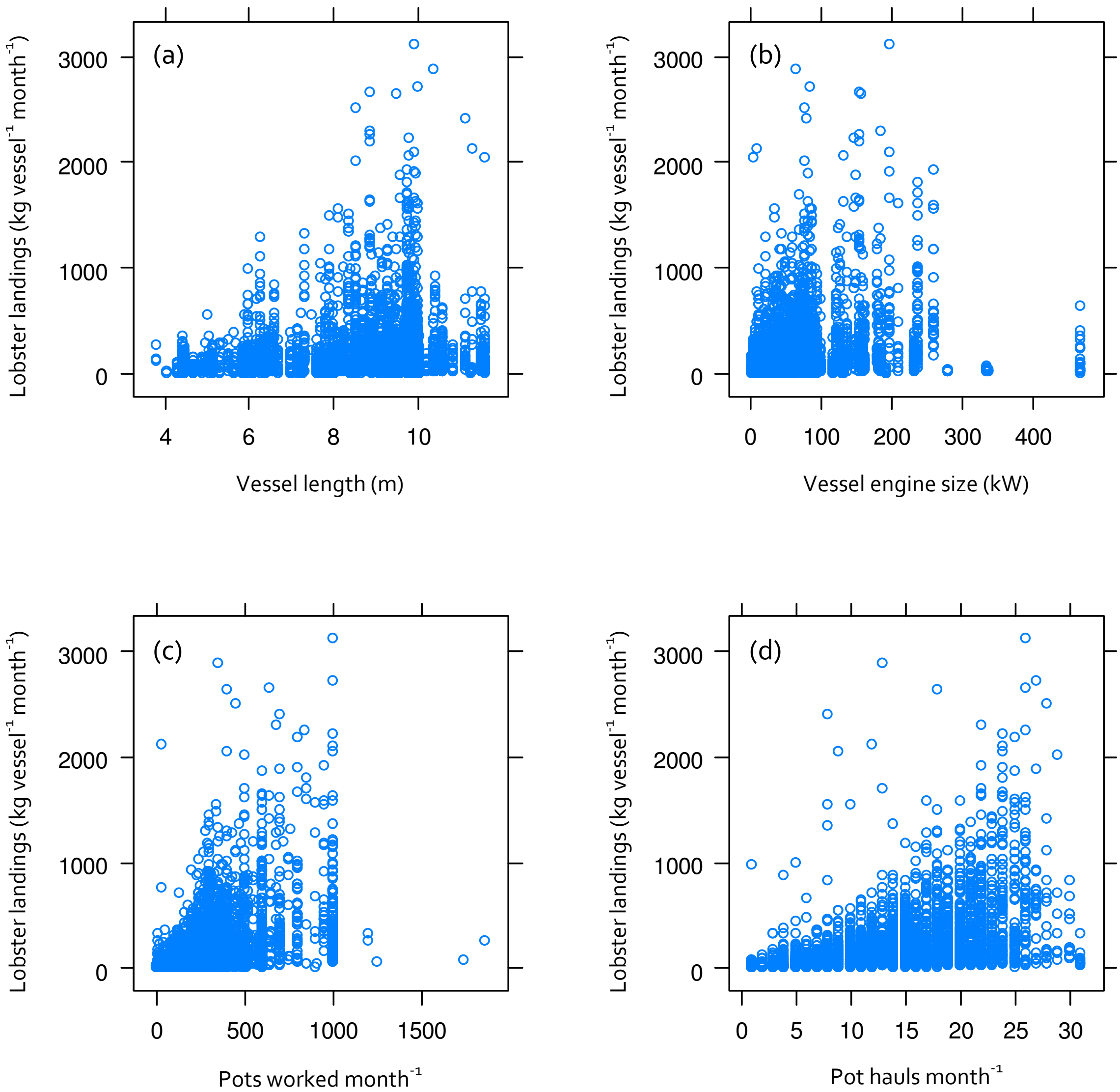

Figure 3.15. Relationship of lobster landings (kg vessel^{-1} month^{-1}) to measures of vessel capacity: a) vessel length (m), b) vessel engine size (kW), and fishing effort: c) number of pots worked, d) number of pot haul days per month

3.3.2 Statistical analysis: linear mixed effects models

Port and vessel random effects in lobster landings

Comparison of models with different random effects structures confirmed that there was variation at both port and vessel level (Table 5), suggesting that baseline lobster landings varied among ports and vessels due to unmeasured variation in these groups. Non-nested models with port or vessel only cannot directly be statistically compared (Crawley 2009) , but the lower AIC and BIC values of model D compared to model C (Table 3.5) suggested that there was greater variability in lobster landings among individual vessels than among different ports. A likelihood ratio test indicated that inclusion of a random slope (see Section 2.2.2) for pot number further improved the model (Table 3.5), suggesting that the relationship between lobster landings and numbers of pots worked varied between ports.

Table 3.12. Comparison of linear mixed-effects models fit by REML, with different random effects structures

Model	Random effects	DF	AIC	BIC	Log-likelihood	Likelihood Ratio	*p* value
A	None	15	11822.61	11919.52	-5896.306		
B	~1 | port / vessel	17	10412.06	10521.90	-5189.032	1414.548	<.0001
B	~1 | port / vessel	17	10412.06	10521.90	-5189.032		
C	~1 | port	16	11566.84	11670.21	-5767.419	1156.774	<.0001
B	~1 | port / vessel	17	10412.06	10521.90	-5189.032		
D	~1 | vessel	16	10480.21	10583.58	-5224.106	70.148	<.0001
C	~1 | port	16	11566.84	11670.21	-5767.419		
D	~1 | vessel	16	10480.21	10583.58	-5224.106	n/a	n/a
B	~1 | port / vessel	17	10412.06	10521.90	-5189.032		
E	~ pot number | port / vessel	21	10345.97	10481.65	-5151.985	74.094	<.0001

Temporal autocorrelation

The data showed that temporal autocorrelation at lags one and two between consecutive observations within groups was significantly different from zero, after which there was some oscillation between positive and negative autocorrelation (Fig. 3.5).

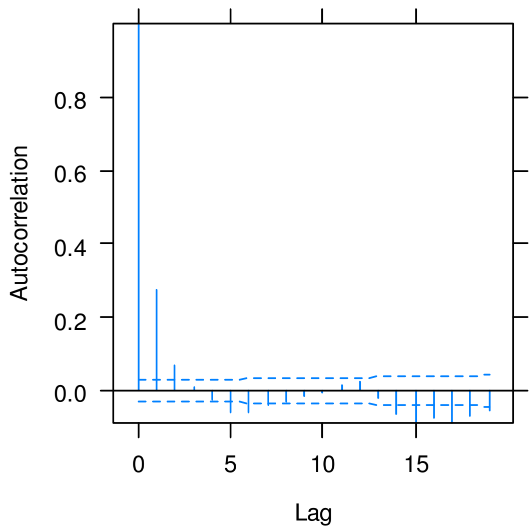

Figure 3.16. Plot of autocorrelation function. Dashed lines represent significance level (α = 0.05).

A model including an autoregressive AR(1) structure resulted in a significantly improved fit compared to a model with no correlation structure (Table 3.6). An AR(2) model (including a further autoregressive coefficient at lag 2) did not result in a significant improvement to the AR(1) model, therefore the simpler AR(1) model was retained. The AR(1) model was also a better fit that an MA(2) model (Table 3.6). However, an ARMA(1,1) model resulted in an improved fit compared to the AR(1) model (Table 3.6), and was retained in subsequent models. These results suggest that there was significant autocorrelation between successive observations within grouping levels (i.e. between multiple data points from individual vessels within ports), and that an ARMA(1,1) correlation structure was optimal among those tested to account for these patterns in the model.

Table 3.13. Comparison of models with different correlation structures (AR = autoregressive, MA = moving average)

Correlation structure	DF	AIC	BIC	Log-likelihood	Likelihood Ratio	*p* value
None	21	10345.971	10481.65	-5151.985		
AR(1)	22	9865.206	10007.34	-4910.603	482.765	<.0001
AR(1)	22	9865.206	10007.34	-4910.603		
AR(2)	23	9863.495	10012.09	-1908.747	3.711	0.054
AR(1)	22	9865.206	10007.34	-4910.603		
MA(2	23	9880.546	10029.15	-4917.273	13.340	0.0003
AR(1)	22	9865.206	10007.34	-4910.603		
ARMA (1,1)	23	9862.810	10011.41	-4908.405	4.396	0.036

Selection of fixed covariates

The least significant fixed effect in the complete model (i.e. a model including all fixed covariates selected *a priori*; Table 3.1) was one of the two harmonic covariates modelling season (Table 3.7); however as these cannot be removed individually (the two covariates model different aspects of the seasonal pattern), a likelihood ratio test was used to compare models with and without the two terms. The comparison suggested that the fit of the model was improved by leaving in both seasonal covariates ($L = 1028.24$, $df = 1$, $p < 0.0001$), despite one being non-significant.

Removal of further non-significant fixed effects and interactions resulted in a final model in which the significant covariates were season, pot number and pot haul days, year, and NAO index, and significant interactions were between year and NAO index, pot number and pot landings, and season and pot landings (Table 3.7).

Positive slope values for year and NAO index indicate that lobster landings have increased over time, and that positive values of the NAO index are associated with higher lobster landings (Table 3.7). The slopes for pot number and pot haul days were 0.003 and 0.103 respectively (Table 3.7), indicating that higher numbers of pots worked and higher frequency of hauling were associated with higher lobster landings. In terms of fishing effort, the number of pot haul days was the strongest predictor of landings, although the number of pots worked and the interaction between pots worked and pot haul days per month were also important. The high *t*-values for season and pot haul days indicate that these were the strongest effects in the model (Table 3.7).

Table 3.14. Summary of final linear mixed-effects model based on 4740 observations from 183 vessels within 12 ports, 2001-2007. Model fitted by REML (AIC = 9813.12, BIC = 9935.892, log-likelihood = -4887.56). Standard deviation of random effects estimates standard deviation of the population, and variance (d^2) estimates of variance around the population mean. Correlations represent correlations between random effect intercepts and slopes at port level and vessel level.

Random intercept effects	Standard deviation	Variance d^2	Correlation		
Port					
Intercept	0.236	0.056	-0.99		
Slope	0.001	<0.001			
Vessel					
Intercept	0.411	0.169	-0.29		
Slope	0.001	<0.001			
Residual	0.688	0.473			
ARMA (1,1) correlation	Parameter estimate				
Phi 1	0.440				
Theta 1	-0.108				
Fixed effects	Value	SE	DF	*t* value	*p* value
Intercept	2.833	0.093	4548	30.550	<0.0001
Season (cosine)	-0.006	0.018	4548	-0.311	0.7555
Season (sine)	-0.686	0.020	4548	-34.448	<0.0001
Year*	0.069	0.010	4548	7.260	<0.0001
NAO	0.041	0.012	4548	3.472	<0.0001
Pot number*	0.003	<0.001	4548	8.251	<0.0001
Pot haul days	0.103	0.002	4548	46.615	<0.0001
Year x NAO	-0.015	0.003	4548	-4.698	<0.0001
Pot number x pot haul days	<-0.000	<0.001	4548	-5.295	<0.0001
Season x pot haul days	0.014	0.002	4548	6.541	<0.0001

* Variables were adjusted due to high correlation with the intercept: years were numbered 1-7, and pot number was centred by subtracting the mean pot number from each value.

Random effects showed that variance (d^2) around the population intercept at port level was lower than variance around the population intercept at vessel level (Table 3.7), illustrating the greater degree of variability in baseline landings among vessels than among ports. Estimated variance around the population model slope was < 0.0001 at both port and vessel level, suggesting that there was significantly more variation in intercepts than in slopes for both ports and vessels.

A negative correlation between the random intercepts and slopes at port level (Table 3.7) indicated that ports with a high positive intercept also have a high negative slope. Ports in which baseline landings are higher thus have lower landings per pot worked (although this does not necessarily imply lower catch rates, since fishing effort is determined by both pot number and pot hauls).

The correlation between fitted values and the log of observed values was 0.887 (t = 132.277, df = 4738, p < 0.0001), with an R^2 of 0.787, suggesting a strong relationship between the observed and fitted values and thus a good fit of the model (Fig.3.6 a). Plots of residuals from the model appear to be normally distributed and centred around zero, and do not show any significant change in variance throughout the range of fitted values (Fig. 3.6.b-d).

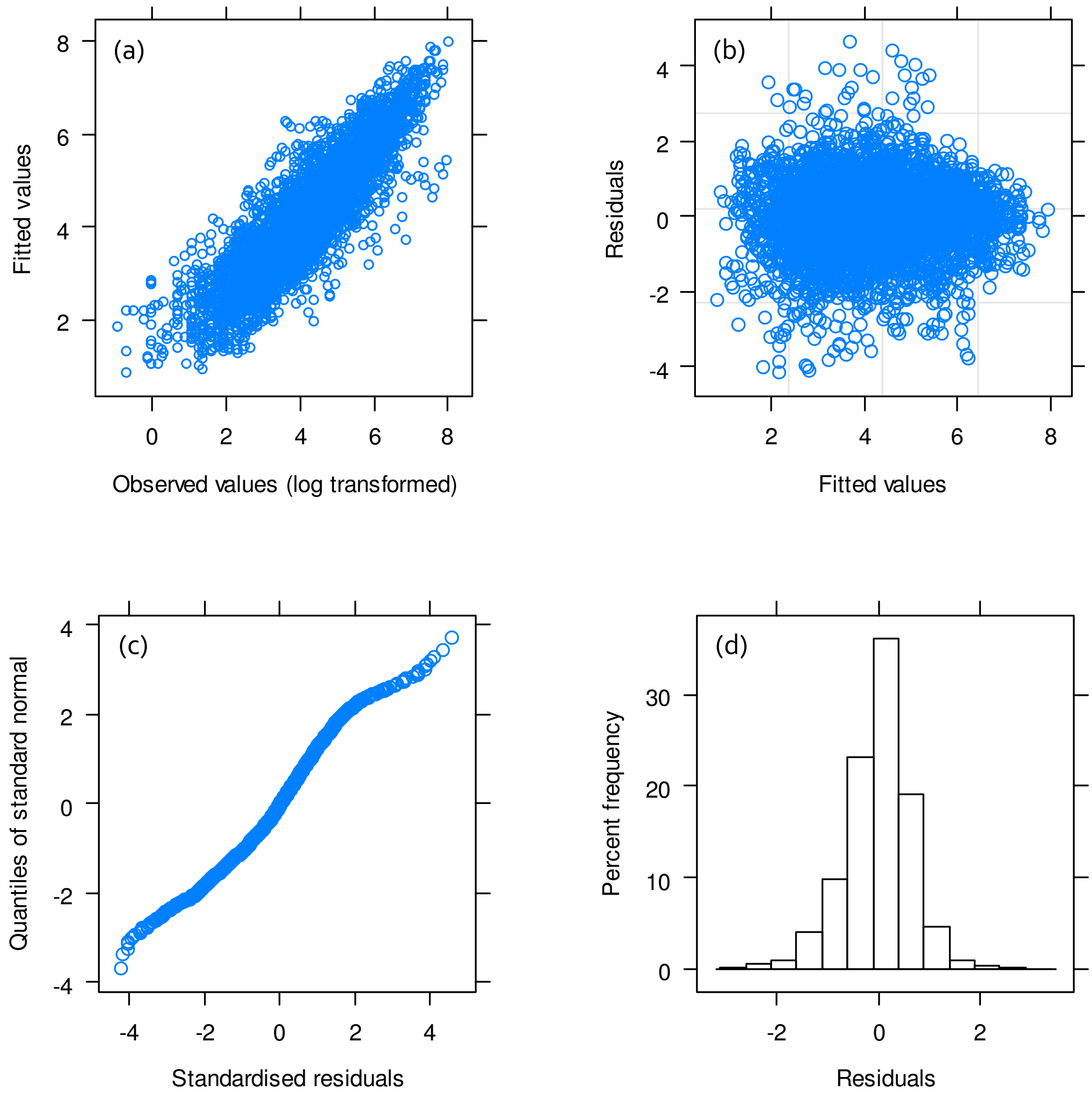

Figure 3.17. Plots checking model assumptions: a) observed against fitted values, b) standardised residuals against fitted values, c) normal quantile-quantile plot, and d) histogram of residuals

No patterns are evident from plots of residuals against the explanatory variables NAO index, pot number, pot hauls or year (Fig.3.7 a-d). However there was some evidence of a seasonal pattern in model residuals (Fig.3.7 e), with residuals appearing to be lower in June and July in particular, suggesting that in these months the model-fitted value exceeds the observed value. This may be a result of fishers' behaviour, as June and July represent the start of peak lobster season, and typically fishers begin putting fishing gear in the water to position themselves in preferred fishing grounds (local fishers, *pers. comm.*, 2009); thus recorded fishing effort is high but catches may be low.

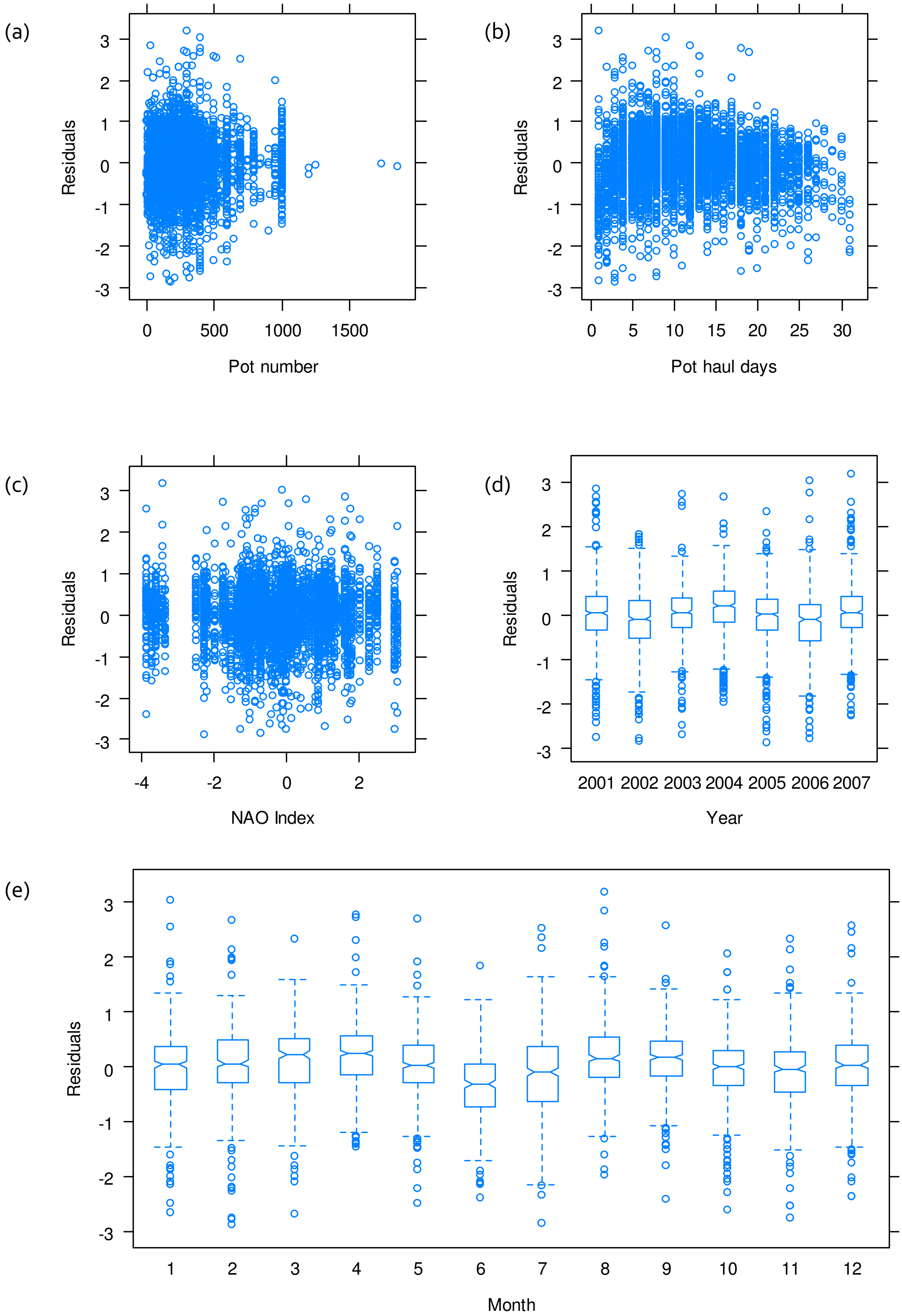

Figure 3.18. Plots of model residuals against a) pot number, b) pot haul days, c) NAO index, d) year, and e) month

Random effect intercepts and slopes from the final model were normally distributed at both port and vessel level, conforming to the assumptions of the model (Fig.3.8 a-b).

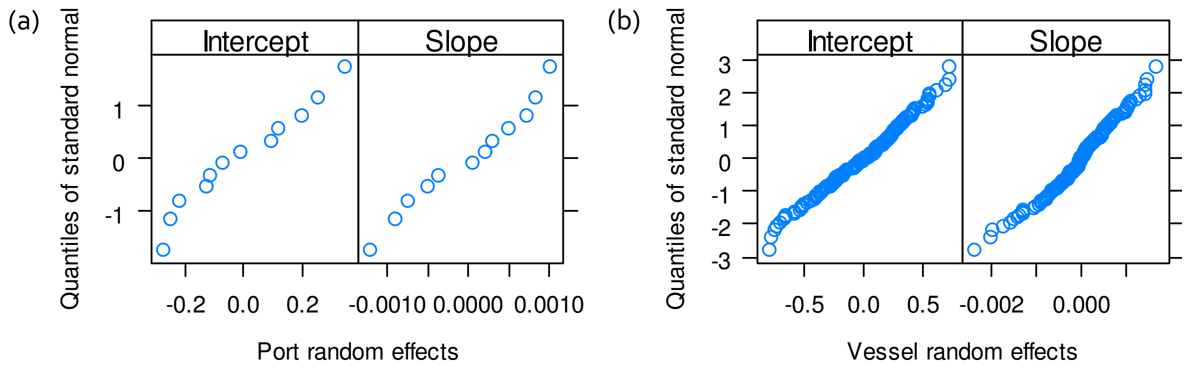

Figure 3.19. Distribution of random intercept and slope effects at a) port level, and b) vessel level

Sources of variability in landings among ports and vessels

No significant correlation was found between distance matrices of geographical distance and random effect intercepts among ports (Table 3.8). However, a plot of random effect intercepts against latitude suggests that ports in the north of the district were generally associated with higher random effect intercepts than those in the south (Fig. 3.9 a), and an independent-samples t-test found a significant difference in random effect intercepts, which were higher in northern ports (mean = 0.109) than in southern ports (mean = -0.152) (t = -3.127, df = 8.071, p-value = 0.014).

Table 3.15. Summary of Mantel test results based on correlations of distance matrices of port level random intercept effects and port attributes (see Table 3.2 for description of attributes); * = significant at 0.05

Port attribute distance matrices	Mantel statistic r_M	Significance
Geographic position (latitude & longitude)	0.065	0.290
Area of hard and patchy substrate within port home range (km^2)	-0.073	0.649
Area of home range (km^2) per active vessel	0.507	0.002 *
Area of hard and patchy ground within port home range (km^2) per active vessel	0.491	0.003 *
Gear density (mean annual pot months km^{-2} home range)	-0.038	0.547
Mean observed probability of fishing activity within port home range	0.102	0.215
Mean engine size (kW)	0.446	0.004 *
Mean vessel length (m)	0.207	0.076

While no significant relationship was found between random effect intercepts and the area of hard and patchy substrate within port home range (HR), there were correlations between distance matrices of random effect intercepts and density of vessels both within port HR, and with hard and patchy ground in port HR (Table 3.8). Random effect intercepts were higher (i.e. higher baseline landings) in ports where vessel density was lower (Fig.3.9 c-d). However, no significant correlation was found between random effect intercepts and density of fishing gear or probability of observed fishing activity (Table 3.8). Although vessel length and engine size were not significant covariates in the model, mean engine size at each port was positively correlated with distances matrices of random effect intercepts (Table 3.8), suggesting that ports with more powerful vessels had higher baseline landings.

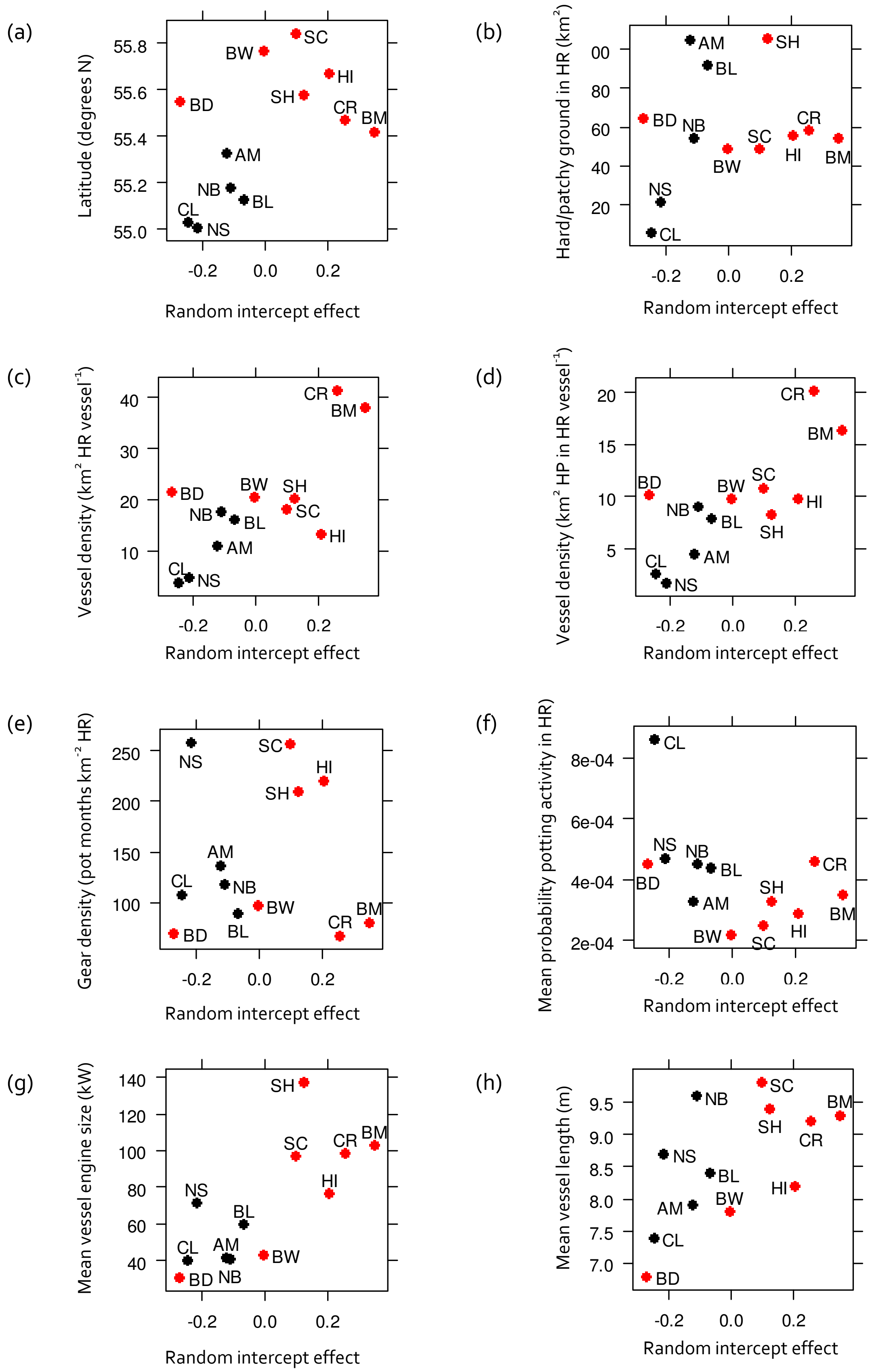

Figure 3.20. Port-level random intercepts and port attributes: a) latitude, b) area hard/patchy ground in port home range (HR), c) vessel density (area home range (HR) per vessel), d) vessel density (area hard and patchy ground (HP) in HR per vessel), e) gear density (pot months per km^2 HR), f) mean probability of potting activity in HR, g) mean vessel engine size (kW) and h) mean vessel length (m). Port names: NS = N Shields, CL = Cullercoats, BL = Blyth, NB = Newbiggin, AM = Amble, BM = Boulmer, CR = Craster, BD = Beadnell, SH = Seahouses, HI = Holy Island, BW = Berwick, SC = Burnmouth (Scottish port). Red = N ports, black = S ports.

At the level of individual vessels, variability among random effect intercepts was found to be weakly positively correlated with both vessel length (r = 0.256, t = 3.561, df = 181, p = 0.0005) and engine size (r = 0.154, t = 2.095, df = 181, p = 0.038), but not correlated with fishing frequency (r = -0.071, t = -0.959, df = 181, p = 0.339).

Relative importance of spatial variability compared to vessel variability

Comparison of models with and without a port level random intercept effect suggested that inclusion of the port grouping factor did lead to a statistical improvement in the model (L = 40.803, df = 1, p < 0.0001). However, correlation between the log of observed landings and fitted values for models including vessel nested within port (r =0.887, t = 132.277, df = 4738, p < 0.0001) and vessel only (r = 0.885, t = 130.628, df = 4738, p < 0.0001) suggested that the improvement in the model by adding a port random effect was of marginal practical significance. Inclusion of the port random effect resulted in a minimal increase in the multiple correlation coefficient (r^2 = 0.787 and r^2 = 0.783 for models including vessel nested within port, and vessel only respectively).

3.4 Discussion

The results presented here highlight the importance of a number of key fishing effort and environmental variables affecting the degree to which variability in lobster landings in Northumberland can be explained. Significant variability in baseline landings was identified among both individual vessels and among fishing ports, and variability at port level was correlated with vessel density and vessel capacity.

3.4.1 Factors affecting lobster landings

There was a strong positive correlation between the log of observed landings and the fitted values in the final model, with fishing effort and seasonal effects the strongest predictors of lobster landings. In terms of fishing effort, the interaction between pot number and pot haul days can be interpreted as reflecting the fact that the effect of the number of pots worked on landings depends on the number of times they are hauled. Since measures of fishing effort were included as predictors in the model, the influence of other covariates can be assumed to represent differences not explained by fishing effort, thus are analogous to their effects on catch rates.

Seasonal patterns in lobster landings are influenced by both biological changes in the fishery and the influence of seasonal weather patterns on fishing conditions. Abundance and catchability of lobsters above the minimum landing size is likely to be higher in late summer following the seasonal moult and growth stages and recruitment of lobsters into the fishery (Miller 1990). Increased feeding activity after moulting may increase attraction to bait and thus increase catchability (Cobb 1995). Furthermore, lobster catchability may vary seasonally depending on lobster activity levels. A study of movement of the European lobster between units of an artificial reef found activity levels to be strongly related to water temperature, with greatest activity in spring and summer (Jun-Nov), and least in winter (Dec-May) (Smith et al. 1999). Levels of lobster activity may significantly affect catchability in pot fisheries (Miller 1990) and changes in activity levels may therefore lead to intra-annual differences in the relationship between CPUE and fishing activity (Smith et al. 2001). Studies of the American lobster (*Homarus americanus*) have found a positive correlation between water temperatures and catch rates, and suggested behavioural responses to be the cause of this, with greater activity linked to warmer temperatures (Drinkwater et al. 2006). Gut content analysis in the American lobster (*Homarus americanus*), suggests that feeding activity may also be related to temperature, with lower attraction to bait in winter (Cobb 1995).

These behavioural traits are consistent with the significant interaction term between season and pot haul days in the model presented here, which suggests that the effect of the number of pot haul days is dependent on season. Local fishers contend that there are seasonal differences in fishing efficiency; it is worthwhile hauling pots more frequently in summer months than in winter months, as catch rates over an equivalent soak time are higher in summer than in winter. Seasonal differences in catchability may also be related to seasonal patterns of habitat use, as it has been suggested that the European lobster makes greater use of inshore habitat in summer, with migration further offshore to deeper water in winter to avoid storm wave action in shallow inshore waters (Smith et al 1999). A higher concentration of lobsters inshore combined with greater activity levels may lead to increased catch rates in summer.

Changes in abundance and distribution of lobster, together with weather conditions, also drive changes in fishers' behaviour, with fishing gear typically being moved more frequently to deeper water further offshore in winter to avoid risk of gear damage in bad weather. The influence of weather conditions is reflected in the model by the significance of the North Atlantic Oscillation (NAO) index, which suggests positive values of the NAO index are associated with increased lobster landings. Positive values of the NAO index are associated with increased westerly winds, which results in improved fishing conditions on the Northumberland coast and greater flexibility for fishers in choosing fishing locations, and milder winters, which may result in increased lobster activity and therefore greater catchability. During winter months when lobsters may be least active or abundant, fishers may also deem it more profitable to target alternate species such as brown crab (*Cancer pagurus*). Habitat requirements of these target species differ, with lobster found on rocky ground in shallow and intertidal zones to depths of 60 m or more (Cobb & Castro 2006; Wilson 2008), while brown crab is also found on coarse sediment and offshore muddy sand (Neal & Wilson 2008), thus fishers' seasonal behaviour and fishing strategies are likely to have implications for catch rates.

The significance of the year term in the model indicates that landings have increased over the study period for reasons not explained by model covariates. This may be related to inter-annual variability in lobster abundance, possibly as a result of variability in recruitment, growth or moult frequency. In warmer years lobsters (*H. americanus*) are found to moult more frequently, resulting in greater recruitment to the fishery (Drinkwater et al. 2006). Year remains a significant predictor despite the inclusion in the model of fishing effort variables, suggesting that change in the number of pots or pots hauls over time is not the cause of this effect. These findings are comparable to those based on logbook data collected by the Centre for Environment, Fisheries and Aquaculture Science (CEFAS) from a small subset of vessels in the Northumberland region since 1985; these data suggest landings per unit effort (LPUE) peak in the late 1990s and decline to low points around 2001-2002, after which they increase slightly (Mike Smith (CEFAS), *pers. comm.*, 2010). The increase detected since 2001 may be related to the age of lobsters caught, reflecting strength of recruitment in different years. Increases in reported landings may also have arisen since 2005 following the introduction of the

Registration of Fish Buyers and Sellers Regulations[9] 2005, which may have reduced the level of unreported landings (Mike Smith (CEFAS) and NSFC, *pers. comm*. 2010). Other changes in fishing practices such as gear type, bait use, or the sophistication of mechanical or technological equipment aboard the vessels are possible explanatory variables, resulting in an increase of fishing power over time (Branch et al. 2006; Marchal et al. 2006a). These factors have been suggested as a possible cause of low explanatory power in some models, since data related to skippers' characteristics, navigational aids and other technology are not readily available, but may have substantial influence on catch rates (e.g. Punt 2000).

Autocorrelation among observations in the model may reflect changes in lobster abundance or catchability over time (e.g. seasonal changes), and also fishers' decision-making and behaviour in response to information on previous catches and fine-scale changes in lobster abundance. Oscillation of autocorrelation beyond the first two lags is likely to result from the fact that the harmonic covariates in the model do not capture seasonal changes perfectly (i.e. onset of seasons may be variable between years). An ARMA correlation structure provided the best improvement to the fit of the model. This is consistent with a previous study which found ARMA models to be optimal for modelling catch rates (Mikkonen et al. 2008). It is suggested that this structure represents a realistic representation of fishers' decision-making based on information available from past catches; fishers' spatial decision-making is based not only on recent catch rates but also on many years of experience in the fishery (Mikkonen et al. 2008).

3.4.2 Spatial variability

The inclusion of the random effect for port was statistically significant, and random effect intercepts at port level suggested generally lower landings in ports in the south of the district than those in the north for the same levels of the fixed effects, although a linear spatial gradient was not identified. The inclusion of fishing effort variables as predictors in the model suggests that this finding is not a result of differences in fishing effort, and implies differing catch rates among ports.

Results identified lower landings per pot in ports which had higher baseline landings (and higher inferred catch rates). Given that ports with higher baseline landings also had higher mean vessel engine size, the negative correlation between baseline landings and landings per pot may be related to differences in the behaviour of small and large vessels. Larger, more powerful vessels tend to work multiple sets of fishing gear, working larger numbers of pots but only hauling a proportion of these on any given day (local fishers, *pers. comm*., 2009). In these cases the reported numbers of

[9] Registration of Fish Buyers and Sellers and Designation of Fish Auction Sites Regulations 2005, UK Statutory Instrument No. 1605 (www.legislation.gov.uk/uksi/2005/1605/contents/made [accessed August 2010])

pots worked are likely to overestimate the number actually hauled, and therefore underestimate the catch per pot.

Previous studies have identified spatial variation in catch rates to be driven by environmental, biological and socio-behavioural factors. For instance, catch rates in Australian shark fisheries varied between study sites, with different age structures and main gear types proposed as possible explanations for differences (Punt et al. 2000). A study of catch rates in Scottish anglerfish (*Lophius* sp.) also found spatial differences, with higher catch rates at Rockall linked to higher densities of anglerfish rather than to differences in fishing activity (Dobby et al. 2008). Differences in catch rates among areas in the Tasmanian rock lobster (*Jasus novaehollandiae*) fishery were related to variable costs (monetary and non-monetary) of fishing in different locations (Hilborn & Kennedy 1992), and catch rates were found to be higher in areas of defended territory in the Maine lobster (*Homarus americanus*) fishery (Acheson 1975). Aside from differences relating to environmental variables, there are no known difference in lobster biology over the scale of the study area discussed here, and the spatial scale considered is at the level of individual ports, therefore the costs of fishing from each port are not expected to vary substantially, although costs of fishing at different locations within port home ranges may be variable. Variability in catch rates implied here may be a result of spatial differences in abundance of lobsters due to environmental variables such as habitat quality, or differences resulting from anthropogenic factors such as levels of fishing pressure; the supporting evidence for each of these drivers is discussed below.

Habitat differences

The boundaries between sedimentary and rocky substrata are a habitat preferred by European lobster, with rocky outcrops offering refuge from predation and shelter from currents, and sandy areas allowing digging for shelter and foraging, as well as migration corridors (Galparsoro et al. 2009). American lobster (*H. americanus*) abundance was found to be higher on moderate boulder habitats, although catch rates were higher on low relief areas, perhaps due to shelter-seeking behaviour on low relief areas or hydrodynamic factors extending the influence of the bait plume from traps (Tremblay & Smith 2001; Dunnington et al. 2005; Geraldi et al. 2009). Information from local fishers suggests that in the south of the Northumberland district the hard and patchy ground is predominantly restricted to areas inshore (within approximately 3-4 nmi of the coastline), with areas further offshore comprising mainly softer sediments fished by trawlers and vessels using prawn creels. In contrast, further North in the district suitable lobster habitat extends >12 nmi from the coast in some areas. However, no relationship was found between the random effect intercepts at port level and the availability of hard and patchy ground within the home range of each port.

Despite this, the availability of suitable habitat may have implications in determining the size of a port home range, and in determining the level of fishing intensity.

Fishing intensity

While the availability of preferred potting habitat was not found to be related to the pattern of port random effect intercepts, a relationship was identified between port random effect intercepts and the density of vessels over the area of hard and patchy ground within port home ranges. This suggests a link between lobster landings and fishing intensity, suggesting generally higher landings in ports with lower fishing intensity (predominantly in the north of the district) than in those with higher fishing intensity (in the south of the district). However, there was no relationship between port-level random effect intercepts and fishing intensity when the latter was measured in terms of fishing gear density, or in mean probability of fishing activity within the home range. It is possible that this may be related to overlap between the home ranges of ports which result in the measure of gear density not accurately reflecting the fishing effort in some areas when calculated on the basis of individual ports. In addition, calculation of fishing intensity variables may be influenced by the absence of data on fishing activity outside 6 nmi when estimating port home range.

3.4.3 Vessel variability

In GLM analysis, accounting for the effect of individual vessels on catch rates may complicate analyses by introducing a large number of parameters; however linear mixed models allow the estimation of fishing power by vessel, and the grouping structure takes account of changes in fleet characteristics over time (Mikkonen et al. 2008).

Typically vessel length and engine power are the variables routinely collected as part of regular fisheries monitoring schemes and used to characterise vessels. In the present case, analysis suggests vessel length and engine size were only weakly correlated with random effect intercepts at vessel level. Other studies have also found significant levels of unexplained variation among fishing vessels. A study of catch rates in the western Mediterranean crustacean trawl fishery found that no single vessel characteristic (length, engine size, gross registered tonnage) was a better predictor of catch rates than vessel, possibly because the knowledge of fishers and presence of technological aids affect fishing power (Sbrana et al. 2003). Similarly, in northwest Mediterranean crustacean fisheries, inclusion of vessel as a predictor explained 18.6% of the variance that was not explained by vessel characteristics (horsepower, gross tonnage and length) (Maynou et al. 2003). Punt (2000) included factors for each vessel in a model to standardise Australian shark catch rates, as vessel efficiency was thought to depend more on fishers' skill and time commitment than on vessel characteristics. In many fisheries catch rates may be related to fishers' familiarity with the life history and behavioural patterns of target species (Maynou et al. 2003). In contrast however, in the Western Mediterranean European hake (*Merluccius merluccius*) fishery, vessel class based on categories of gross registered tonnage explained 54.3% of variance in catch rates (Goñi et al. 1999).

The causes of variation among vessels found herein may be related to a number of factors, including differences in fishing gear and practices, technological and mechanical equipment aboard the vessel, knowledge and experience of individual skippers (the "skipper effect" (Bradshaw & Eaton 2003)), and fine-scale spatial behaviour of individual vessels. In the dataset considered, vessel length and engine size were significant predictors of fishing effort in terms of the quantity of pots worked (modelled separately), but were only weakly correlated with random effect intercepts at vessel level. The results presented support the conclusions of other studies that identify a need to improve understanding of vessel characteristics and fishing behaviour and the way in which they are related to catch rates (Sbrana et al. 2003; Marchal et al. 2006b). Recent work in this area has found catch rates to be linked to indices of spatial diversity in fishing strategies and tactics; inclusion of these variables in calculating fishing effort was found to improve the precision of relationships between fishing effort and fishing mortality (Marchal et al. 2006b).

3.4.4 Relative importance of variability at port and vessel level

The inclusion of the port random effect had only a marginal effect on the correlation between the fitted and observed values, leading to minimal improvement in the multiple correlation coefficient. This suggests that the variability occurring in landings between different vessels is of far greater importance than the broad-scale spatial variability between different ports.

Economics-based theories of fishers' spatial behaviour suggest that where the costs of fishing alternate grounds are equal, fishers will allocate their effort in proportion to the available resource, thus leading to an equalisation of catch rates over space (Gordon 1954; Hilborn & Kennedy 1992). In the Gulf of Maine, spatial patterns of catch rates were found to correspond to patterns of lobster density, suggesting that lobster abundance may regulate fishing effort (Steneck & Wilson 2001). Conversely, differences inferred in catch rates between ports in Northumberland suggest that this equalisation has not occurred over the scale of the NSFC district. This may be because fishers are unaware of broad-scale spatial differences in catch rates, or are insufficiently mobile to respond by re-allocating fishing effort (e.g. because of vessel capability or costs incurred by further travel). The marginal contribution of the spatial effect compared to variability in landings among individual vessels suggests that differences in catch rates may not be detectable to fishers if they are masked by high variability in landings at the level of individuals within ports and throughout the year. Furthermore, even if fishers were aware of differences, the scale of the difference may mean that the economic costs of responding to them (incurred through additional expenses in terms of fuel and travel time) would outweigh any potential benefits in terms of landings. These findings are consistent with studies in the Spermonde Archipelago, Indonesia, where small-scale fishers perceived small scale contrasts in CPUE, but were either unaware of larger-scale contrasts among ports or unable to respond to them, for example due to greater travel costs or physical/economic risk (Pet-Soede et al. 2001). It is relatively rare for vessels in Northumberland to move their base of operation between ports, and when this does occur it is usually for practical reasons such as differences in facilities between ports (local fishers, *pers. comm*., 2009). However, vessels may extend the boundaries of port home ranges towards adjacent ports, and one question that warrants further investigation is the degree to which variable overlap between port home ranges is the result of fishers responding to differential catch rates in the fishing grounds of adjacent ports.

3.5 Conclusion

Spatial variability among ports was not accounted for by the measures of fishing effort, season or weather patterns included in the model, and therefore implies differences in lobster catch rates among ports in Northumberland. However, this variability is minimal in comparison to the variability in landings among individual vessels. Further investigation of the characteristics of skippers and vessels is warranted to explore the source of high variability among vessels and identify whether there are any variables that could be added into routine data collection. The data presented were collected from monitoring of commercial fisheries rather than from formal experiments, which limits the extent to which conclusions can be drawn, and the lack of independent estimates of lobster abundance restricts the interpretation of the results. However, these data currently represent the most extensive source of information available for management of the Northumberland lobster fishery and this analysis is a first step towards understanding the sources of variability in lobster landings, which may be used to develop indicators of relative abundance and monitor fishery dynamics. Analysis of fine-scale spatial variation and movement in response to catch rates would provide further insight into the sources of variability identified here.

Chapter 4.

Drivers of fishers' spatial decision-making and territoriality in the Northumberland lobster fishery

Abstract

An important knowledge gap in contemporary fisheries management is in understanding the drivers of fishers' decision making and spatial behaviour. In particular, the influence of the social context on fishing patterns, including territorial behaviour that may regulate access to fishing grounds, remains poorly understood. Semi-structured interviews are used here to explore fishers' motivations for decision-making and spatial behaviour at the level of individuals and fishing communities in the Northumberland lobster (*Homarus gammarus*) fishery. Wind, weather, personal experience and gear congestion were found to be most highly prioritised among factors affecting individuals' decisions about where to fish. However, principal component analysis and redundancy analysis found that individual fishers were heterogeneous in their perceptions of the importance of factors affecting their decision making, and differences among fishers were not explained by home port, vessel length, pots worked, months worked or fishing experience. No evidence was found of fishers maintaining individual territories, but fishers perceived varying degrees of territorial behaviour at different ports. Differences in fishers' explanations of territorial behaviour at each port are interpreted with reference to both a) economic defendability theory, which suggests that territoriality depends on the costs and benefits of defence in relation to the available resource and foraging populations, and b) theories of social norms and collective action, which emphasise elements of the social structure in influencing behaviour and decision-making. The chapter concludes that ecological and economic factors are important in determining the relative costs and benefits of territorial behaviour, but that decisions are also influenced by community characteristics that influence social rules and norms, and the propensity of fishers to cooperate to defend fishing grounds. Based on these findings it is recommended that future work takes greater account of the social context of fishing activity, and consideration is given to acknowledgment of informal systems of access to resources which may be conducive to more effective resource management.

4.1 Introduction

A major gap in contemporary fisheries management is in understanding the factors driving fishers' decision-making and spatial patterns of fishing behaviour. The behaviour of fishers in allocating their fishing effort may have important implications for understanding spatial patterns in exploitation of fishery resources, as fishers may respond to changes in resource distribution, abundance and catch rates by re-distributing their activity (Gillis 2003). Given the increasing use of spatial measures such as marine protected areas (MPAs)[10] for both fisheries management and marine conservation objectives worldwide, determining drivers that underpin spatial decision-making and effort allocation is important for helping to predict implications of fishers' responses to particular marine policies (Wilen et al. 2002; Smith & Wilen 2003; Valcic 2009). Appreciating the relative importance of drivers of change in resource use behaviour could help to design management measures that better reflect the local context, such as taking account of socio-economic characteristics that could shape fishers' responses in likely scenarios (Hilborn 2007b).

Currently, managers' conceptions of fishers' behaviour often fail to reflect variability, complexity and heterogeneity in fishers' decision-making (Hart & Pitcher 1998; Hutton et al. 2004; Salas et al. 2004; Salas & Gaertner 2004). Much of the work predicting fishers' spatial behaviour and the distribution of fishing activity has been directed at modelling the environmental and economic drivers of behaviour (e.g. Hilborn & Ledbetter 1979; Bockstael & Opaluch 1983; Hutton et al. 2004; Pradhan & Leung 2004). However, complex social arrangements interact with environmental and economic factors to influence fishers' decision-making (Bene & Tewfik 2001; Wagner 2004). Anthropological studies have shown that fishers' behaviour may be influenced by a variety of social norms, relationships, informal rules and institutions that create shared expectations about behaviour (Jentoft 2004; Wagner 2004; Acheson & Gardner 2005). One important manifestation of social influences on behaviour is the development of informal systems of property rights, marine tenure systems and territorial behaviour.

Historically, it has been argued that a key problem facing fisheries management is that fisheries represent a classic case of the tragedy of the commons, with a race for fish occurring where fishers target an open access resource with short-term individual economic interest in mind (Hardin 1968). It has been suggested that alternative forms of property management regimes, such as the allocation of property rights to individuals or groups, can lead to more sustainable management of fishery resources by increasing propensity for collective action and stewardship of the resource

[10] Defined by IUCN as, "Any area of intertidal or sub-tidal terrain, together with its overlying water and associated flora, fauna, historical and cultural features, which has been reserved by law or other effective means to protect part or all of the enclosed environment" (Kelleher 1999).

(Schlager & Ostrom 1992; Ostrom 1999; Agrawal 2001). Common property theorists have argued that open access resources in practice may be managed through common property regimes that regulate resource use through a variety of social institutions, informal rules and norms (Berkes 1985; Berkes et al. 1989). In such cases, social norms and rules that guide individuals' behaviour create shared expectations about the behaviour of others, reducing transaction costs in interaction between individuals, and engendering trust. These changes can help avoid the race for fish by reducing costs of cooperation and increasing the likelihood of collective action for mutually beneficial outcomes.

Such institutions may be formalised to varying degrees, from legally defined ownership of areas (e.g. Ruddle 1989) through to forms of customary marine tenure, which may or may not be legally recognised (Ruddle et al. 1992; Aswani 2005), or more informal systems of territoriality (e.g. Acheson 1972; Levine 1984; Acheson 1988; Wagner 2004). In some cases legal codification and institutionalisation of informal social norms that influence fishers' spatial behaviour could have benefits for fisheries management by encouraging localised stewardship among resource users (Berkes et al. 1989). Local systems of marine territory have in some cases been given legal recognition; for instance in the UK the Devon inshore potting agreement (IPA) remained voluntary for over 20 years before being legally recognised and enforced by a local byelaw (Blyth et al. 2002). Legal recognition of such systems may become necessary when technological, social or economic change weakens the effectiveness of voluntary or informal agreements, although codification of these systems may weaken their flexibility, which can be a key strength in enabling adaptation to change (Ruddle et al. 1992). The focus of this chapter is on investigating informal territoriality, looking at how fishers operate on the basis of social norms, rules and institutions.

There are a number of definitions of territoriality, many emerging from behavioural ecology, which emphasise to varying degrees two key characteristics of territorial behaviour: exclusivity of use and active defence of an area. In the context of human resource use, a territory can be defined as "an area occupied more or less exclusively by an individual or group by means of repulsion through overt defence or some form of communication" (Dyson-Hudson & Smith 1978). There are many examples of areas in which informal rules or norms about rights of access exist in the absence of formal rights of ownership by either individuals or groups of fishers (e.g. Acheson 1972; Levine 1984; Ruddle et al. 1992; Alegret 1998; Begossi 1998; Woodhatch & Crean 1999; Wagner 2004). Territorial defence of a fishing ground is one way in which fishers exert control over resources. Defence of fishing grounds may be through active means such as damaging fishing gear of trespassing fishers (e.g. Acheson 1975) or more passive means such as placement of traps to maintain control over space (Blyth et al. 2002). Territorial behaviour that regulates the access of fishers to particular areas may have implications for economic theory of spatial behaviour in that it can affect potential costs associated with different fishing grounds and thus allow higher catch rates to be maintained in some areas than others (Acheson 1975). However, identifying whether or not territoriality exists is complicated by the high degree of variability in the characteristics of territories, which may vary in the degree to which they are exclusive or overlap, the degree to which they are defended and the methods of defence, and their permanence, stability and flexibility over time (Dyson-Hudson & Smith 1978). Boundaries may be clearly demarcated or diffuse, and territories may apply only to particular resources, technologies or times (Pollnac 1984).

There is debate over the factors that influence the development of and changes brought about in informal systems of territoriality, with a number of inter-related causal variables having been identified, which include environmental, ecological, social and political drivers (e.g. Pollnac 1984). Two bodies of theory are particularly useful in examining the drivers that influence the development and change of territoriality: economic defendability, and theories of social norms and collective action. The theory of economic defendability (Dyson-Hudson & Smith 1978) relates to resource abundance and predictability in relation to the foraging population and degree of competition for the resource, predicting that where resources are abundant and predictable then territoriality will be high (unless resources are so abundant that they are not limiting), whereas if resources are scarce or unpredictable, alternative strategies such as fishers adopting greater mobility may be more advantageous than maintaining a territory (Dyson-Hudson & Smith 1978). Benefits of territoriality are expected from increased availability of resources and greater efficiency in resource exploitation as a result of increased ability to monitor resources when others are excluded (Cashdan 1983). The costs of territoriality relate to the time, energy and risks involved in defence of an area (Dyson-Hudson & Smith 1978). The development of territoriality is therefore seen as a phenomenon resulting from the rational choice of individuals as to the balance of costs and benefits involved in territorial behaviour.

However, the development of territoriality inherently involves social interaction among individuals to determine accepted rules. While ecological and economic factors are important in the development of territorial behaviour, informal territories are commonly regulated by social norms and rules (e.g. informal allocation of fishing grounds) that guide the behaviour of individuals. The ability of groups to create rules and local institutions is therefore important in determining whether systems of territorial behaviour arise and whether individuals can benefit from collective action. Informal agreements and cooperation norms are generally thought to be easier to achieve in small groups where resource users interact frequently and are able to monitor each other, enabling the development of norms and trust, which can facilitate collective action (Ostrom et al. 1999; Dietz et al. 2003). Explanations of differences in local resource management or territorial behaviour should therefore consider drivers relating to the social context, such as community cohesiveness (Levine 1984). Understanding fishers' decision-making requires an appreciation of many drivers underpinning behaviour at both the level of individual fishers, and of fishing communities.

One case where there has been considerable research into informal regulation of resource access is the lobster fishery of Maine, where informal systems of territoriality among fishers have led to economic and ecological benefits (e.g. implementation of voluntary local conservation measures, higher numbers of lobsters per trap, more larger lobsters, and higher profits) (Acheson 1990), helped facilitate voluntary fisheries management measures such as trap limits and closed seasons (Acheson 1998), and ultimately contributed to the development of a co-management law in which fishers share responsibility for management of the fishery (Acheson & Taylor 2001). In Europe, the history of the Common Fisheries Policy (CFP) has contributed to a lack of legitimacy in fisheries management, as rules are not perceived to ensure a fair distribution of resources (Woodhatch & Crean 1999). Fisheries management thus far has tended to overlook existing informal rules for resource management, yet increasing attention is warranted to learn lessons from local management systems that have been successful (Blyth et al. 2002). The impending 2012 reform of the CFP recognises importance of small-scale fisheries to social fabric, cultural identity and economy of coastal communities, and acknowledges maintaining these benefits to be a legitimate social objective of fisheries management, providing impetus for greater consideration of the social context of fisheries management (Commission of the European Communities 2009; Symes & Hoefnagel 2010).

This chapter seeks to identify factors influencing fishers' short-term (day-to-day) decisions about the spatial allocation of their fishing effort in the Northumberland potting fishery, a multi species fishery targeting predominantly European lobster (*Homarus gammarus*) and brown crab (*Cancer pagurus*), but also velvet swimming crab (*Necora puber*) and prawns (*Nephrops norvegicus*). Target species are fished using pots, which are typically fished in 'fleets' of 20-40 per string. Pots are baited and deployed, and left to soak for typically 1-2 days in summer, and often longer in winter, depending on weather conditions. Potting vessels in the district are all 4-12m in length, with most skippers being owners or co-owners of vessels. The majority of vessels work within the 12 nmi limit and employ one or two crew members. The relative similarity among fishers and their fishing practices provides a rationale for choosing this case study to examine differences in fishers' motivations and decision-making, and explore whether territorial behaviour is displayed. Furthermore, the ecological characteristics such as the restricted range of the fishery (e.g. relating to the distribution of suitable habitat) and relatively low target species mobility are considered to be conducive to territorial behaviour (Wilson et al. 2007). Fishers' perceptions of rights of access to and ownership of fishing grounds are discussed with a view to identifying how social, ecological and economic drivers influence the development and change of behaviour related to territoriality. Specifically the objectives of this chapter are to address the following questions:

1. How do fishers perceive the relative importance of environmental, economic and social factors affecting decisions about spatial allocation of fishing effort?
2. To what extent does territoriality occur in different ports?
3. To what extent can drivers of territorial behaviour be explained by the theory of economic defendability, or by social and cultural characteristics of communities?

4.2. Methods

4.2.1 Data sources: semi-structured interviews

Data were collected through in-depth face-to-face interviews with fishers to determine what factors underpin their decision-making and behaviour (Holland & Sutinen 1999; Anderson & Christensen 2006). Interviews were conducted between March and September 2009 with 44 fishers (94% of active fishers) at 5 ports (Table 4.1).

Table 4.16. Port, interviewee and fleet characteristics (percentages given as percentage of respondents who replied)

Port / interviewee characteristics	Port				
	Blyth	Amble	Boulmer/Craster	Seahouses	Holy Island
Active potting vessels	11	17	4	9	6
Interviews (% of active vessels)	10 (91)	16 (94)	3 (75)	9 (100)	6 (100)
Mean age (SE)	47 (3)	52 (3)	47 (8)	42 (4)	56 (5)
Mean years experience fishing (SE)	23 (3)	29 (4)	31 (9)	25 (3)	40 (5)
Mean years experience potting (SE)	19 (4)	18 (3)	31 (9)	19 (3)	32 (6)
% formerly/currently trawling* (n)	50 (5)	75 (12)	0 (0)	89 (8)	67 (4)
% from fishing background (n)	50 (5)	87 (13)	100 (3)	100 (9)	100 (6)
% long-term resident of port (n)	22 (2)	75 (12)	100 (3)	78 (7)	100 (6)
Mean vessel length (m) (SE)	9.0 (0.56)	7.8 (0.47)	8.2 (0.32)	9.9 (0.35)	8.5 (0.51)
Mean engine size (kW) (SE)	106 (28)	56 (11)	138 (25)	187 (43)	119 (39)
Mean no. of lobster pots (SE)	410 (60)	388 (55)	583 (44)	636 (74)	575 (101)
Mean no. of total pots (incl. prawn*) (SE)	540 (112)	458 (67)	583 (44)	813 (166)	575 (101)
% using other gear (n)	40 (4)	56 (9)	67 (2)	33 (3)	0 (0)

* prawn pots (or creels) are listed separately as they are designed primarily to target prawns rather than lobster and are usually worked on softer sediment than lobster and crab pots

The target population for the survey comprised skippers of registered fishing vessels holding Northumberland Sea Fisheries Committee (NSFC) shellfish permits, who were considered by NSFC fishery officers to be actively targeting shellfish (potting within the last 12 months). Lists of active fishing vessels were corroborated by cross-checking fishing vessel lists obtained from NSFC with interviewees at each port. Due to the small number of fishers at each port (Table 4.1) an attempt was made to interview all those identified. Initial contact with a number of fishers was made through introductions by NSFC officers. Subsequent interviewees were contacted via snowballing methods (i.e. interviewees provided contact details or introductions to others) (Bunce et al. 2000), or by approaching fishers on the quayside. Thirty to forty percent of fishermen in all ports work single-handedly, while others work with one or two crew members. All interviews were conducted with vessel skippers (the majority of whom were owners or co-owners of vessels), and in some cases vessel crew were also present. Vessel skippers were targeted as they are most likely to be the individuals who make decisions concerning where to fish. While the use of snowballing methods can lead to bias in the event that respondents may be more likely to provide introductions to others similar to themselves (Richardson et al. 2005), the small number of fishers in the target communities meant that it was possible to interview a very high percentage of fishers using this method.

Interviews were carried out at times and places convenient to fishers and the purpose of data collection and intended use of data were discussed before each interview. The ports chosen for interviewing were chosen to represent a range of ports within the district, both geographically and in terms of port characteristics such as size and composition of fishing fleet (Table 4.1). Interview questions were piloted with three fishers (two retired fishers and one current fisher who was not part of the target population) to determine suitable wording.

Interviews were conducted face to face and were semi-structured, lasting between 30 minutes and 3 hours. Background information was collected on respondents' demographic history, vessel details and seasonal fishing practices (Section A; Appendix 1). Respondents were asked a combination of open-ended and closed questions designed to elicit information on fishers' decision-making, in particular in relation to spatial behaviour (Sections B-C; Appendix 1). Open-ended questions on short-term and long-term behaviour were initially asked to obtain fishers' initial views on the factors that influence their decisions about where to fish. Subsequently, fishers were prompted with 14 factors identified from the literature on fishers' decision-making, and asked to rate their importance in their day to day decisions about where to fish. Each factor was rated on a four point scale, from 'not important' to 'very important', and fishers were given an opportunity to add and rate the importance of any additional factors they felt had been omitted. Qualitative statements made in relation to the rating of each factor were also recorded.

Pilot interviews highlighted the fact that interviewees' views on territoriality were difficult to elicit, and often were expressed in response to tangential questions. Questions were therefore revised to broaden the wording of questions, and additional questions were included to give further opportunities for respondents to discuss this topic. Interviewees were asked a series of closed and open-ended questions about formal and informal rules in the fishery that affected where people choose to fish, the extent to which there was conflict over space in the fishery, and the degree to which fishers were considered to be protective of fishery resources. Fishers were also asked for their opinions on various aspects of the local fishing community (Sections D-E; Appendix 1).

The majority of interviews were digitally recorded and later transcribed. Responses to each question were stored in a Microsoft Access relational database. Due to the small size of both ports, data from Boulmer and Craster were grouped together in the analysis to protect the anonymity of individual fishers (Maurstad 2002).

4.2.2 Data sources: observations of fishing activity

Maps of the extent of port home range overlap were created based on sightings of fishing vessels within the district from 2004-2008, recorded by Northumberland Sea Fisheries Committee (NSFC).

Probability of fishing activity throughout the district was estimated using kernel density analysis in Hawth's Tools (Beyer 2004), and the home range of fishers from each port estimated using the 95 percent volume contour. Home range is defined in this context as the smallest area accounting for a specified proportion (in this case 95%) of the distribution of vessel activity from each port (following Van Winkle 1975). The extent of the home ranges depicted do not represent the absolute extent of the fishing grounds or boundaries of use, but illustrate the area in which 95% of the fishing activity from each port is expected to occur based on the sample of observed activity (see Chapter 2 for more detail on methods). The area in which port home ranges overlapped with those of other ports was identified and calculated as a percentage of the home range.

4.2.3 Quantitative data analysis

Responses to closed questions were extracted from the database and the responses of fishers summarised. Differences in the perceived importance of factors affecting fishing behaviour (Section B; Appendix 1) between fishers in different ports were assessed using the nonparametric permutation test for analysis of similarities (ANOSIM).

Factors affecting fishers' behaviour were examined using principal components analysis (PCA) to identify any underlying variables influencing decisions about where to fish based on correlations between the measured variables (Zuur et al. 2007). Loadings for each variable were estimated and a bi-plot of the first two components displayed. Differences in perceived importance of the factors were further explored using redundancy analysis (RDA), which is a form of PCA in which the axes are constrained to be linearly related to selected explanatory variables (Zuur et al. 2007). The explanatory variables used were vessel length (m), number of lobster and crab pots worked, months fished per year, and fishing experience (years worked). The conceptual model for the RDA was based on the hypothesis that these variables constrain fishers' decisions about where to fish, characterising their vessel capabilities and scale of operation (vessel length and number of pots), seasonal fishing activity (months worked) and practical fishing experience and accumulated knowledge (years fishing).

Analyses were conducted in the vegan and base packages in R (Oksanen et al. 2009; R Development Core Team 2009).

4.2.4 Qualitative data analysis

There were many instances in which interviewees made statements relevant to one question when responding to another, therefore all qualitative data were extracted from the Access database and transferred to NVivo V.7 (QSR 2006) for qualitative data analysis. Qualitative statements made by fishers were manually coded according to a set of themes (Table 4.2) which were derived *a priori* from relevant literature, in particular from a model proposed for the analysis of territorial use rights in fisheries (TURFS) (Pollnac 1984).

The first codes related to whether or not respondents felt that there was territoriality among fishing vessels or ports, and corresponded to characteristics of territoriality, including exclusive use and boundaries, active defence of fishing grounds, and perceptions of access and ownership. Subsequently, responses were coded to identify factors driving change in territorial behaviour, or explaining differences in the degree of territoriality among ports.

Table 4.17. Qualitative coding themes used in content analysis; adapted from Pollnac (1984)

Coding theme	Description
Evidence for territoriality	
Perceptions of access and ownership	Perceptions of who owns and has rights of access to fishery resources
Boundaries of fishing grounds	Perceptions of boundaries of fishing grounds at each port
Defence of fishing grounds	Methods of defending fishing grounds from other resource users
Attitude towards new entrants	Opinions on acceptance of new fishers at each port
Explanations for territorial behaviour	
Costs and benefits of territoriality	Rational cost-benefit explanations for territorial behaviour
Species distribution / abundance	Relative abundance of target species and potential benefits of territoriality
Fishing intensity	Change over time, level of congestion and change in fleet structure
Technological change	Implications for vessel capability (e.g. speed) and value of local knowledge
Legality	Implications of legal context for cost of territorial defence
Social norms and values	Influence of social norms and values on fishers' behaviour
Community	Perceptions of community cohesiveness
Tradition	Influence of traditional fishing practices and fishing locations
Accepted behaviour	Perceptions of code of practice or socially accepted behaviour among fishers

4.3 Results

4.3.1 Factors affecting spatial allocation of fishing activity

Fishers' prioritisation of factors affecting their decisions about spatial allocation of fishing effort (Fig. 4.1) did not vary significantly between ports (ANOSIM R = -0.35, p = 0.71). The mostly commonly prioritised factors, considered very important by 80% of fishers, were wind and weather (grouped as one factor). If strong winds were forecast, fishers tended to move their pots to deeper water to prevent damage to gear in rough seas. Weather conditions were also thought to affect lobster activity and hence catchability, with four fishers mentioning that they expected to get better catches when there was a slight swell, as lobsters would be more active than in clear, calm conditions.

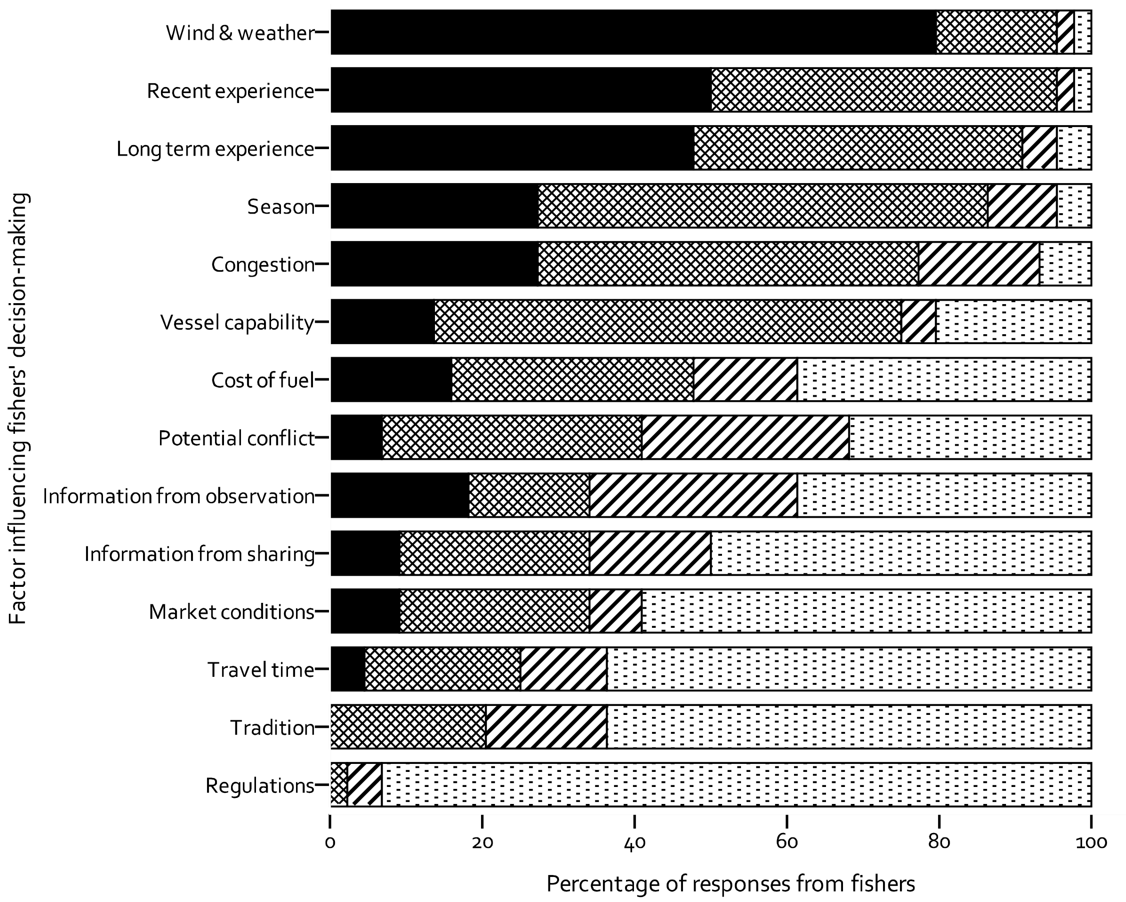

Figure 4.21. Fishers' perceived importance of factors affecting short-term decisions about fishing location: very important (solid shading), important (cross-hatch), less important (diagonals) and not important (dots)

Both recent and long-term experience in the fishery were highly prioritised by the majority of fishers (perceived to be important by 95% and 91% of fishers respectively; Fig. 4.1). Short-term experience (information obtained from most recent fishing trips or most recent experiences of different fishing grounds) was considered important in making decisions on the basis of recent catches, with pots often being re-deployed in the same location if catches were good in the previous haul. However, seven fishers noted that short-term experience was not always reliable, and fishing success could be due to luck, as resources were considered to be unpredictable over space and time. Similarly, several fishers kept logbooks and considered long-term experience, built up throughout their career, to be important in developing knowledge of which areas were productive at particular times of year or under certain weather conditions. However, seven fishers commented that the productivity of different fishing grounds could change from year to year.

Season was perceived to be important or very important by 86% of fishers, due to both changing weather conditions and seasonal biological cycles or movements of target species. Full time fishers commented that they tended to move fishing gear closer inshore in summer to target lobster and velvet crab, and further offshore in winter to target large lobsters and brown crab. Six fishers believed seasonal differences had become less important over time, with some commenting that lobsters seemed to be casting their shells earlier than they used to, and could increasingly be targeted all year-round rather than only seasonally. Others noted that season was important as an indication of where to fish, but localised abundances might vary within seasons from year to year.

Congestion, or the number of vessels fishing in a particular area, was considered important or very important by 77% of fishers in their decision-making. Fishers preferred to try and find 'fresh ground' to place gear on when possible, but fifteen fishers commented that this had become increasingly difficult due to greater numbers of pots being worked. While some commented that the presence of other vessels in an area indicated there must be something worth catching, others suggested that everything there would already have been caught, therefore it was preferable to move to alternative grounds. Congestion was one of the factors mentioned by fishers in discussing conflict with other potters, while nine fishers also discussed conflict with other gear types such as trawling, which was generally perceived to be less of a problem than it was in the past.

Perceptions of the value of information from other fishers when deciding where to fish were mixed, with 34% perceiving both observation of others and sharing information to be important or very important. While fishers said that observation of others was a source of information about what others were catching and where, twelve commented that they didn't pay attention to anyone else. Information from sharing with others was not considered at all important by 50% of respondents, with fishers commenting that most would be unlikely to tell the truth about what they had caught and where they had caught it.

Vessel capability (including factors such as vessel speed, size and navigational or hauling equipment aboard) was predominantly discussed in terms of safety, with smaller vessels being more restricted to inshore fishing grounds, and larger vessels having greater freedom to explore areas further afield. Similarly, fuel was seen by 48% of respondents to be an important factor, particularly by fishers that tended to travel further, who said that they considered fishing closer to home if catches were poor or if fuel prices were particularly high. Market conditions were considered important or very important by 34% when deciding where to fish, and some commented that this was more important for vessels with high running costs. Eight fishers also commented that there were productive lobster fishing areas that they tried to leave alone during peak season when prices were lowest, or that when prices were high they might take more of a risk in where they decided to fish.

Tradition, in terms of areas traditionally fished by individuals or across generations, was not seen to be very important by any fisher. Some acknowledged that people had particular areas they had always fished, but others said that this had become less important among younger generations. Regulations were generally not seen to be important, as there were currently no formal regulations that restricted where people fished. However five fishers commented that the recent pot limitation (NSFC byelaw 15[11], implemented part-way through the fieldwork period in June 2009) would affect the spatial behaviour of those fishing large numbers of pots, as they would be restricted to only 800 pots within the NSFC district.

Principal component analysis (PCA) showed that there was no single trend of variation in the data. The first four components identified explained only 52.1% of variance in the data (Table 4.3), and the first two explain only 31.6% of variance in the data, making the correlation biplot (Fig. 4.2) difficult to interpret. The PCA biplot suggests positive correlations between weather and short-term experience, between tradition and information from other fishers, and between travel time and potential conflict (Fig. 4.2). The plot also suggests possible negative correlations between perceived importance in decision-making of information from others and importance of markets and regulations. However, given its poor representation of variance in the data, strong trends should not be interpreted from the biplot.

PCA loadings show that the first principal component, which explained 16.4% of the variance in the data, was related primarily to the perceived importance of wind and weather conditions, short-term experience, and gear congestion (Table 4.3). The second axis, explaining a further 15.2% of the variance, is related to travel time and potential conflict (Table 4.3). The third component is related to the perceived importance of information from other fishers, and the fourth component is related to long-term experience, regulations and market conditions (Table 4.3).

[11] NSFC Byelaw 15 (www.nsfc.org.uk/byelaws.html accessed July 2010])

Table 4.18. Summary of principal component analysis. Mean and standard deviation (SD) of ratings for each variable and loadings for first four principal components based on normalised data. Ratings relate to perceived importance of the variable in affecting decision making, based on a scale of 1-4, where 1 = not important and 4 = very important. Principal component eigenvalues are shown as the cumulative percentage of explained variance, and factor loading scores of <0.40 are not displayed.

Variable ID	Variable	Mean rating	SD	Principal component loadings & cumulative % variance explained			
				PC1	PC2	PC3	PC4
				16.4%	31.6%	42.5%	52.1%
A	Weather & wind	3.73	0.62	-0.50			
B	Short-term experience	3.43	0.66	-0.49			
C	Long-term experience	3.34	0.78				0.49
D	Season	3.09	0.74				
E	Congestion	2.98	0.85	-0.44			
F	Vessel capability	2.68	0.96				
G	Fuel costs	2.25	1.14				
H	Potential conflict	2.16	0.96		0.49		
I	Information (observation)	2.14	1.13			0.41	
J	Information (sharing)	1.93	1.07			0.58	
K	Travel time	1.66	0.96		0.47		
L	Tradition	1.57	0.82				
M	Regulations	1.09	0.36				0.43
N	Market conditions	1.84	1.10				0.55

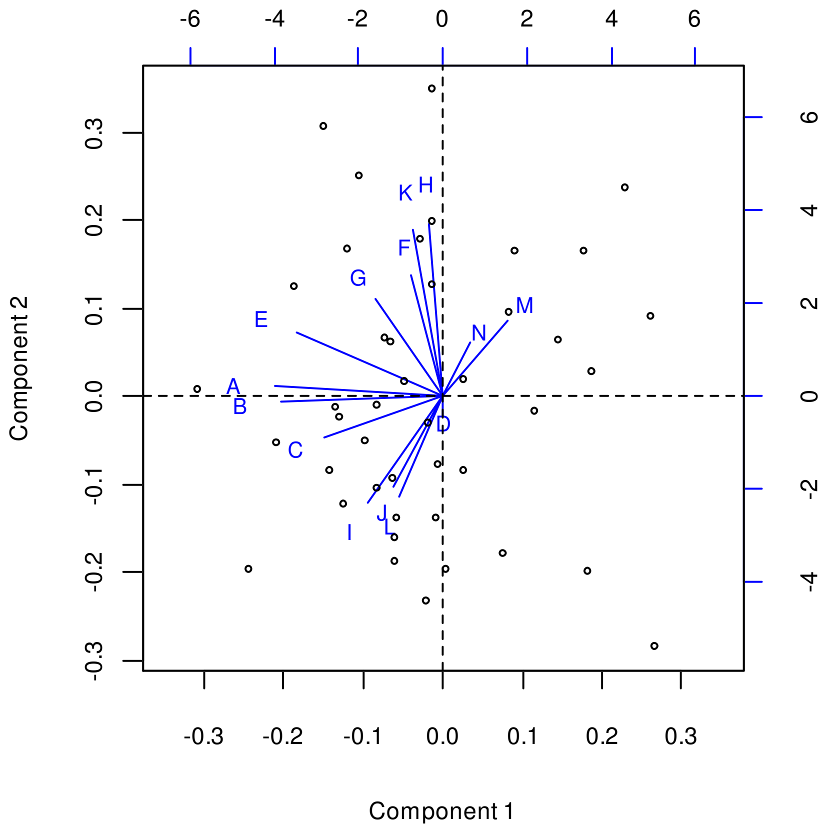

Figure 4.22. Correlation biplot representing correlation matrix between variables affecting fishers' decision-making (variable codes as listed in Table 4.3). The length of the line indicates how well the variable is explained by the first two axes (Zuur et al. 2007). The angles between the lines give an indication of the correlation between the variables, with smaller angles representing greater correlation. PCA 1 and PCA 2 explain 31.6% of variance in the perceived importance of variables affecting decision-making.

A redundancy analysis (RDA) triplot suggests that three of the selected explanatory variables, number of lobster pots worked, vessel length, and months of the year worked, were positively correlated to each other (Fig. 4.3). These variables appear to be negatively correlated with fishers' perceptions of the importance of congestion, vessel capability and short-term experience. There also appears to be a negative effect of fishing experience on rating of fuel, travel time and regulations, and a positive effect of fishing experience on information sharing and tradition (Fig. 4.3). The first two axes represent 72% of the variance in relationships between variables and explanatory factors (Table 4.4), suggesting that the two dimensional representation (Fig. 4.3) describes the observed variance in the data reasonably well. However, the first two axes explain only 9% of the variance in the perceived importance of factors affecting decisions about where to fish (Table 4.4). The very high residual variation in the data suggests that the explanatory variables used do not explain variance in fishers' perceptions.

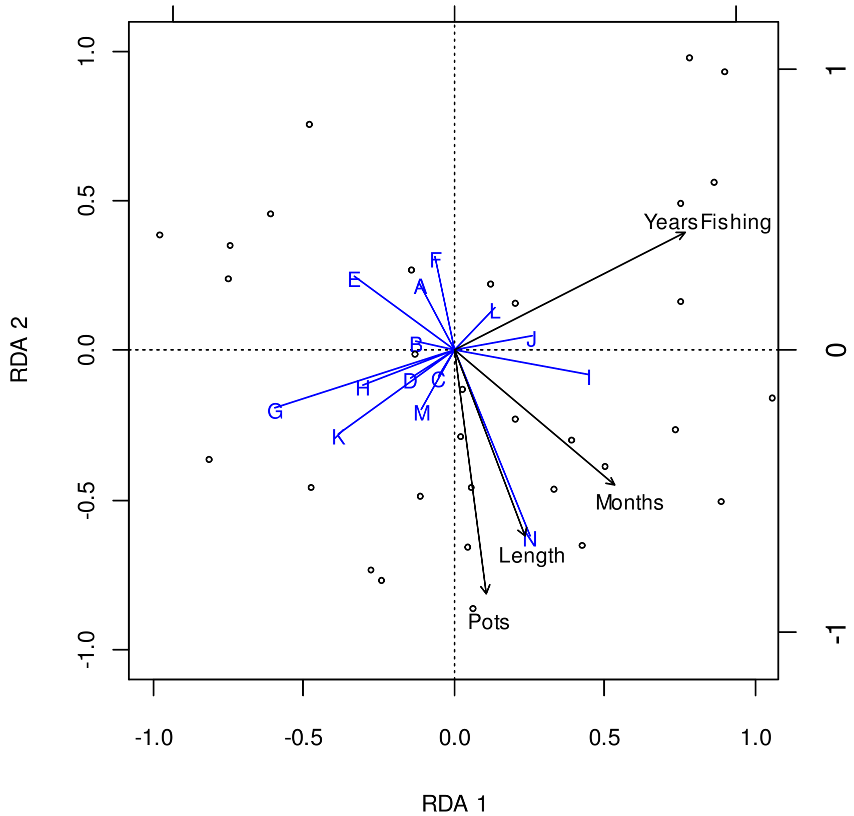

Figure 4.23. RDA correlation triplot of interviewees (circles), variables perceived to influence decisions about where to fish (blue; variable codes as listed in Table 4.3) and selected explanatory variables (black). The angles between the lines give an indication of the correlation between the variables, with smaller angles representing greater correlation. Eigenvalues for RDA 1 and RDA 2 were 0.05 and 0.04 respectively, representing only 9% of variation in the perceived importance of variables affecting decision-making.

Table 19.4. Summary of redundancy analysis (RDA). The total sum of scaled eigenvalues is 1. Column 3 indicates the cumulative percentage of overall variance in fishers' perceived importance of variables affecting decisions about where to fish. Column 4 indicates the cumulative percentage of variance explained in the relationships between the perceived importance of variables affecting decision-making and the selected explanatory variables.

Axis	Scaled eigenvalue	Cumulative % of variance in variables	Cumulative percent variance in relationships between variables and explanatory factors
1	0.05	5	42
2	0.04	9	72
3	0.02	11	90
4	0.01	12	100

4.3.2 Evidence of territoriality: observations of exclusive use of fishing grounds

Mapping of port home ranges based on sightings of fishing vessels from 2004-2008 (see Chapter 2 for methods) suggests that the extent to which fishing grounds were fished exclusively by vessels fishing from a particular port varied considerably among the ports (Fig. 4.4). The percentage of the home range fished exclusively by boats from the home port ranged from 19% in Boulmer and Craster, to 69% in Seahouses (Table 4.5).

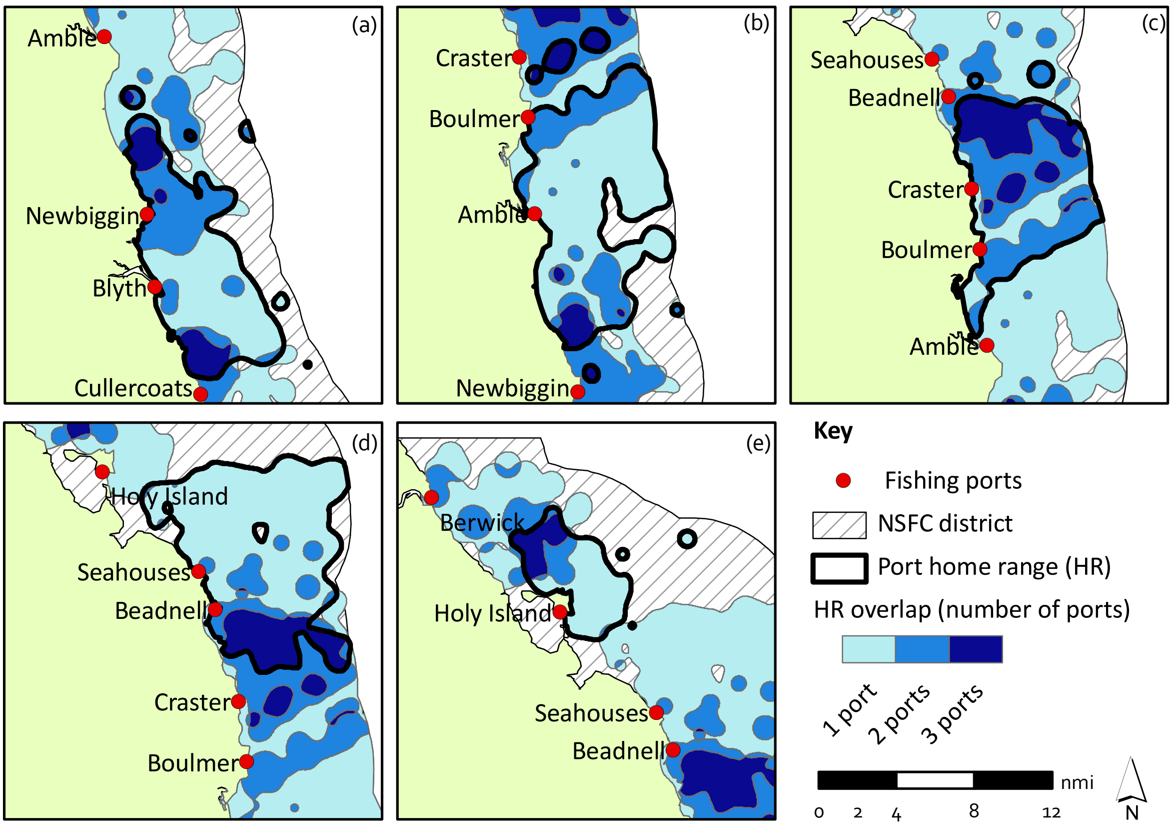

Figure 24.4. Overlap of port home ranges within NSFC district (extending to 6 nmi from shore) in a) Blyth, b) Amble, c) Boulmer and Craster, d) Seahouses and e) Holy Island.

Table 4.20. Port home range (HR) characteristics

Port	Home range 2004-2008 (km^2)	Area of exclusive HR use (km^2)	% HR exclusive use
Amble	260	163	63
Blyth	188	88	47
Boulmer & Craster	188	35	19
Holy Island	76	47	62
Seahouses	257	178	69

4.3.3 Evidence of territoriality: perceptions of exclusive use and defence of fishing grounds

In response to questions about the ownership of and rights of access to marine resources, the majority of fishers (n=30, 70% of those who responded) stated that either nobody or everybody owned the sea and fishery resources (Table 4.6). The remainder of fishers attributed ownership to fishers (although some said fishers "think" they own the sea) or to government authorities, or were unsure about ownership (Table 4.6).

Table 4.21. Fishers' perceptions of resource access and ownership. Number of respondents giving response by port.

Perception	Amble	Blyth	Boulmer/Craster	Seahouses	Holy Island	Total (%)
Ownership						
Everybody/nobody	7	6	3	8	6	30 (68)
Fishermen	5	1	0	1	0	7 (16)
Government	1	2	0	0	0	3 (7)
Unsure	2	1	0	0	0	3 (7)
No response	1	0	0	0	0	1 (2)
Access						
Anyone (with licence)	12	7	0	4	2	25 (57)
Full time fishermen	2	3	1	0	0	6 (14)
Traditional/local fishers	0	0	2	2	3	7 (16)
No response	2	0	0	3	1	6 (14)
Informal rules						
Yes	2	1	1	2	1	7 (16%)
No	8	6	0	6	4	24 (55%)
Ambiguous	5	2	2	1	1	11 (25%)
No response	1	1	0	0	0	2 (5%)

The majority of respondents (n=25, 57%) thought that anyone had a right to access the sea and fishery resources, although several respondents clarified this by noting that fishermen had to fulfil legal obligations, such as obtaining a licence and abiding by the rules and regulations. Respondents also noted that while anyone had a right to go fishing, in practice people needed some knowledge or experience to succeed. Six fishers (five from the ports of Amble and Blyth, where there are a number of part time or seasonal fishers) thought that rights of access should be restricted to full time fishermen. A further seven fishers (5 of which were from the smaller, more rural ports of Boulmer, Craster, and Holy Island) claimed that only local or traditional fishermen (those who had descended from fishing families and been brought up in the area) should have a right to access the resource. Although most acknowledged that people legally had a right to fish anywhere within the district, some acknowledged that this was not the case in practice, as vessels may be deterred from fishing (e.g. through verbal confrontation, gear damage or social exclusion). For instance, one fisher from Holy Island commented: "*If someone came up from Newcastle with a boat he would be shunned by the rest of the fishermen and wouldn't last 5 minutes*".

No fishers claimed to maintain exclusive use over fishing grounds, either as an individual or as part of a fleet from a particular port. The majority of respondents in response to direct questioning did not perceive there to be any informal rules or agreements regarding allocation of fishing grounds among vessels within or between home ports, although several fishers gave ambiguous answers to the effect that informal rules either had existed in the past, or did exist in other ports (Table 4.6).

Fishers at all ports described competition for space among vessels within and between ports, particularly in productive inshore areas at the height of the lobster season (July-October). Such competition was said to occasionally lead to conflict, for instance when gear entanglement occurred. However, most fishers saw this as an accepted part of the job, and not something that would lead to hostility or affect decisions about where to fish. While individuals have preferred fishing grounds, this competition was described as a scramble among fishers to position themselves on the best fishing grounds during periods of high congestion, rather than an attempt to maintain exclusive use to an area. However some respondents suggested this had changed over time, with individuals in each port said to have fished "*their own little areas*" in the past. Some fishers commented on generational differences in how fishers perceived their rights of access to fishing grounds as individuals:

> *"Older fishermen that have been fishing there all their life, they maybe think they have a right over me but at the end of the day their shellfish licence is the same as mine." (Seahouses)*

In discussing the exclusivity of areas fished by vessels from different ports, fishers acknowledged a tension between formal rules (i.e. national legislation and local byelaws) and fishers' behaviour in practice. Several fishers mentioned that in the past boats from each port tended to stay within particular fishing grounds, and maintaining boundaries relied either on mutual cooperation or active defence of fishing areas. Some described the situation as an informal agreement, for example one stated:

> *"You used to be a stone's throw away from the Seahouses boats but you knew not to go in amongst their gear - it was just a gentlemen's agreement, I don't think anything would happen if you did but it would cause bad feeling." (Holy Island)*

Others noted that incursions into the fishing grounds of other ports would have led to sanctions in the form of damage to fishing gear, one respondent stating:

> *"Up until about 10 years ago, we had areas where we fished and areas where they fished… it wasn't a law but it was an unwritten law that we kept to. … If you went north of the line 20 years ago you'd have your buoys cut off if you infiltrated into their territory." (Blyth)*

Fishers commonly noted that spatial patterns of fishing had changed over time, with vessels increasingly travelling further afield from their home port and "*pushing the boundaries*", yet a number of fishers acknowledged explicitly or implicitly that despite changes in recent years, there were still boundaries that to some degree influenced spatial behaviour, one fisher commenting:

> *"[Conflict] doesn't happen very often because people keep within their own areas, an unwritten gentlemen's agreement if you like. It's part of the reason why people don't move too far - you've got to think about fuel and time to get your gear and stuff like that, but that's part of it as well." (Blyth)*

Fishers recognised a degree of conflict between ports, particularly as a result of boats travelling further afield than in the past. The main locus of conflict discussed by interviewees (including those in Blyth, Seahouses and Holy Island) was in the vicinity of the ports of Boulmer and Craster, where vessels from Amble had increasingly been fishing. Fishers in Boulmer and Craster stated that they had remained in the same grounds they had historically fished, while adjacent ports had expanded their activities. All respondents in these ports acknowledged conflict over space between themselves and vessels from Amble, and fishers described trying to defend patches of fishing grounds by strategic placement of fishing gear. All recalled incidents in which Amble vessels fishing further north than usual had experienced damage to their gear or been exposed to more aggressive conflict. However, this was described as an infrequent occurrence and was attributed to the actions of other vessels, with interviewees saying that they preferred to avoid conflict. For example, one stated:

> *"I don't like cutting ropes because I don't like it done to me. Sometimes it happens but if I have gear over my pots and have to cut a rope I try to pass it under or join it back up again, or if it's one of the Amble boats I'll cut it and tie a big knot so they know they've been over the top of someone." (Boulmer/Craster)*

Similarly, all interviewees in Amble mentioned conflict with vessels from Craster and Boulmer to the north, and to a lesser extent with vessels from Newbiggin to the south. Boats from these ports were described by some as being very territorial. Several fishers described incidents of conflict with boats from these ports, from verbal exchanges at sea to experiences of gear damage while fishing in the vicinity of the ports. Amble vessels considered such actions as a warning that they were "treading on the toes" of boats from those ports. One fisher for example commented:

> *"...if they see an Amble bow they just go and cut it off or damage it, they think you shouldn't be there. Boats that go up there get a lot of hassle; they must think the sea there is theirs." (Amble)*

Several fishermen spoke of the danger of retaliating and cutting others' gear. They acknowledged that it was often difficult to be certain of who was responsible, and retaliation could escalate to the point of large scale conflict in which they might lose a lot of fishing gear. In spite of this, some that did fish in the areas of conflict expressed a determination not to be driven away, and admitted to retaliating occasionally.

In contrast, skippers from Blyth were more inclined to argue that they were able to fish anywhere unhindered by conflict (aside from more general competition for space), and that the distinct fishing grounds of different ports had been blurred by the movement of vessels from adjacent ports to fish from the deep water harbour at Blyth. It was noted though that fishers who had switched harbours still tended to fish in areas with which they were familiar, and also that some still avoided the areas fished by boats from other ports to prevent animosity. Between the ports of Seahouses and Holy Island, a small amount of conflict was reported among those who were fishing further afield, although in general fishers from both ports said that they were on good terms with, and were able to work alongside, each other.

4.3.4 Characteristics of fishing communities in relation to territoriality

Target species and habitat distribution

Differences in habitat availability and area of suitable potting ground were discussed in relation to the relative costs and benefits of territoriality, in particular with respect to reported conflict between the ports of Amble, Boulmer and Craster. Fishers suggested that greater availability and quality of potting ground in the vicinity of Boulmer and Craster made it economically worthwhile to defend fishing grounds, while in Amble there was little to be gained from territorial behaviour as limited fishing grounds meant vessels from other ports had little incentive to encroach upon their grounds. Furthermore, the physical environment surrounding Amble was seen to limit the likelihood of other vessels moving into the area, one fisher stating for example:

> *"...we don't have anything to worry about here because we've got so much poor ground either side of us that it's too big a leap for other boats to come here." (Amble)*

A number of fishers from all ports suggested that the abundance of potting ground in the vicinity of Boulmer and Craster meant that potential for higher catches was one explanation for the decisions of skippers from Amble to fish there despite increased travel time, fuel cost and risk of conflict. In contrast, others indicated that frustration and expense associated with frequent gear damage outweighed potential benefits and dissuaded them from fishing in the area. One fisher commented:

> *"…you seem to get your gear sabotaged. Once that happened a few times I moved back down this way - it's further to travel up there … you find your markers cut off and gear piled in a heap. By the time you get there and clear that heap up and re-bait your pots you're working against the tide, it just wasn't adding up." (Amble)*

Fishers recognised the advantages to deterring other vessels in areas of productive fishing grounds, both in terms of the short-term benefits of reduced competition for the same target species, and potential long-term benefits through being able to "look after" areas of ground. However, it was noted by fishermen in Amble that areas of potential conflict could change depending on variability in the distribution and availability of the resource over time, one respondent commenting:

> *"There are boundaries but they aren't strict, they change from year to year … they wave about a mile or two depending on what other people are doing. If they're fishing further north and doing well they couldn't give a monkeys if you come up a bit further north."(Amble)*

Some felt strongly that stewardship of fishing grounds and exclusion of outsiders could enable further benefits to accrue in comparison to other areas. These fishers suggested that defence of fishing grounds may be selective, related to concern that boats coming in to the area may not comply with stock conservation measures such as the ban on landing undersized and V-notched lobsters. One fisher for example said:

> *"If you've got an area you've fished and looked after for a number of years … then someone turns up and seems a bit shady … then there might be some element of discouragement. … I think without that sort of attitude, people looking after their patch, then the fishery could get destroyed…" (Blyth)*

Fishers from Boulmer and Craster also discussed the impact of encroachment from other ports on the degree to which they were able to make decisions at a local level, one stating:

> *"Years ago when I was young there was one year they all agreed to leave the lobsters until the middle of September while the lobsters were in poor condition. They asked places either side to respect it. … Now though if you didn't put your pots in when everyone else does you might as well not bother, within a fortnight there's nothing left." (Boulmer/Craster)*

Technology

Changes in technology (including design of vessels, fishing gear and navigational aids) were perceived to have affected the costs and benefits of territoriality in two ways. Firstly, faster vessels had enabled fishers to travel greater distances from their home port, both out to sea and along the coast. Secondly, the development of geographic positioning systems (GPS), navigational equipment and ground discrimination systems were considered by some to have made local knowledge less integral to successful fishing, and to have enabled outsiders to enter the fishery, one fisher stating:

> *"When I started at sea I had to learn the landmarks from my father and uncles, and you didn't get strangers coming because they didn't have the local knowledge, but with the advancement of satnav and everything anyone could come into your area..." (Seahouses)*

Fishing intensity

Fishers at all ports were unanimous that potting activity had increased both in terms of the number of pots and the area covered, with boats moving both further offshore and along the coast to look for fresh ground. The increase in quantities of gear worked was attributed to increasing modernisation, greed, and rising costs of fishing, particularly in terms of vessel running costs. Expansion of fishing grounds was seen by some as an inevitable consequence of the increase in the numbers of pots worked, with one fisher commenting:

> *"In the 80s and 90s boats only had one set of gear ... the trend has been to increase gear and work 2 or 3 sets..... It's not necessarily a good thing as it takes up lots of ground ... but everyone has done it virtually so you have to go with the flow." (Seahouses)*

While the numbers of pots worked was perceived to have increased, the number of active vessels was said to have declined substantially in some ports, particularly in small villages such as Boulmer where there is little infrastructure for modern vessels. A two-thirds reduction in the number of active vessels at Boulmer over current fishers' lifetimes was attributed to the retirement of older fishers and increasing costs of fishing. One skipper talked of large scale organised destruction of the fishing gear of encroaching vessels having taken place in the past, but acknowledged that this type of activity would be unlikely today as the risk of suffering large scale gear loss or damage from escalating conflict would be too high for the small number of fishers remaining.

Structure of fishing fleets

Fishermen in all ports commented on changes within the fishing industry that had impacted on spatial patterns of potting activity. Some fishers in Blyth and Seahouses in particular noted that the demise of the local trawling fleet due to increasing legislation and decline of white fish stocks had allowed the expansion of potting into offshore areas where there would previously have been conflict with trawling vessels. At the same time, there had been a movement of fishers from trawling into potting, with two thirds of respondents having previously been or being currently engaged in trawling (Table 2). Some fishers suggested that those who had moved from trawling to potting tended to be those that fished further from home and became involved in conflict.

Fishers also noted changes in the seasonal pattern of fishing over time. Increasing legislation on netting for salmon and white fish, along with a perceived increase in problems with seals when netting, were reported to have led to an increasing tendency for vessels to fish with pots all year round. Fishers described the fishery as having been more multi-species in the past, with typical seasonal activity involving targeting salmon in the summer, lobster and crab in autumn, and netting for white fish over winter. Changes in seasonal patterns of some vessels were seen to have had consequences for others, and were another factor invoked to explain territoriality of vessels in Boulmer and Craster, one respondent stating:

> *"Now they can't really see their salmon season through because they think if they don't get their pots in, the Amble men will catch all the lobsters, so I can see why they get upset, but the sea doesn't belong to anyone, you can't stop anyone from going up there." (Amble)*

Legal context

Several fishers from Amble suggested that the risk of conflict had declined in recent years due to increasing likelihood that interfering with others' fishing gear would be treated as a crime, one fisher commenting:

> *"You know you're breaking the law if you do that kind of thing now, but in the past interfering with someone's fishing gear wasn't seen as a crime, people would have done it blatantly. Now it's a lot less vehement, more restrained – not that anyone is any more flexible than they were, but there's more chance of [officials] getting involved – the repercussions are far greater now." (Amble).*

Social norms and community cohesiveness

Several examples of shared expectations of behaviour were illustrated by fishers' statements. Fishers at all ports talked about avoiding outright conflict with other vessels from both the same and different ports. In particular all fishers at Holy Island discussed cooperating and working alongside each other to avoid conflict. Others also noted that avoiding conflict influenced their spatial behaviour. One respondent contended:

"…there's an undercurrent of cooperation – you don't impinge on some areas. It's not their ground but you know how far you can go without too much hassle." (Amble)

Fishers also discussed changes in traditional values, with fishers commenting that 'traditional' fishers from all ports would stick to their own fishing grounds, whereas younger fishers and new entrants to the potting fishery were motivated by greed and did not respect traditions, one fisher stating:

"We work the same ground we've worked for years, would never dream of trying to take anybody else's stuff. Although it doesn't belong to them, it's off their place and I wouldn't go there. We were brought up that way but maybe it's old fashioned." (Blyth)

In turn, some younger fishers argued that older generations were more obstructive and territorial, whereas the younger generation were more willing to cooperate.

There were mixed views in all ports about community cohesiveness. In Amble and Blyth some argued that increasing fisheries legislation had meant that people tended to look out for themselves, although others argued that fishers still relied on each other and cooperated. Divisions within the fishing community in these ports were implied between full time fishers and part time or seasonal fishers, and also as a result of fishers from nearby areas moving to these ports. Fishers from the more rural ports of Boulmer, Craster, Seahouses and Holy Island suggested that while the remaining boats worked together well, communities were less close than in the past as a result of increasing numbers of tourists and holiday homes, with fishing families said to be "*dying out*".

Notably, fishers from Boulmer, Craster and Amble characterised each other unfavourably. Those in Boulmer and Craster depicted Amble fishers as "*lawless*" and motivated by greed, one fisher stating:

"[The trawlermen] are really the biggest problem, they're the worst offenders because it's big boat mentality, catch as much as possible as quick as possible, and they've forced us into doing the same, otherwise it'd just be a waste of time. Once you get south of Boulmer you notice a difference in the people." (Boulmer/Craster)

In contrast, Amble fishers describing those from Boulmer and Craster as small, old-fashioned, close-knit communities who were "*living in the olden days*", or "*still in the dark ages*", with one respondent commenting:

"I can understand if they want to protect their traditional way of life, and see people from Amble as commercial heathens impinging on their lifestyle and traditions, but they're just small minded and petty." (Amble)

4.4 Discussion

This chapter contributes to the literature on fishers' decision-making and spatial behaviour through application of a mixed methods approach as a way to identify which factors affect fishing practices. Results illustrate the complexity of factors driving spatial decision-making at the level of both individual fishers and fishing communities; these are discussed here in turn. Firstly, factors affecting individual decision-making are discussed in context of relevant literature. Secondly, evidence for territoriality at each port is assessed with respect to key traits of informal rules, presence of boundaries and defence of fishing grounds. Lastly, perceptions of fishers regarding territoriality are discussed in the context of two selected bodies of theory relating to explanations for territorial behaviour identified in the introduction to this chapter: economic defendability and theories of social norms and collective action.

4.4.1 Factors affecting spatial allocation of individual fishing activity

A number of factors were perceived by fishers to influence their spatial behaviour; weather conditions, personal experience and gear congestion were most commonly prioritised. These findings are consistent with other studies; for instance, choice of fishing ground by English Channel static gear fishers was determined primarily by information and experience of stock abundance, weather, tides and seasons, although density of fishing gear was one of the factors least mentioned by Channel fishers, which differs from the results presented here (Robinson & Pascoe 1997). In contrast to studies in which fishers responded that their behaviour was influenced by regulations (e.g. Anderson & Christensen 2006), in Northumberland few perceived regulations to be important. There are currently no regulations in place that affect where lobster fishers can fish within the NSFC district, other than a pot limitation that means pots in excess of 800 must be worked outside the district. However, increasing spatial regulation of fishing activity was one factor that several fishers expected to become more important in the future. In a Danish North Sea gillnet fishery, fishers indicated that information from other fishermen, distance and fuel cost were less important than other factors (Andersen & Christensen 2006), which is consistent with the results presented here. The high importance of short-term and long-term personal experience among Northumberland fishers is also consistent with other studies. For instance, in New England trawl fisheries personal experience was very important, with the majority of fishers keeping personal records or log books that they used to inform current fishing patterns (Holland & Sutinen 1999).

PCA results found that underlying trends explained only a small amount of the variance in the data, emphasising the complex nature of fishers' decision-making. Predicting the behavioural response of fishers to change depends on a number of relatively independent factors that were not explained by differences related to the explanatory variables analysed (namely port, vessel length, quantity of fishing gear and months worked per year). The very limited ability of these explanatory variables to explain differences in fishers' perceived importance of factors influencing their decision-making suggests that there may be a number of other important explanatory variables that were not included in the analysis. Although it is possible that some of the differences between fishers may result from their interpretation of interview questions and the rating scale, the results corroborate research suggesting heterogeneity in fishers' decision-making behaviour (Salas et al. 2004). Such heterogeneity poses a challenge to fisheries managers in predicting how fishers will respond to spatial management measures, and highlights the importance of understanding individualistic responses and preferences (Robinson & Pascoe 1997; Wilen et al. 2002; Salas & Gaertner 2004; Christensen & Raakjær 2006). Further research is therefore warranted to investigate variables that may better characterise differences among fishers.

Several studies have highlighted factors other than rational cost-benefit calculations that influence decision-making, including skill level, familiarity with fishing grounds, perceptions of risk, peer pressure, technology and potential conflict (Bene & Tewfik 2001; Salas et al. 2004; Abernethy et al. 2007; Daw 2007). The perceived importance of factors identified here such as vessel congestion, potential conflict, and information from observing to or talking to other fishers highlights the importance of the social context in fishers' decision-making. While some of these factors may have an underlying economic rationale, they may not be consistent with models that assume short-term profit maximisation. For instance the rationale for fishers staying within 'traditional' grounds close to their home port (e.g. Cabrera & Defeo 2001) may be a result of unfamiliarity with other areas and minimising risk-taking or uncertainty (Holland & Sutinen 1999; Hutton et al. 2004). Alternatively, however, it may reflect 'satisficing' objectives, with fishers content with covering their costs or achieving a desired level of profit rather than profit-maximising (Holland & Sutinen 2000).

4.4.2 Evidence of territoriality among fishers

Formal versus informal rules

The majority of fishers stated that the sea is open to everyone, yet this view does not necessarily imply that there is no sense of territory among fishers, as systems of informal property rights often imply rights of occupation rather than ownership (Wagner 2004). In Catalonia, trawling vessel fishers commonly claimed that the sea belongs to everyone, yet informal systems of property rights occurred (Alegret 1998). While fishers in Northumberland did not claim either exclusive use or ownership of an area, the language used in discussing relationships with vessels from other ports implied a degree of appropriation (e.g. referring to the fishing grounds of other ports as "their" ground), and the contradiction between the formal ownership of resources and resource access in practice was often apparent. It is important to recognise that the language and discourse used by fishers' in discussing their opinions on territoriality may be self-serving, reflecting biased views of historical change or personal agendas in staking claim to particular fishing grounds. Nevertheless, understanding fishers' perceptions of a situation may in some ways be more important in understanding how it influences their behaviour than a more objective view.

Exclusive use and definition of boundaries

Maps of observed fishing activity suggested that no port maintained exclusive use of the whole of the mapped home range. This is not unexpected, since home range does not necessarily equate to territory, however overlaps with home ranges of other ports were far greater in some areas than others. Notably, the combined home range of Boulmer and Craster vessels, where greatest conflict was identified, showed the highest percentage overlap by other ports. Areas of exclusive use tended to be close to vessels' home ports, with greater overlap north and south towards the edges of home ranges and closer to adjacent ports. While this may be in part a function of the costs of travel to particular areas, it may also imply a form of 'nucleated' territoriality, in which fishers' sense of ownership and rights of access diminish with distance from home port (Acheson 1988). In the *cofriadas* in Catalonia, trawl fishers perceived their rights over fishing grounds to be related to the proximity to their home port (Alegret 1998).

Very few fishers spoke of definite territorial boundaries in place between ports, although several discussed boundaries that would not have been crossed in the past. Fishers discussed various forms of conflict over space. Within ports, competition for space was seen predominantly to be a scramble for the best spots rather than continued use of a particular area by any individual. Similarly, in Maine group territories exist rather than individual territories due to the seasonal and inter-annual variability in resource distribution, which would make it difficult for fishers to make a living if restricted to small individual territories (Acheson 1990). However, while in Maine various factors determine whether individuals fish in preferred or more marginal fishing grounds within group territories, fishers in Northumberland maintained that allocation of local fishing grounds was a case of 'whoever gets there first'. However, some fishers did refer to individual territories in the past, and suggested that newcomers may be forced to fish more marginal areas.

Defence of fishing grounds

Between ports, three main forms of active defence were apparent. Firstly, fishers mentioned attempting to block the access of outsiders by strategically placing gear on particular fishing grounds. Similar practices have been recognised in other studies of territoriality among static gear fishers, with occupation representing the principle means through which territories are maintained (Blyth et al. 2002; Acheson & Gardner 2005).

Secondly, several fishers talked about sanctions occurring when encroaching on the grounds of other ports, often in the form of damage to fishing gear. On occasion such sanctions led to retaliation, verbal conflict or, very rarely, to damage to fishing vessels, although often it was said to be difficult to prove who was responsible, and fishers were reluctant to admit to such actions. Often these incidents were said to be related to instances of entanglement of gear, with pots having been deployed over those of another fisher, but gear damage was also perceived to be a warning that fishers were unwelcome in a particular area, since most fishers commented that the appropriate conduct would be to re-tie the ropes, even if cutting them was unavoidable. Such sanctions have been described in other fisheries (e.g. Begossi 1998) and share many similarities with territorial systems described in the Maine lobster fishery (Acheson 1972; Acheson 1988; Acheson 1990).

Finally, fishers talked about discouraging people from entering the fishery, particularly if they were considered to be greedy (working many pots), or not complying with conservation measures. Control of access to resources through acceptance into social groups has been identified as a form of territoriality (Cashdan 1983). This was discussed by fishers primarily in terms of outsiders entering the fishery, but potentially applied to any new entrants. In Maine, state law suggests that anyone with a license can fish for lobster, while in reality active fishers must be part of a 'harbour gang', to which acceptance is determined by a number of factors but importantly includes willingness to abide by local fishing norms (Acheson 1975). In Northumberland, fishers discussed a variety of means of excluding fishers, including social sanctions (outsiders would be 'shunned') and discouragement through gear damage. Differences were mentioned in the ease of gaining acceptance in different ports, with smaller ports where fishers were able to control the access to moorings being least accepting of outsiders.

4.4.3 Characteristics of fishing communities in relation to territoriality

Economic defendability

Economic defendability theory falls into the broader theme of rational choice theory, emphasising agency of individuals in making rational economic decisions about costs and benefits of particular actions. In terms of variability over space and time, patterns of territoriality in Northumberland appear to conform to the predictions of economic defendability theory. Firstly, territoriality appears to vary with distance from port, as mapped fishing grounds illustrated a greater degree of exclusive fishing adjacent to home ports. Reduced competition for resources and higher monitoring costs further from port mean there is less advantage in maintaining a territory (Acheson 1975; Begossi

2006). Secondly, some fishers suggested that boundaries may change over time depending on abundance and distribution of resources, with conflict occurring at particular times of year and depending on the fishing success of those defending the resource. Territorial behaviour may not be well defined and territories may not be rigorously defended, but rather both depend on economics at any one time (Begossi 2001).

In addition, there may be local differences in abundance of the target species or at least in the availability of suitable potting ground in relation to the size of local fishing fleets at different ports. Where suitable habitat is more dispersed, fishing areas may be larger, resulting in increased costs of defence (Dyson-Hudson & Smith 1978). Systems of individual territory in the Nova Scotia lobster fishery are thought to be linked to areas of uniform and productive habitat, whereas in areas of uneven habitat individual territories may give way to common ground, allowing greater movement by fishers throughout the season (Wagner 2004). In Northumberland, greater territoriality may therefore be expected where the availability of lobster fishing grounds is more extensive in the northern ports of Boulmer, Craster, Seahouses and Holy Island.

However, whether or not territorial defence is considered worthwhile relates to the degree of competition for the resource, which is a function of its scarcity relative to the foraging population (Cashdan 1983). The level of competition from outsiders was discussed by fishers as being partly influenced by distribution of available fishing grounds, physical geography and land-based infrastructure. More isolated communities such as Boulmer, Craster and Holy Island, where port infrastructure is more limited, have greater ability to control the access of vessels to port facilities, and as a result may be able to be more selective about the number and type of vessels operating from the port. In contrast, physical infrastructure at the port of Blyth appears to have led to a greater degree of shared fishing grounds among vessels from different ports, with vessels from several nearby communities now operating from Blyth. In Amble, the physical distance from other ports was seen to be a deterrent to any potential intruders as well as the poorer quality of fishing grounds, which was one explanation for the lack of active territorial defence.

Competition for fishing grounds from vessels operating from other ports was also influenced by different levels of fishing intensity at different ports. Expansion of some fishing fleets and the decline in others was seen to have altered the costs and benefits of defence, with increasing congestion, improved technology and ability to travel greater distances changing perceived boundaries. Changes in technology and organisation of the fishery have been said to influence the cost-benefit ratio associated with maintaining a territory in a number of other cases. For instance, in Newfoundland, inshore fishing and competition for space was confined to local waters until technology advanced, leading to greater encroachment on grounds of other communities and sanctions through gear destruction (Anderson & Stiles 1972). Similarly, the introduction of larger, faster boats and new technology in Maine enabled fishers to travel further offshore and deploy more gear, leading to reduced dependence on small, well-defended inshore territories, and larger areas of 'mixed fishing' (Acheson & Gardner 2005). In the Devon Inshore Potting Agreement (IPA) in the UK, conflict over space following the introduction of more durable shellfish pots and improved trawling technology led to a voluntary agreement between fishers to designate areas for use by different gear types (Woodhatch & Crean 1999; Blyth et al. 2002).

The role of technology has also been important in altering the value of local knowledge. In Catalonia one means of appropriation of resources or territory by trawl fishers is through the accumulation of local knowledge and cognitive maps of the environment (Alegret 1998). Similarly in Sardinia fishers have no legal rights of ownership but appropriate areas through developing the area-specific knowledge needed to exploit resources (Morelli 1998), and in Japan fishers maintain control over access to productive areas within group fishing grounds by keeping them secret from others (Ruddle 1989). In Northumberland, the development of modern navigational technology was discussed by fishers as having altered the costs and benefits of defence, making it easier for fishers to encroach on new ground as local knowledge is no longer vital to exploit resources.

Fishers' perceptions suggested that these changes have been compounded by changes in the legal and political environment, which have emphasised the open access nature of marine resources and potential legal consequences of conflict between fishers, increasing the costs of defence and reinforcing the entitlement of fishers with a licence to fish anywhere within the district. Greater law enforcement in Maine was also seen to increase the cost of informal sanctions at a local level (Acheson & Gardner 2005). Legislative changes in fisheries more widely have led to changes in fleet structure within ports, with a number of fishers moving from trawling to potting, and an increasing tendency for potters to work all year round, leading to perceived increases in fishing intensity. While developments in vessel capability and navigational technology have occurred throughout the district, it is these changes relative to localised changes in fishing intensity and competition that may have altered the relative costs and benefits of territoriality in each port.

As described in other fisheries, territories are dynamic and vulnerable to incursions from outsiders, and boundaries may change over time (Anderson & Stiles 1972, Blyth et al. 2002). Northumberland fishers' discussion of the benefits of territoriality centred partly around greater access to resources and security of income, while the actions of fishers pushing the boundaries and encroaching onto the grounds of others were also discussed in terms of rational cost-benefit decisions, with fishers being seen to weigh up whether or not the additional costs of travel time, fuel and potential conflict were outweighed by the expected gains. Boundaries can therefore be interpreted as moving due to competition and conflict depending on costs and benefits (Acheson & Gardner 2005).

Social capital, norms and collective action

The findings presented support to some extent theories of social norms and collective action that emphasise the role of social structure in shaping the behavioural strategies of individuals. Some fishers emphasised underlying cooperation and said that they stayed in particular areas to avoid conflict. While this has an economic rationale, it also has a social objective in terms of maintaining social relationships and trust. Similarly, other studies of territorial behaviour have shown that while many fishers explore new areas and tentatively encroach on others' grounds, most try to avoid conflict (Anderson et al. 1972; Acheson 1975; Wagner 2004). However, this study identified a number of fishers for whom 'freedom of the sea' appeared to be more prominent than conflict avoidance, and they expressed a determination to not be driven away from any fishing grounds. Whether or not factors such as increased fishing pressure lead to more defined territories or to higher levels of conflict may therefore depend on the degree to which behaviour is mediated by social norms such as conflict avoidance (Pollnac 1984).

Differences between communities in Northumberland were suggested by the manner in which they characterised each other, with communities in Boulmer, Craster and to some extent Holy Island being characterised as 'traditional', 'close-knit', 'old-fashioned' and 'clannish', while ports of Amble and Blyth in particular were described as more modern, motivated by money and greed, less respecting of tradition, and less likely to comply with rules. These findings support those of other studies which contend that differences in community characteristics may affect the likelihood of informal rules and norms developing. For instance, in New Zealand crayfishing communities, differences in territorial systems were suggested to relate to the characteristics of fishing communities, with higher cooperation and community cohesiveness linked to more cooperative spacing as opposed to a 'free for all' or individual territories (Levine 1984).

Fishers in Boulmer, Craster and Holy Island discussed self-enforcement of rules and local agreements intended to protect lobster stocks and ensure the long-term sustainability of the fishery. Most of the fishers in these ports had descended from fishing families in small communities where ties between fishing families are long-established. In such circumstances, informal systems of territory may be important in community dynamics and social relationships, reinforcing both social and spatial boundaries (Anderson et al. 1972; Wagner 2004). Furthermore, Holy Island is connected to the mainland by a tidal causeway and is at times isolated from the mainland, perhaps leading to greater community cohesion. The characteristics of these communities support the contention that informal agreements and cooperation norms may be easier to achieve in small groups where resource users interact frequently and are able to monitor each other (Ostrom et al. 1999; Dietz et al. 2003; Acheson 2006). Such circumstances may be more likely to lead to more cohesive communities that are guided by values and norms encouraging cooperation, which in turn may be conducive to more successful fisheries management (Jentoft 2000).

In contrast, in Amble and Blyth a greater degree of social stratification appeared to be evident with newcomers in the fishing industry, seasonal and part-time fishers, and often fishers coming from surrounding areas from either non-fishing backgrounds or different sectors of the fishery. Amble and Blyth in particular represent larger towns closer to urban centres, where there is potentially a greater degree of change in demographic processes and social diversity (Symes & Frangoudes 2001). Fishers also distinguished between 'proper' fishers and seasonal or part-time fishers, a common distinction in UK fishing communities (Ota & Just 2008). Similarly in Maine there was greater hostility towards part time fishers than towards new full-time fishers, with part-time perceived to have an unfair advantage by having additional employment (Acheson 1972). Development of cooperative behaviour such as territoriality may depend on shared viewpoints and willingness to cooperate; for instance, the ability to defend territories in Maine is attributed partly to the presence of 'political teams' (Acheson 1990). Where there are divisions within communities such behaviour may be less likely, thus differences in community characteristics may contribute to differences in the degree of territorial behaviour among ports.

4.5 Conclusion

Historically, research perspectives on fisheries have largely focused on the agency of individuals, and factors influencing the spatial distribution of fishing effort remain poorly understood. This chapter has demonstrated that a number of complex and inter-related social, economic and ecological factors drive fishers' decisions about how they allocate fishing effort. The complexity identified presents a challenge for managers in predicting fishers' responses to changes (e.g. in the environment or in management regimes).

In addition, this research has identified social and environmental characteristics of fishing ports that influence the potential costs and benefits of cooperation among fishers to defend fishing grounds. Although UK fisheries management recognises the importance of inshore fisheries to coastal economies and societies, little attention has been paid to the informal rules and arrangements which inshore fishers have used to regulate spatial behaviour and access to resources. The results presented support other research findings in showing territorial behaviour among fishers may be linked to a sense of stewardship and concern for the long-term sustainability of the resource. Given the limited number of management measures currently in place for UK shellfisheries, identifying drivers of behaviour that may have positive implications for resource management could help re-appraise management strategies, and help policy makers to identify management measures that may be supported by local fishers and suited to the local context. Identifying the relationship between areas of fishing grounds at sea and fishing communities on land may also help in understanding the potential impact of spatial management areas such as marine protected areas.

Understanding the complex and interrelated drivers of human behaviour may help to devise ways to achieve management objectives through encouraging cooperation and trust that shape the informal property rights which may ultimately be conducive to effective resource management. However, variability in social, economic and environmental drivers of behaviour suggests that these factors may be strongly related to a local context and difficult to generalise, therefore integrating formal and informal rules may be challenging. In summary, the findings suggest that future work should place more emphasis on understanding the social and political context in which fishers operate, and analyses of fishers' behaviour must therefore consider fishers as part of fishing communities. Such an approach implies the need to determine social institutions, relationships and traditions that may facilitate cooperation as well as competition.

Chapter 5.

A social network approach to linking information flow, success and spatial behaviour of fishers

Abstract

In the context of increasing spatial management of the marine environment, understanding spatial dynamics of fishers' behaviour may be useful for predicting implications of spatial management measures for the sustainability of fisheries. It is widely recognised that social factors are important in shaping decision-making and spatial behaviour of resource users, including social relationships through which fishers share information. This chapter uses social network analysis (SNA) to explore the links between information flow, fishing success and spatial behaviour of fishers in the Northumberland (UK) lobster fishery (*Homarus gammarus*). Results illustrate fishers' perceptions of the importance of information from other fishers in informing their decisions about where to fish, and highlight differences in network structure among ports. Relationships are demonstrated between fishers' position in information-sharing networks (indicating incoming and outgoing information) and their fishing success as perceived by peers. Positive correlations identified between communication networks and networks representing spatial interaction at sea point towards the existence of social-spatial groups in fishing behaviour. The implications of these findings are considered at an individual (e.g. implications of individual fishing success) and group level (e.g. implications for overall efficiency of resource exploitation). SNA is a useful tool for further study of how information-sharing networks respond to change, for example that resulting from spatial displacement of fishing activity or changes in resource availability.

5.1 Introduction

Failures of modern fisheries management may be attributed to a failure to understand fishers as much as to a failure to understand stocks (Hilborn 1985; Hilborn 2007b). In the context of increasing spatial management of the marine environment (e.g. through marine protected areas), understanding the spatial dynamics of fishers' behaviour may be critical to predicting potential implications of spatial management measures for fisheries. Modelling the spatial behaviour of fishers has therefore become an increasingly important area of research. Much of this modelling work to date has focused on the decision-making and behaviour of individuals, and only recently have studies begun to incorporate the influence of social variables such as information-sharing that may shape individual decision-making (Allen & McGlade 1986; Little & McDonald 2007; Little et al. 2004; Wilson & Yan 2009; Wilson et al. 2007).

Social relationships in fisheries (i.e. relationships between two or more individuals) have a variety of implications both for individual decision-making behaviour and wider fisheries management, as they have the potential to facilitate learning and information exchange, and foster the development of trust and social capital. In turn these factors may contribute to how cohesive a particular group or community are. The concept of social capital is based on the idea that social relationships are a resource that individuals can use to increase their well-being (Rudd 2000). Various definitions of social capital exist, but broadly social capital is used to refer to the norms and networks that exist within and between groups, including norms of trust, reciprocity and exchange, rules and sanctions (e.g. concerning agreements over allocation of fishing grounds), and connecting networks and institutional infrastructure (Rudd 2000; Pretty 2003; Grafton 2005). The development of social capital in social networks may lower the transaction costs (i.e. costs related to monitoring, specification of the terms of interactions, and enforcement required in interactions with others (Rudd 2000)) of individuals working together by enabling individuals to have greater certainty in predicting the behaviour of others. Social capital may facilitate cooperation and collective action among fishing communities, therefore the social context in which fishers operate is important for wider fisheries management as well as for individuals (Rudd 2002). While negative aspects of social capital are recognised (e.g. if social norms constrain individual behaviour or stifle innovation) (Portes 1998), where fishing communities are concerned with long-term sustainability of the fishery the presence of social capital may have positive implications for fisheries management.

A key component of social relationships among fishers concerns the exchange of information, since the successful exploitation of fishery resources is dependent in part upon fishers' knowledge and skill in targeting a resource. Fishers often hold extensive knowledge of the marine environment, which informs their fishing behaviour and decision-making (Johannes et al. 2000; Mackinson 2001;

Crona 2006; Grant & Berkes 2007). Where target species are highly variable in space and time, the location of target species is a major source of uncertainty for individuals (Mangel & Clark 1983; Wilson et al. 2007). In such circumstances fishers may rely on prior knowledge and experience, as well as active searching, to adapt to changes in the environment (Berkes et al. 2000). In small-scale fisheries where both target species and fishers have low mobility, such knowledge may be essential for successful fishing (Cashdan 1983).

The acquisition of information and management of knowledge are relevant to both individual and group levels. Individual fishers may acquire information and build up knowledge through personal experience of particular fishing grounds over time. The development of fishers' knowledge also enters the social domain however, in that fishers may gain information to mitigate uncertainty by observing the behaviour of other fishers and by engaging in social relationships within which information is shared (Gezelius 2007).

Fishers' strategies in managing the information and knowledge they hold may confer advantages and disadvantages to both themselves and others. Economic models assuming rational profit-maximising behaviour suggest that secrecy is likely to be the most cost-effective strategy for fishers, particularly where there are high levels of competition for resources in small areas (Palmer 1991). In systems of competitive resource exploitation in which it is difficult to exclude others, fishers may conceal information about the productivity of fishing grounds in an attempt to secure increased benefits for themselves (Palsson 1982). This may be particularly prevalent in situations where resources are relatively sedentary, since such knowledge may be valuable over a longer time period than in more mobile fisheries (Acheson 1981). Unless there are strong social norms that preclude lying, fishers may even give misinformation about their catches and fishing location (Allen & McGlade 1986; Palmer 1991).

In contrast, where there is competition for resources it may be considered advantageous for fishers to engage in social groups in which sharing of information is reciprocated (Acheson 1981; Van Ginkel 2001). Such relationships can lead to increased fishing efficiency by reducing the time spent searching individually for productive grounds (Rudd 2002). The balance fishers are required to achieve between cooperative and competitive behaviour means it is important for fishers to be able to assess the value of information from others, and mutual trust is therefore important in information-sharing relationships (Rudd 2002).

At the level of individuals, differential ability or inclination of fishers to form such relationships may have implications for resource exploitation patterns and foraging efficiency. It has been suggested that fishing communities often comprise 'leaders' and 'followers', with rivalry and personal reputation important influences in behaviour (Van Ginkel 2001). The position of individuals in social networks and the types of information-sharing relationships in which they engage may therefore be expected to differ. Modelling work suggests social network structure may have implications for performance of individual resource users where there are differences in skill level among fishers, with those closer to skilled individuals achieving higher performances as a result of information flow (Little & McDonald 2007). The success of individuals may therefore be influenced by knowledge of where and when others are successful (Palmer 1991).

At a group level, the structure of social networks and patterns of information sharing may also have implications for individual fishers' decisions about where to fish, and for the overall spatial distribution of fishing activity. Models of learning and adaptation in fisheries suggest that greater frequency of interaction with particular individuals lowers the cost of acquiring information and leads to a tendency towards formation of groups among individuals who encounter one other repeatedly. Resource users who are connected are more likely to hold similar information about the resource, leading to similar decision-making and spatial behaviour (Little et al. 2004; Wilson & Yan 2009).

To date, work on the relationships between social networks, individual performance and spatial behaviour has been largely based on modelling or qualitative ethnographic fieldwork. Social network analysis (SNA) provides a tool to begin to examine these theories empirically by quantifying properties of networks and the position of individuals within networks. SNA can be defined as the study of social-relational systems comprising data on a set of actors, their attributes, and the links between them (Wasserman & Faust 1994). An increasingly popular tool in social science research (van Duijn & Vermunt 2006; Borgatti et al. 2009), the potential for SNA to give insight into network properties that have implications for natural resource management is gaining greater recognition (Bodin et al. 2006).

There are a multitude of ways in which relations among individuals may be measured, including measures of actors' similarity (e.g. similar choice of fishing grounds), social relations (e.g. friendship), interactions (e.g. advice-seeking) or flows (e.g. information or money) (Borgatti et al. 2009). SNA has been used in a number of fisheries studies. These include investigating social capital, leadership, and differences in ecological knowledge among resource users in Kenyan fisheries (e.g. Crona & Bodin 2006; Bodin & Crona 2008), and exploring the structure of decision-making and power in fisheries governance (Johnson et al. 1988; Marín & Berkes 2010).

From an information-sharing point of view, patterns in communication networks may influence the ability of individuals to access new information (Haythornthwaite 1996). SNA has been used to look at effects of resource scarcity on information-sharing behaviour and the role of kinship and friendship in forming relationships between fishers, both within and between small-scale fishing communities (e.g. Ramirez-Sanchez & Pinkerton 2009). SNA has also been used to explore effects of communication patterns on migratory behaviour of fishers (Johnson & Orbach 1990). However, there are a number of other ways in which SNA can shed light on relationships between social networks, individual fishers' performance and fishers' spatial behaviour.

This chapter aims to explore the role of fishers' social networks in relation to their spatial behaviour and fishing success in the context of the Northumberland lobster (*Homarus gammarus*) fishery. The relatively low mobility of European lobster (Smith et al. 2001) is expected to lead to information on resource distribution having a high value to resource users for successful exploitation, since knowledge of productive areas is valuable for longer than might be the case in more mobile fisheries (Palmer 1991; Acheson 1981). Furthermore the absence of catch-restricting quotas in the fishery may increase the economic incentives for secrecy since maintaining exclusive use of a productive area may lead to an increase in annual catch (Gezelius 2007). The analysis of whole networks (i.e. including data on all individuals in a network) using SNA can involve time-consuming data collection; therefore the small size of potting communities in Northumberland provides an ideal context in which it is feasible to obtain data on whole networks to investigate these links. In particular the following objectives are addressed:

1. What are fishers' perceptions of the value of information from observation of other fishers' behaviour and information-sharing with other individuals in making decisions about where to fish?
2. How does the structure of communication networks differ among fishing ports?
3. How is fishers' success related to position in information-sharing networks?
4. Are information-sharing networks among fishers linked to spatial interaction at sea?

5.2 Methods

5.2.1 Semi-structured interviews

Semi-structured interviews were used to obtain information on two aspects of interactions among fishers: social interaction in the form of general communication and information-sharing (relating to fishing locations and catches), and spatial interaction at sea (frequency of interaction with other vessels, presumed to indicate similarity of spatial behaviour). Data were collected through interviews with fishers at four ports (Blyth, Amble, Seahouses and Holy Island), which were selected on the basis of obtaining a geographic spread and range of port and fleet characteristics within the study area (Table 5.1). Target populations for interviews were defined as the skippers of all potting vessels that had been active in each port over the past 12 months. Interviews were conducted with skippers rather than crew members or vessel owners (if different) as vessel skippers are most likely to be the individuals who make decisions about where to fish.

Table 5.22.Summary of port characteristics and data collected through interviews with fishers; figures in parentheses represent numbers of fishers as a percentage of active fishers at each port.

Port and interviewee characteristics	Port			
	Blyth	Amble	Seahouses	Holy Island
Port s				
Latitude (degrees North)	55.13	55.33	55.58	55.67
Population (2001 census)	35,691	6,044	1,803	162
Main fishing activities	Potting, trawling	Potting, trawling	Potting	Potting
Interviews				
Active fishers	11	17	9	6
Number providing network data (%)	10 (91)	16 (94)	9 (100)	6 (100)
Complete network	No	No	Yes	Yes
Estimated relational data lost (%)	10	6	0	0
Number providing map-based data (%)	10 (91)	15 (88)	9 (100)	6 (100)

Quantitative and qualitative data on the importance of information in fishers' decisions about fishing location were collected (Section B, Appendix 1; methods as described in Chapter 4). Fishers were asked to rate the importance of knowledge gained from observation of other fishers and information-sharing in their decision-making (see Chapter 4 for perceptions of all factors considered to affect decision-making). Ratings of importance were given on a scale of 1-4 (1 = not important, 2 = less important, 3 = important, 4 = very important), and descriptive statistics were calculated summarising fishers' responses. Qualitative explanations for these responses (given spontaneously or elicited through further questions) were recorded and analysed through iterative coding in NVivo V.7 (QSR 2006) to identify common themes in fishers' responses.

5.2.2 Collection of network data

The aim was to collect relational data for whole networks; therefore an attempt was made to interview all fishers in the target population, since sampling a proportion of individuals within a network can lead to a significant loss of relational data (Hanneman & Riddle 2005). The term relational data is used to indicate that the network data collected refers to the relations between individuals (nodes) in the network, rather than to attributes of the nodes themselves. In total, network data were collected from 41 fishers, representing 95% of the target population (Table 5.1). An approximate estimate of the percentage of relational data lost due to missing data from the 5% of fishers not interviewed was calculated as 100 - *k*, where *k* is the sample size as a percentage of the population (Burt 1983) (Table 5.1). The target population at each port was considered to represent one network, in which different types of relations between individuals are possible. Within each network, there may be separate sub-networks (hereafter termed components) between which there are no links; these are considered to be part of the same network.

In ports where incomplete networks were obtained (Blyth and Amble; Table 5.1), the proportion of relationships (hereafter termed ties) reported by interviewees that were reciprocated (i.e. fisher *a* reported a tie with fisher *b* and *vice versa*) was calculated to assess whether it was reasonable to assume reciprocity and estimate missing tie values on the basis of ties reported by other respondents[12]. However, reciprocity of ties was below 50% in all incomplete networks, therefore data from fishers who were not interviewed were treated as missing in subsequent analysis.

Relational data on spatial interactions among fishers were obtained by asking respondents to recall the names of vessels they regularly encountered at sea when fishing. Subsequently communication and information-sharing relationships among fishers were elicited through a series of questions (Section E; Appendix 1, Fig. 5.1). Firstly, respondents were asked to recall the names of skippers or vessels with whom they regularly communicate or talk to, either about topics concerning fishing or on a social basis. Secondly, fishers were asked to recall the names of any skippers or vessels with whom they share information about their fishing location and catches. Follow-up questions were asked to explore why fishers shared information with the particular individuals named. Finally, information on the perceived success of individual fishers was obtained by asking respondents to name other potting fishers they considered to be particularly successful. Qualitative explanations for these perceptions and fishers' interpretation of success were recorded to assess whether fishers shared similar views as to what characterised a successful fisher.

[12] For example, if fisher *a* was interviewed and fisher *c* was not, a tie would be reported from *a* to *c*, but not *vice versa*; if reciprocity was considered likely, the tie from *c* to *a* could be assumed to be equal to that from *a* to *c*.

All network questions were asked using a free recall method initially, giving fishers the opportunity to name any individuals either within or outside of their home port. Once recalled lists had been recorded for each relationship type (i.e. interaction at sea, communication or information-sharing), respondents were prompted with a list of active vessels from the relevant port. Vessel lists were obtained from Northumberland Sea Fisheries Committee (NSFC) and cross-referenced with fishers throughout the interview process.

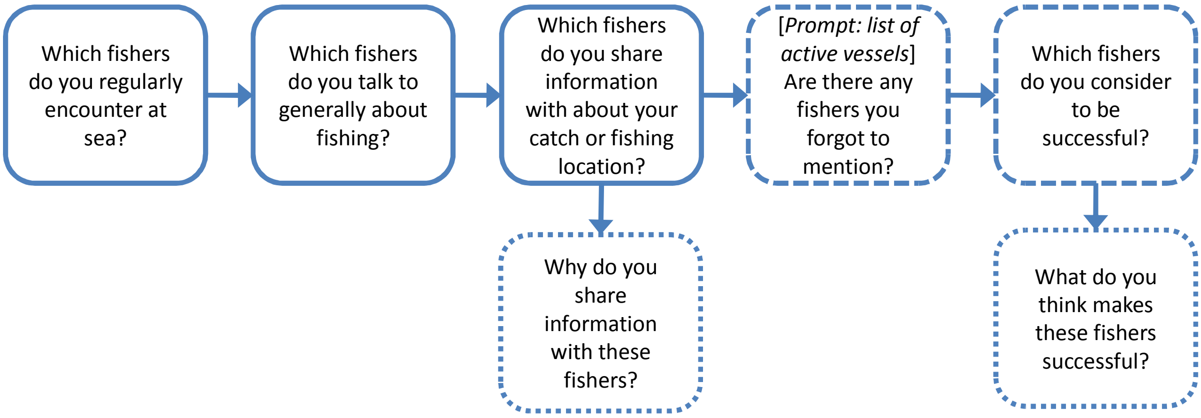

Figure 5.25. Series of questions used to elicit social network data, comprising free recall questions (solid lines), recognition questions (dashed lines) to prompt on basis of current active vessels in each port, and open-ended explanatory questions (dotted lines). Names provided at each stage may differ from those given at previous stages.

Respondents' perceptions of specific interactions may not be closely related to observed measures of same interactions due to memory loss and differences in how people recall events. However, recollections tend to better reflect individuals' patterns of aggregated behaviour over time than specific instances (for a summary of these arguments see Krackhardt 1987 and Freeman et al. 1987). Furthermore, it has been argued that measurement of cognitive social structure, i.e. how individuals perceive relations, may be more important in predicting behaviour than observations of interactions (Borgatti et al. 2009). This may be particularly the case in information-sharing relationships, where degree of trust and extent of information shared between individuals is not easily observable. The measures collected here are therefore expected to reflect general patterns of behaviour and fishers were not asked to report specific frequencies of interaction.

A second measure of fishers' spatial interaction at sea was calculated on the basis of maps of individuals' fishing grounds which were collected during interviews and digitised in GIS (see chapter 2 for methods). Presence or absence of fishing activity by each fisher was recorded for each grid cell in a 1 x 1 km grid covering the extent of fishing grounds for each port. Following Rjinsdorp (1998) a measure of the spatial similarity of fishing grounds of each pair of fishers was calculated using a coefficient of overlap (Equation 5.1). The coefficient ranges from 0-1, with 0 representing no overlap between vessels, and 1 representing complete overlap, with fishing activity by both vessels occurring in exactly the same grid cells.

$$O = 2\sum_{j}(P_{aj}P_{bj}) \bigg/ \left(\sum_{j} P_{aj}^{\ 2} + \sum_{j} P_{bj}^{\ 2}\right)$$

Equation 5.2. Coefficient of overlap (Horn 1966), where P_{aj} represents the presence of fishing activity by fisher *a* in grid cell *j* as a proportion of the total number of grid cells covered by the fishing grounds of fisher *a*, while P_{bj} refers to the same measure for fisher *b*.

5.2.3 Analysis of relational data

Social network analysis (SNA) methods were used to investigate relational data and the structural properties of social networks among fishers. All SNA analysis was conducted in Ucinet (Borgatti et al. 2002), and network graphs were constructed in NetDraw (Borgatti 2002). Five relational matrices were derived from the data for use in further analysis (Table 5.2). Data collected on communication and information sharing were first compiled into one general communication network, in which the strength of each tie was given a value of 0-4 depending on fishers' responses. Previous studies have found that respondents have closer relationships with recalled ties than those recognised from a list (Brewer & Webster 1999). Higher scores were therefore given if respondents reported a tie through recall methods and weaker scores if the tie was only recalled after prompting with vessel lists. All information-sharing ties (recalled and recognised) were scored more highly than general communication ties, thus 0 = no tie, 1 = communication (prompted), 2 = communication (recalled), 3 = information-sharing (prompted) and 4 = information-sharing (recalled).

Table 5.23. Relational matrices used in SNA data analysis

Relation	Measure	Description	Value	Directed
Social	All communication	All communication ties reported	Ordered (0-4)	Yes
	Information-sharing	Information-sharing ties only	Dichotomous	Yes
	Reciprocal information-sharing	Reciprocated information-sharing ties only	Dichotomous	No
Spatial	Perceived spatial similarity	Vessels frequently encountered at sea	Ordered (0-2)	No
	Coefficient of overlap	Spatial similarity based on mapped fishing area	Ordered (0-1)	No

Information on ties between each fisher in the communication network was directed (i.e. the matrix was asymmetric, since it was possible for example for fisher *a* to report that they share information with fisher *b*, but not *vice versa*). A second matrix was derived based only on information-sharing ties reported, which were dichotomised to indicate only presence or absence of a directed tie between fishers. A third matrix was derived based only on information sharing ties that were reciprocated. The three communication matrices were assumed to indicate a gradient of increasing tie strength in terms of the level of communication among fishers (general communication links being weaker than one-way or reciprocal information sharing links). Reciprocal links are considered to be strongest, since reciprocity is believed to increase degree of trust and long-term obligations between individuals (Pretty 2003).

Reported ties representing spatial interactions with other vessels at sea were symmetrised, since the nature of the data indicates a measure of interaction according to spatial proximity, which by definition is reciprocated. However, to take account of the presence of unreciprocated ties reported, matrices were symmetrised by calculating the sum of reported ties (i.e. 0 = no tie, 1 = unreciprocated tie, and 2 = reciprocal tie). There are a number of possible explanations for unreciprocated ties, including errors or omissions in fishers' recollections, or differences among fishers in the frequency of interactions which were considered frequent enough to report.

Finally, the coefficient of overlap matrix (based on Equation 5.1) contained the map-based measure of spatial overlap between each pair of respondents within the networks, which was undirected since the data represent an interaction as opposed to a flow of information (i.e. if fisher *a* interacts with fisher *b*, the reverse is inherently also true).

5.2.4 Network structure

A number of measures were calculated to describe the structure of relational networks at each port. These included the number of ties in each network, the mean strength of ties (where applicable), and the network density, which represents the number of ties reported as a percentage of all possible ties. The number of components (sub-groups in the network which are not connected to each other), and isolates (the number of fishers who were not connected to any others) were reported to illustrate network fragmentation. The components reported are weak components rather than strong components, in that they take account only of the presence or absence of ties, and not of their directionality (Scott 2000). The numbers of reported ties both within and outside of fishers' home ports were calculated, and an index of the relationship between internal (I) and external (E) ties is given using the E-I index (Equation 5.2), values of which range from -1 to +1, with negative values representing a dominance of inward links, and positive values representing a dominance of outward links (Krackhardt & Stern 1988).

$$\text{E-I} = (\text{EL} - \text{IL}) / (\text{EL} + \text{IL})$$

Equation 5.3. E-I index (Krackhardt & Stern 1988), where EL = external links and IL = internal links

Ties outside of the target population referred to a combination of ties to potting fishers in other ports, inactive potting fishers, or fishers in other sectors (e.g. trawling). In order to enable statistical comparison of social and spatial network measurements, only ties between vessels within the target population were included in further analysis.

5.2.5 Relationships between fishers' social network position and success

Qualitative data on fishers' perceptions of the characteristics of successful fishermen and explanations for the perceived fishing success of individuals among their peers were coded using NVivo V.7 (QSR 2006) to identify themes in responses.

The validity of peer perceptions as a measure of success was assessed through Spearman's rank correlation with two independent measures of success: 1) total volume of landings, and 2) performance estimated by an indicator of catch rates. Firstly, total lobster landings (t) of each interviewee in 2007 (the latest complete information readily available at the time of writing) were obtained from NSFC (<10 m vessels) and the Marine and Fisheries Agency (>10 m vessels). Secondly, an indication of relative performance was obtained for each interviewee from a linear mixed model which modelled lobster landings from 2001-2007 using a combination of fishing effort and environmental variables, and included vessel as a random effect (see Chapter 3 for details). Random intercept coefficients represent an indicator of differing performance in terms of landings by each vessel, which are not explained by fishing effort variables included in the model and can therefore be considered analogous to an indicator of differing catch rates. Where interviewees had skippered more than one vessel over this period, the mean random intercept coefficient of relevant vessels was used. To identify any characteristics of fishers perceived to be successful, Spearman's rank correlations were also used to explore relationships between peer perceptions of fisher success and attributes of individual skippers and vessels (specifically, vessel length (m), engine size (kW), number of pots worked, age (years) and fishing experience (years)).

Fishers and their communication ties were plotted at each port using a multidimensional scaling technique in which the position of fishers is dependent on the number and strength of ties, and fishers with similar patterns of ties are positioned close to each other (Scott 2000). The perceived success of individuals was calculated as the percentage of their peers who named them as successful fishers, and this measure was indicated in the plots to visualise the position of these individuals in communication and information-sharing networks. Joint count analysis (JCA) was undertaken to assess whether reciprocal information-sharing links were more likely to occur among fishers who were perceived to be successful than between successful fishers and fishers who were not perceived to be successful. JCA tests whether the density of ties within and between two groups (e.g. successful and unsuccessful) differs from what is expected by chance. The test is analogous to a Chi Squared test of independence, but statistical significance is determined by comparing within and between group tie density against random graphs generated with the same density and number of nodes in each group (Hanneman & Riddle 2005). Due to the small samples and exploratory nature of the study, significance values at $\alpha = 0.1$ are reported in addition to those at $\alpha = 0.05$.

Measures of network centrality may have implications for the function or performance of individuals within a network (Sparrowe et al. 2001). To assess the relationship between fishers' success and their position in information-sharing networks, two measures of centrality were calculated for each fisher: degree centrality and closeness. Degree centrality measures the number of direct ties at each node in the network (Scott 2000; Wasserman & Faust 1994). Closeness looks beyond direct ties to take account of broader connectedness in terms of the distance from each node to all other nodes in the whole network (Scott 2000; Wasserman & Faust 1994). This may have implications for how quickly information is passed to or from fishers via indirect ties, since shorter distances between nodes are assumed to relate to fewer transmissions of information, shorter times and lower costs (Freeman 1979). Closeness is usually calculated as the reciprocal of farness, which is the sum of the length of the paths (number of ties) to each other node in the network. Due to the presence of isolates (see 2.2.3) and missing data, closeness was calculated using the sum of reciprocal distances to each node, so that infinite distances have a value of zero (Borgatti et al. 2002).

When applied to directed data, both degree centrality and closeness centrality comprise two parts: in-degree and out-degree. In-degree measures are calculated on the basis of ties reported by others, and represent incoming information shared by other fishers. Out-degree measures reflect ties reported by the fishers themselves, representing information that is shared with others. Both measures were normalised (expressed as a percentage of the maximum possible measure in each network) to allow comparison across individuals in all ports (Hanneman & Riddle 2005).

Linear multiple regression computed using ordinary least squares was used to assess any relationships between centrality measures and perceived success, with success treated as a dependent variable, and paired in-degree and out-degree centrality measures used as predictor variables. The degree centrality and closeness measures were highly correlated with each other, therefore two separate multiple regressions were carried out to assess independent effects of each measure. The statistical significance of predictor variables was estimated using permutation tests (Hanneman & Riddle 2005).

5.2.6 Relationships between social and spatial ties

The association between social networks and spatial interactions was tested using the quadratic assignment procedure (QAP) (Hubert & Schultz 1976, cited in Krackhardt 1988), which calculates the Pearson correlation between corresponding cells in two matrices containing the same actors, and estimates the statistical significance of the result through a permutation test to assess the probability of a correlation coefficient equal to or larger than that calculated occurring by chance. QAP procedures are used since network data are interdependent and potentially autocorrelated, thus violating the assumptions of parametric statistical tests (Krackhardt 1988).

Four associations were tested using QAP. The first looked at the association between general communication networks and perceived measures of spatial interaction at sea, which tested whether the strength of communication ties was correlated with the strength of reported spatial interaction among pairs of actors (termed dyads). The second tested the same association, using the map-based coefficient of overlap as an alternative measure of spatial similarity to perceived interaction, and the third tested the correlation between the two measures of spatial interaction. The final correlation tested the hypothesis that the stronger the communication ties between individuals, the more their spatial networks overlapped. The association was tested between the general communication networks, which contained information on the strength of ties, and a similarity network, which contained data on the number of spatially similar contacts shared by each pair of fishers. The latter was constructed by calculating a matrix from a dichotomised perceived spatial network (0 = no tie, 1 = unreciprocated or reciprocated tie) which for each pair of actors records the number of ties reported in common.

5.3 Results

5.3.1 Perceived importance of information sharing and observation

Fishers' perceptions of the importance of information obtained from talking to or observing other fishers was mixed, with only a relatively small percentage perceiving this information to be very important in decision-making (Fig. 5.2). The prevailing view among respondents was that fishers were secretive about their fishing location and catches, and information would only be shared to the extent that it did not disadvantage fishers' own activities (Table 5.2). Fishers commented that if they find a productive area of ground they try to keep it to themselves to avoid an influx of other vessels' fishing gear. It was suggested that successful fishers tend to be more secretive, as it is more likely that others may emulate their behaviour. Successful fishers with extensive fishing experience also described sharing more information with similar individuals, with one fisher commenting:

> *"There's no malice in not sharing with some that aren't very successful as they're probably not interested – they tend to just plod along and follow others, and they can't teach you anything."*

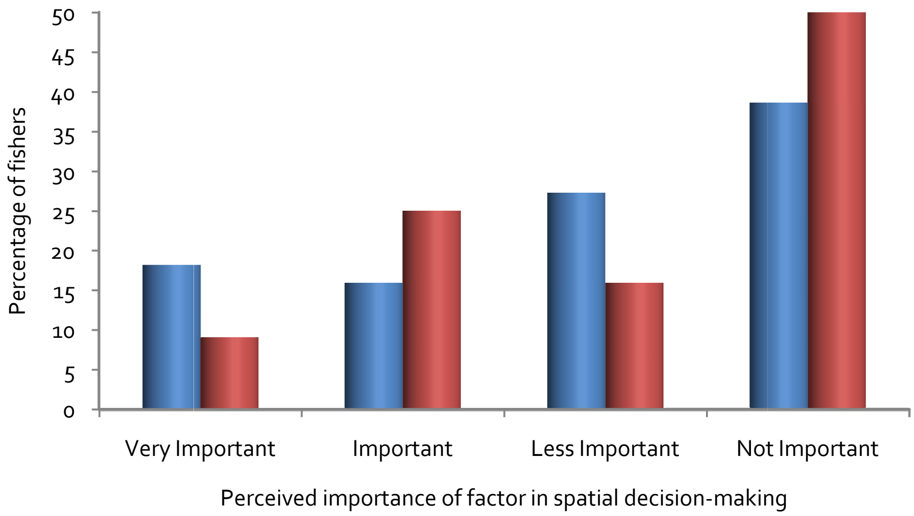

Figure 5.26. Fishers' perceived importance of information obtained by observing other fishers (blue) and by sharing information with others (red) in their spatial decision-making

Three fishers commented that while they might try to glean clues from each other, it would be considered a sign of weakness to openly ask for help, with one fisher suggesting, "*...if you were a serious fisherman you wouldn't want to ask*". It was also acknowledged that fishers are not always honest, and 14 respondents described 'fibs', 'white lies' or 'stock answers' as being an accepted part of conversations concerning catches and fishing grounds. Stock answers were described as being vague or non-committal, requiring fishers to assess whether others were telling the truth.

Table 5.24. Perceptions of observation of other fishers' behaviour, information sharing about fishing location and catch among fishers, and explanations for sharing of information with particular individuals. Note that not all comments were in response to a direct question, and individual fishers may have suggested multiple factors. Comments may reflect behaviour of respondent or perceptions of general behaviour among fishers.

Fishers' perceptions on sources of information and information-sharing	Times mentioned
Sources of information	
Fishers are secretive about where they fish and what they catch	31
Observation of other vessels is a source of information about where others fish	28
Sharing information can be detrimental to personal fishing success	19
Fishers may be dishonest or give misleading information	14
Information may be obtained from shellfish merchants	13
Information obtained from observation is not useful in decision-making	12
Fishers may selectively share information with others	7
It is difficult to piece together information from indirect sources (e.g. observation, merchants)	3
Sharing of information	
Information shared with friends	14
Information shared with those who reciprocate	8
Information shared with those having similar fishing patterns	6
Information shared with family	5
Information shared with those considered genuine or respected	4
Information shared with those who have benign intentions	4
Information shared with those having dissimilar fishing patterns	3
Information not shared even with friends	3
Information shared with successful fishers	2
Information shared with fishers of same generation	2
Information shared with local boats	2

While fishers may avoid sharing their most valuable information, there were instances in which fishers talked about sharing details with particular individuals who they trusted, believed to be honest, and thought would reciprocate (Table 5.3). Friendship was the most commonly mentioned factor in fishers' explanations of why they shared information with particular individuals, although it by no means ensured the exchange of details about catches and fishing locations. In three cases fishers talked about friendships in which information was not shared, which was usually accepted in good humour. In some instances information-sharing relationships were described with fishers who were family members. Historically, fishing in the Northumberland region has been dominated by a number of extended families, whose names remain common in fishing ports today. However, while one fisher commented that these 'big families' tend to stick together and five fishers mentioned sharing information with family members, another fisher suggested that even relatives will openly lie to each other about what they have caught and where.

Six fishers said they shared information with skippers of similar sized vessels that had similar spatial and temporal fishing patterns. One fisher suggested that information was more important when working offshore in winter as target species are patchier and vessels aggregate when they hear of a productive area. In contrast, three fishers said they would only share details with vessels that did not have similar fishing patterns, as they would not expect them to act on the information. Four fishers indicated that there were norms associated with sharing information, with information being shared only with those who they thought would not act upon it to the detriment of the sharer (those with benign intentions; Table 5.3). For instance, one fisher stated, "*...some people I wouldn't tell a thing to because they'd commandeer the place and take it off you*". Information shared may therefore be more important in longer-term knowledge development than shorter-term decision-making.

Information obtained from observation of other fishers was more often seen as 'very important' than information-sharing (Fig. 5.2). Fishers said they were aware of the location of others' pots at sea, and the advent of increasingly sophisticated navigation and plotting equipment had made it easier to mark locations for future reference. Consequently it was difficult for fishers to be secretive about where they fished, although they might be secretive about what they caught at any particular location. One fisher explained that observing others' behaviour (e.g. whether or not pots are re-deployed in the same place) may provide some insight into the productivity of particular locations.

In Amble and Blyth in particular, fishers obtained information on other vessels' landings from seafood merchants. The majority of fishers sold their catch to one of two main merchants in the region, who pick up produce daily from each port. It was described by 13 respondents as common practice for fishers to look at the books while recording their catch, or to ask the van driver directly about what other vessels had weighed in. This information was said to be passed on by fishers talking on the quay or socialising in pubs (one fisher commenting, "*...word gets down the coast within hours*"), and may be related back to where pots had been observed at sea. However, 12 fishers dismissed information from observation and from merchants as being useless if the lobsters in question had already been caught. Furthermore, three fishers suggested that with vessels covering a vast area and catches from individual fleets of pots highly variable, it was difficult to identify the precise location of successful fleets unless it was revealed.

5.3.2 Network structure

Communication networks contained between 24 and 109 within-group ties in different ports, with the mean number of ties per fisher ranging from 4.0 in Holy Island to 6.8 in Amble (Table 5.4). Only 3 fishers reported not communicating with any other fishers and none were isolated (i.e. all fishers either named ties or were named by other fishers, including those who were not interviewed). Over 70% of reported ties in all ports were within the defined network boundaries (calculated as number of within-group ties as a percentage of the sum of within-group and outside-group ties). Both mean tie strength and network density appeared to be negatively related to network size, with highest mean tie strength and highest density in the smallest port of Holy Island, indicating that a greater proportion of possible ties were realised. In each network, all fishers were contained within a single component (a set of actors in which each actor could reach every other by a direct or indirect path), and no fishers were completely disconnected from others.

Table 5.25. Summary of communication network, information-sharing network, perceived spatial network (before symmetrisation) and coefficient of overlap. Figures in parentheses represent mean number of ties per fisher in each port.

Network metrics	Port			
	Blyth	Amble	Seahouses	Holy Island
Number of fishers	10	16	9	6
Communication network (directed, valued data: 1 = weakest, 4 = strongest)				
Total number of ties within group (mean)	45 (4.5)	109 (6.8)	52 (5.8)	24 (4.0)
Total number of ties outside group (mean)	17 (1.7)	1 (0.1)	6 (1.0)	9 (1.5)
E-I Index	-0.45	-0.98	-0.79	-0.45
Number reporting no ties	0	2	1	0
Isolates	0	0	0	0
Mean tie value	1.3	0.9	1.6	2.7
Density [a]	45%	43%	72%	80%
Number of components [b]	1	1	1	1
Information-sharing network (directed, binary data: 0 = tie absent, 1 = tie present)				
Total number of ties within group (mean)	22 (2.0)	33 (1.9)	12 (1.3)	17 (2.8)
Total number of ties outside group (mean)	4 (0.4)	1 (<0.1)	0	3 (0.5)
E-I Index	-0.69	-0.94	-1.00	-0.70
Number reporting no ties	2	6	2	1
Isolates	0	1	2	0
Density	22%	13%	17%	57%
Reciprocity	16%	22%	20%	31%
Number of components [b]	1	2	1	1
Perceived spatial network (undirected, valued data: 0 = tie absent, 1 = tie present, 2 = reciprocal tie present)				
Total number of ties within group (mean)	36 (3.6)	86 (5.4)	43 (4.8)	30 (5.0)
Total number of ties outside group (mean)	8 (0.8)	9 (0.6)	15 (1.7)	11 (1.2)
E-I Index	-0.64	-0.81	-0.48	-0.46
Number reporting no ties	1	0	0	0
Isolates	1	0	0	0
Density	36%	34%	60%	100%
Number of components [b]	1	1	1	1
Map-based coefficient of overlap (undirected, valued data: min = 0 (no overlap), max = 1 (complete overlap))				
Mean value	0.11	0.11	0.11	0.14
Standard deviation	0.08	0.09	0.07	0.09
Minimum / maximum	0.00 / 0.27	0.00 / 0.43	0.00 / 0.23	0.00 / 0.30

[a] based on binary network; [b] excluding isolates

The number of information-sharing ties (and hence network density) was much lower than general communication ties, although density remained high in Holy Island in comparison to other ports. Visual inspection of social networks at each port (Fig. 5.3 a-l), highlights fewer ties and greater network fragmentation in networks with stronger communication ties (i.e. strength of communication ties assumed to be: general communication < information-sharing < reciprocal information-sharing). The degree to which reported information sharing ties were reciprocated varied among ports, being highest in Holy Island and lowest in Blyth (Table 5.4). Isolated fishers with no in-coming or out-going information-sharing relationships were present in both Amble and Seahouses.

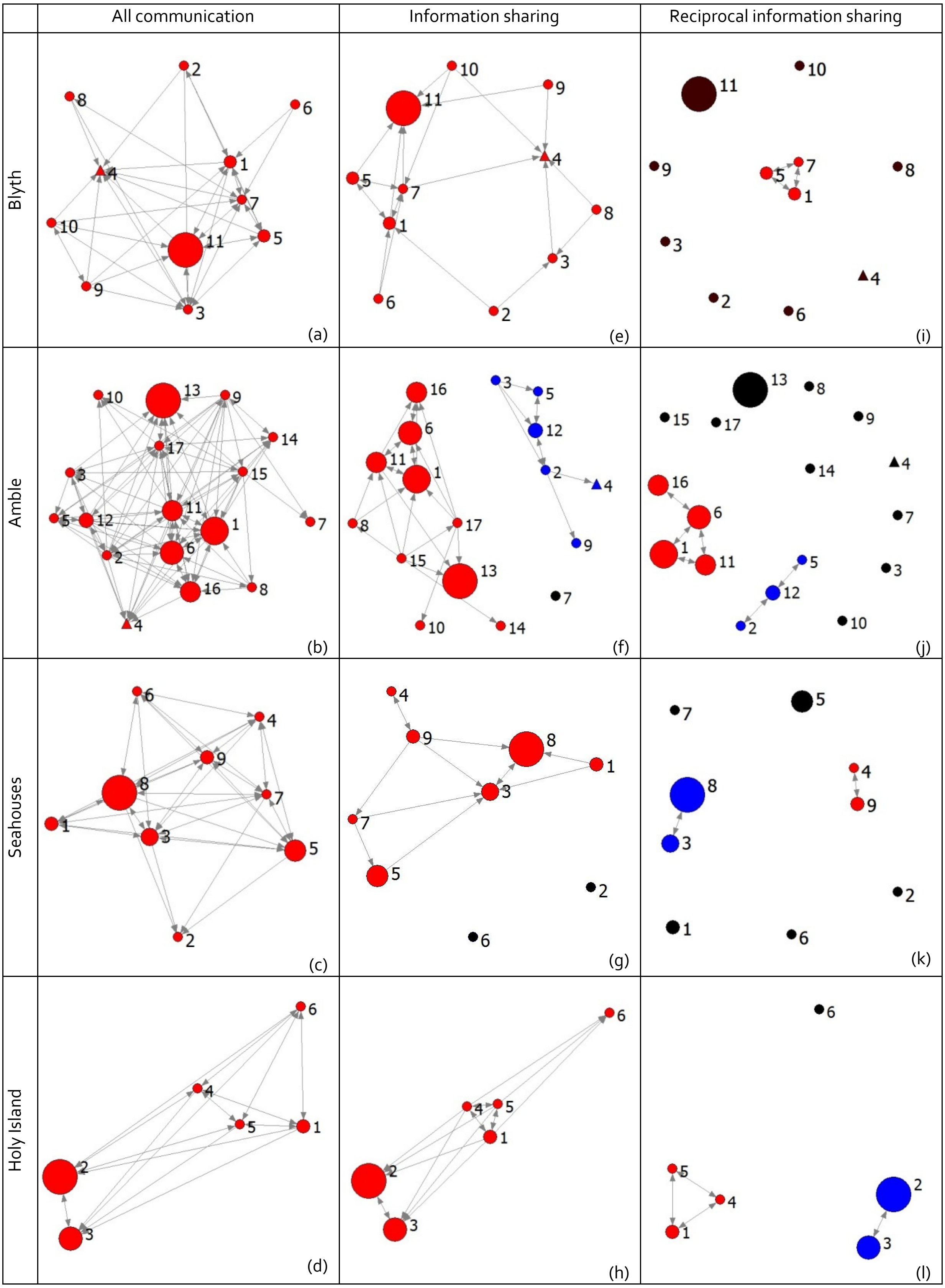

Figure 5.27. Social network diagrams for each port showing a-d) full communication ties, e-h) information-sharing ties, and i-l) reciprocal information-sharing ties. Nodes (circles) represent fishers, adjacent labels represent fisher identification numbers and node size represents number of times fisher was named as successful by peers. Arrows and lines indicate direction of communication flow (i.e. arrow from fisher 1 to fisher 2 indicates that fisher 1 claims to communicate with fisher 2). Node colours represent separate components of the network at each stage. Red nodes indicate the largest component (see Section 5.2.4), black nodes indicate isolates. Layout of graphs is based on multidimensional scaling (MDS). Triangles indicate fishers not interviewed.

In the largest port of Amble, two disconnected components were evident (Fig. 5.3 f), indicating subgroups between which information sharing did not occur, although the full communication network suggests that these components were bridged by weaker ties, through which indirect observation and imitation might have led to information flow. If only reciprocal information-sharing ties are considered, the majority of fishers in all ports except Holy Island appeared to be isolated (Fig. 5.3 i-l). Reciprocal ties show a greater degree of network fragmentation, with the maximum number of nodes in a single connected component being four fishers, not all of whom were connected to each other (Fig. 5.3 j). All other information sharing relationships comprised single dyads or triads (two or three linked nodes respectively) (Fig. 5.3 i-l).

Perceived spatial networks contained between 30 and 86 ties in different ports, with the average number of ties per fisher ranging from 3.6 to 5.4 (Table 5.4). Fishers reported spatial interactions with vessels outside the defined network boundary, indicating overlap of spatial fishing patterns with vessels from other ports or gear types; however over 70% of all reported ties were within-group ties. Network density varied substantially between ports, and was lower than network density in the communication network at all ports except Holy Island, where density was 100% indicating that all vessels shared similar spatial patterns to some extent. In contrast, the mean and standard deviation of the map-based coefficient of overlap, indicating spatial similarity of each pair of fishers, was similar among all ports (Table 5.4).

5.3.3 Social networks and fishing success

Fishers' explanations for considering others to be successful highlighted a number of factors taken into account, including not only equipment, resources and financial investment, but also skill, determination and commitment (Table 5.5). Fishers' assessments of who was successful therefore included a number of fishers who owned large vessels capable of working high quantities of gear, put in long hours, were willing to work in poor weather conditions, and employed several crew members, all reflecting a potential for higher landings than other vessels (although it was noted by four fishers that this did not necessarily equate to net profit given the high levels of investment involved). Other vessels were considered to be successful on the basis of their 'catching ability', which was described as reflecting their knowledge, hard work and dedication to achieve high landings relative to the scale of their operation, which often involved smaller vessels, operating single-handedly, and working small quantities of pots. Two fishers were recognised as successful in a broad sense, having also done well at fishing activities other than potting.

Table 26.5. Characteristics of fishers perceived to be successful and number of times mentioned. Note that each respondent may have indicated more than one characteristic.

Characteristic	Times mentioned
Hard-working / dedicated	10
Large quantities of gear	7
High volume caught	6
Larger / faster vessel	5
Knowledgeable	4
Large number of crew	4
Works long hours	4
High catching ability	3
Works in all weather	3
Successful in all fishing activities	2
Works alone	2

Peer perceptions of success were positively correlated with indicators of both landings (Spearman's *rho* = 0.659, significance < 0.001) and catch rates (Spearman's *rho* = 0.347, significance = 0.035), with correlation strength suggesting that peer perceptions more closely reflected the volume of landings. This was supported by positive correlation of peer perceptions with vessel length (Spearman's *rho* = 0.355, significance = 0.023), engine size (Spearman's *rho* = 0.487, significance = 0.001) and number of pots worked (Spearman's *rho* = 0.582, significance < 0.001), since larger, more powerful vessels working more gear are likely to have higher total landings than smaller vessels (local fishers, *pers. comm*., 2009). No significant correlations were found with fishers' age or years of fishing experience.

Visual representation of information-sharing networks (Fig. 5.3 e-l) and qualitative information from fishers suggest that reciprocal relationships appeared to frequently involve fishers who were perceived to be successful. The most apparent exceptions were fishers 11 in Blyth and 13 in Amble, who did not engage in any reciprocal information-sharing relationships (Fig. 5.3 j-k). The number of observed reciprocal information-sharing ties between successful fishers was greater than the number expected in all ports, although this was only statistically significant in Amble (Table 5.6).

Table 5.27. Joint count analysis testing observed versus expected ties between 'successful' and 'unsuccessful' fishers, ** = statistically significant at α = 0.05, * = statistically significant at α = 0.10

Port	Ties	Expected	Observed	Difference	*P* >= difference	*P* <= difference
Blyth	Unsuccessful – Unsuccessful	1.5	0.0	-1.5	1.000	0.151
	Unsuccessful – Successful	1.3	2.0	0.7	0.659	1.000
	Successful – Successful	0.2	1.0	0.8	0.151	0.994
Amble	Unsuccessful – Unsuccessful	2.4	0.0	-2.4	1.000	0.070*
	Unsuccessful – Successful	2.9	2.0	-0.9	0.859	0.341
	Successful – Successful	0.7	4.0	3.3	0.010 **	1.000
Seahouses	Unsuccessful – Unsuccessful	0.3	0.0	-0.3	1.000	0.681
	Unsuccessful – Successful	1.1	1.0	-0.1	0.796	0.683
	Successful – Successful	0.6	1.0	0.4	0.523	0.962
Holy Island	Unsuccessful – Unsuccessful	0.8	1.0	0.2	0.691	0.949
	Unsuccessful – Successful	2.4	2.0	-0.4	0.895	0.402
	Successful – Successful	0.8	1.0	0.2	0.711	0.946

Multiple regression coefficients were positive for all centrality metrics related to incoming information ties, suggesting that fishers' perceived success was greater among those who had greater numbers of direct contacts sharing information with them and greater access to incoming information from the wider social network. Conversely, when controlling for incoming centrality measures, perceived success was negatively related to metrics related to outgoing ties, indicating that fishers who shared information with fewer contacts were more successful (Table 5.7). Closeness measures gave an improved fit compared to degree centrality measures (Table 5.7), suggesting that indirect ties were important in determining access to information.

Table 5.28. Regression statistics for multiple regressions between fishing success and normalised centrality measures

Predictors	Standardised coefficient	Two-tailed probability	R^2	Adjusted R^2	F	One-tailed probability
Out-degree centrality	-0.291	0.050	0.493	0.454	18.482	< 0.001
In-degree centrality	0.704	< 0.001				
In-closeness	0.655	< 0.001	0.497	0.459	18.799	< 0.001
Out-closeness	-0.300	0.049				

5.3.4 Social networks and spatial behaviour

Positive correlations between the strength of communication ties and the strength of perceived spatial ties were found at all ports except Holy Island, where there were no differences among ties in the perceived spatial network (Table 5.8). Permutation tests suggested correlation coefficients were statistically significant, indicating that fishers with stronger communication ties also had stronger perceived spatial interactions.

Table 5.29. QAP correlations between communication networks (ordered (0-4), directed), perceptions of vessels encountered frequently at sea (ordered (0-2), undirected), and coefficient of overlap based on map-based interview data (continuous (0.0-1.0), undirected). The shared spatial interaction matrix is calculated from the cross-product similarity of dichotomous undirected matrices. Statistical significance - ** = at 0.05%, * = at 0.1%.

Port	Communication x Perceived spatial interaction	Communication x Coefficient of overlap	Perceived spatial interaction x Coefficient of overlap	Communication x Shared spatial interaction
Blyth	0.594 ($p < 0.001$) **	-0.016 ($p = 0.465$)	0.135 ($p = 0.219$)	0.378 (p=0.007) **
Amble	0.445 ($p < 0.001$) **	0.250 ($p = 0.004$) **	0.339 ($p = 0.002$) **	0.255 (p=0.016) **
Seahouses	0.526 ($p = 0.001$) **	0.317 ($p = 0.023$) **	0.388 ($p = 0.020$) **	0.112 (p=0.315)
Holy Island	n/a	0.233 (p = 0.093) *	n/a	n/a

Positive correlations were also found between strength of communication ties and coefficient of overlap in the ports of Amble, Seahouses and Holy Island, again suggesting that stronger ties among fishers were associated with a greater degree of similarity in spatial fishing behaviour. However, no correlation was found between the strength of communication ties and coefficient of overlap between pairs of fishers in the port of Blyth. Furthermore at this port the two measures of spatial similarity (perceived interaction at sea and map-based coefficient of overlap) were not correlated with each other (Table 5.8).

In the ports of Amble and Blyth, positive correlations were found between the strength of communication ties between pairs of fishers and the number of spatially similar contacts that they reported in common (Table 5.8), suggesting that fishers with stronger communication ties were more likely to have spatial interactions with the same vessels.

5.4 Discussion

The results presented herein highlight differences in network structure among ports, demonstrate a relationship between fishers' centrality in information-sharing networks and their fishing success, and point towards the existence of social-spatial groups in fishing behaviour at sea.

5.4.1 How do fishers perceive their information-seeking strategies?

Qualitative data from interviews with Northumberland fishers' concerning their information-sharing relationships corroborate other studies in at least four ways. Firstly, fishers' acknowledgement that secrecy, and to some extent deception, were commonplace in relation to information shared among fishers about fishing location and catches is consistent with such information having a high value in static gear fisheries with target species of relatively low mobility (Acheson 1981). The small number of respondents perceiving direct information sharing to be very important in decision-making may be attributed to widespread agreement that the majority of fishers are secretive. While some studies have identified strong social norms that preclude outright lying (e.g. Norwegian purse-seine fleet, Gezelius 2007), Northumberland fishers suggested that it was not uncommon to give misleading information. This is consistent with fishers under-estimating catch or reporting inaccurate location of fishing grounds when talking to others (Palsson 1982; Palmer 1991). However, the social acceptability of this behaviour may be dependent on the degree of trust, reciprocity and honesty expected in particular relationships. The social consequences of lying may differ depending on the social context, being more severe in small communities where fishers share cross-cutting social ties that relate to aspects of social life outside fishing (Palmer 1991).

Secondly, Northumberland fishers reported that successful fishers tended to share information both more frequently amongst themselves, and with vessels sharing similar fishing patterns, while others tended to observe and imitate the behaviour of those considered to be successful. This supports the contention that there are often 'leaders' and 'followers' in fishing communities (Van Ginkel 2001), and that fishers tend to share information with others of similar skill levels (Acheson 1988).

Thirdly, trust is important in information-sharing relationships, and may be related to kinship, but also to friendship and enduring ties over time. This is supported by literature in the field of social capital which suggests that the development of trust is important to lower transaction costs in social relationships (Rudd 2000; Rudd 2002; Grafton 2005). SNA studies of information sharing among farmers suggest that trust in others depends on individual reputation, moral standing, and benign intentions (e.g. not seeking to profit at others' expense) (Sligo & Massey 2007).

Indirect information flows and observation are important sources of knowledge for fishers, but assessing their reliability and usefulness may be more difficult than information obtained directly, particularly if they require piecing together separate sources of information on catches and fishing locations. Both strong and weak ties have been identified as important to information exchange, and while strong ties are important for direct information-sharing, weaker ties may be important for diffusion of information from observation and indirect sources, particularly where weak ties have different sets of connections and therefore access to different information (Haythornthwaite 1996). This is related to the theory of 'the strength of weak ties', which suggests that weak ties may provide more diverse information, and help reduce network fragmentation (Granovetter 1973).

5.4.2 How does the structure of communication networks differ among ports?

Communication and spatial networks, and particularly information-sharing networks, were relatively insular at each port (indicated by negative E-I index scores), supporting previous research that has shown social-spatial groupings to be closely related to fishers' home port and gear type (St. Martin & Hall-Arber 2008). The greater degree of insularity in information-sharing networks compared to general communication networks is consistent with social capital literature that suggests such bridging ties (linkages across similar groups or networks) may be weaker than bonding ties (linkages between similar individuals within groups or networks) (Grafton 2005). In particular fishers are more likely to share information with friends and family, but may be more reticent to share information with outsiders (Van Ginkel 2001).

The ports of Holy Island and Blyth show the greatest degree of outward communication. A deep water harbour in Blyth has attracted vessels from neighbouring ports, which tend to maintain ties with vessels in their former ports. In addition, a number of potting vessels in Blyth also engage in trawling activity, and therefore have links with vessels from other sectors. Even those which are not engaged in trawling may maintain communication with trawling vessels in order to minimise the risk of gear entanglement and conflict between gear types at sea. In contrast, all skippers at Holy Island are long-term local residents with a fishing background, but have developed ties with vessels from neighbouring ports. In both cases such external ties to other groups or networks may be seen to represent bridging social capital, which can be important for increasing cooperation and conflict resolution between groups (Grafton 2005; Bodin & Crona 2008).

Variation in network density has implications for the flow of information among fishers. Higher network densities, where a greater proportion of possible links are realised, may provide greater opportunities for flow of information. However, such benefits may be relative to the size of the network (Scott 2000). Results presented here show that the highest communication network density was found in the smallest network, Holy Island, where the mean number of communication ties per fisher was lower than that at all other ports. Despite the small size of the network however, the mean tie strength and mean number of information-sharing contacts were higher than in other ports. These findings may be explained in the context of literature on the formation of information-sharing relationships, which suggests that trust is an important element of tie formation (e.g. Sligo & Massey 2007). Trust may be engendered by frequency of interaction, which in turn may be more likely to occur in small groups. Furthermore, Holy Island is connected to the mainland by a tidal causeway and is at times isolated from the mainland, perhaps leading to greater community cohesion.

Development of relationships involving trust may have wider benefits for natural resources management by generating potential for the development of shared expectations of behaviour and social norms, and enhancing the propensity for collective action (Rudd 2000; Pretty 2003; Ostrom 2009). However, while properties of social networks may confer advantages in one area, they may confer disadvantages in another (Bodin et al. 2006). For instance, in communication and information-sharing networks where network density is high there may be greater homogeneity of knowledge and thus increasingly similar spatial behaviour (Crona & Bodin 2006). This may result in less efficient foraging efficiency than in a network with more heterogeneous knowledge of the local environment (Wilson et al. 2007). A high degree of within-group ties may also lead to a lower degree of innovation and incoming information, potentially reducing the ability of a group to respond to change (Newman & Dale 2005).

The suggestion that high network density can lead to greater homogeneity of knowledge and spatial behaviour is to some extent supported by the fact that the perceived spatial network in Holy Island is entirely homogeneous, with all fishers reporting spatial ties with all others. However, the map-based coefficient of overlap suggests that there was differentiation in spatial fishing patterns, and the high degree of within-network density may have been balanced by a greater number of ties outside the network, as well as possible differentiation in spatial behaviour according to vessel capability. Decisions about fishing locations are inevitably influenced by a number of factors, including vessel capability, fuel costs, congestion and fishers' preferences, but decisions about these factors may be made in the context of knowledge conveyed through social interactions that help fishers evaluate their decision-making (Johnson & Orbach 1990).

Heterogeneity of knowledge may be higher where there is a greater degree of fragmentation in networks. While communication networks at all ports comprised only one component, where only information-sharing links or reciprocal information-sharing links were included there was greater network fragmentation (Fig. 5.3). While previous studies have identified a strong moral norm of reciprocity in information-sharing among fishers (e.g. Gezelius 2007), here a high proportion of information-sharing relationships was not reciprocated, which highlights the value of collecting directed data for SNA to analyse information-sharing, where the direction of information flow may be important. These results are consistent with studies that report a gradient of strength in the social bonds held by fishers. For instance, in Norway various strengths of social networks were identified, with links closest among fishers sharing kinship or friendship bonds; both cooperation and competition were found to be greater where social bonds were strongest, and bonds were more significant in times of scarcity, when fishers shared only with their closest neighbours (Gezelius 2007).

5.4.3 How is fishers' success related to position in information-sharing networks?

Network graphs suggested Northumberland fishers were more likely to engage in reciprocal information-sharing relationships with other successful fishers, and this pattern was statistically significant in Amble, where a greater number of fishers perhaps lead to a higher degree of differentiation. The lack of differences in other ports may be related to difficulty in detecting statistically significant differences in networks with a small number of ties. The results presented support the arguments that successful fishers are more inclined to seek information from, and imitate, successful fishers (Acheson 1981) and that fishers share information with those with whom they expect reciprocal relationships will be beneficial in the long-term (Acheson 1988). However, fishers may also share information with others regardless of skill level or reciprocity on the basis of longstanding social relationships (Palmer 1991), which may to some extent explain the large number of non-reciprocated information-sharing ties in Northumberland.

SNA approaches to analyse social capital suggests that the position of actors in a network may confer both opportunities and constraints to individuals (Borgatti et al. 2009). Measures of network centrality may have implications for the function or performance of individuals within a network. For instance, studies of employees in organisational settings have found that individual performance is positively related to centrality in advice-sharing networks (Sparrowe et al. 2001). In Northumberland, indicators of success were positively related to inward measures of centrality (i.e. incoming information from others), and negatively related to outward measures of centrality (i.e. information shared with others). Two questions are relevant to these findings: the first relates to the implications for individual fishers, and the second relates to the underlying processes which led to this pattern of tie formation.

Fishers with a high number of incoming ties, and who are highly connected throughout the network via indirect incoming ties, may have greater access to information from a variety of sources which can inform their fishing decisions. Such a position in the network may therefore contribute to greater efficiency in fishing behaviour and increased fishing success. In contrast, fishers with fewer incoming ties may receive less incoming information, potentially resulting in greater uncertainty in their decision-making, contributing to lower efficiency and success. Information sharing ties may develop for a number of reasons, including individuals' prior relationships, trustworthiness, reputation and credibility. However it is also possible that less successful fishers may seek out those they consider to be successful, and share information, which may or may not be useful, in an effort to establish reciprocal relationships. Conversely, successful fishers may be more likely (as indicated by qualitative data) to be more secretive about the information they hold, particularly concerning fishers with whom they do not consider reciprocal information sharing to be beneficial. Patterns of relations may therefore be self-reinforcing. These findings support those of modelling work which suggests that some fishers (*cartesians*, i.e. risk-avoiders who stick to fishing grounds with the best known return) will try to obtain information, while others (*stochasts*, i.e. risk takers who search for new areas of productive ground) will try to avoid giving it (Allen & McGlade 1986).

Closeness measures were found to be more strongly correlated with perceived success than degree centrality measures, suggesting that indirect ties were important in determining fishers' access to information. The measure of closeness takes account of indirect connectedness of each fisher to all others in the network, therefore a higher degree of closeness may reflect greater potential for incoming information passed between fishers. This may include information gained from sharing or observation of others, or obtained by others through indirect sources (e.g. through shellfish merchants). Individuals with higher closeness centrality may obtain this information more quickly or more frequently than others, since shorter distances between nodes may imply greater speed and lower costs in transmission of information (Freeman 1979).

5.4.4 Are communication networks linked to spatial interaction at sea?

Correlations between communication networks and spatial interaction networks suggest the existence of social-spatial groups, in which fishers with stronger communication ties were more similar in their spatial behaviour. These results are consistent with findings that fishers' position in communication networks influences behaviour at a broad scale, with social similarity and sharing of information about resource availability and profitability leading to similar migration patterns in the North Carolina shrimp (*Penaeus* sp.) fishery (Johnson & Orbach 1990). In contrast, commercial fisheries data in the New Zealand hoki (*Macruronus novaezelandiae*) fishery showed that while fishers' spatial behaviour was related to their own previous catches, there was no evidence that they responded to the catch rates of other vessels, suggesting that information sharing either did not occur, or was not considered to be useful (Vignaux 1996). However, it may be the case that where information is shared selectively, individuals may respond to catch rates of sub-groups rather than that of the entire fleet.

There are two possible explanations for the development of the patterns identified between communication networks and spatial interaction networks: opportunity-based and benefit-based

(Borgatti et al. 2009). Firstly, opportunity-based ties may arise if greater initial spatial similarity leads to increased likelihood of regular encounters among fishers, conducive to the development of social relationships and trust, which lead to communication and potential information sharing. Increased chance of encounters between fishers may result for a number of possible reasons, including similar search patterns by vessels of comparable capability, imitation of other fishers (Wilson et al. 2007), or potentially even greater interaction ashore (e.g. adjacent sheds or moorings). Secondly, ties may be benefit-based in that individuals seek benefits of information sharing by establishing relationships with other fishers, and these relationships may increasingly lead to similarity of knowledge and thus increasingly similar decision-making and behaviour. Opportunity-based and benefit-based ties may therefore be mutually reinforcing.

While physical proximity (e.g. interaction at sea) increases chance of interactions between individuals, it has been proposed that the effect of physical proximity on development of information-sharing relationships is mediated by a number of factors, including being aware of and valuing what others know, the accessibility of that information, and the perceived cost of obtaining it (Borgatti & Cross 2003). The relationship between perceived fishing success and network centrality (Table 5.7) highlights that fishers are likely to be aware of and value the knowledge of others they consider to be successful. Qualitative data from interviews with fishers in Northumberland also suggested that both the accessibility of information, in terms of assessing its accuracy and relevance (how up-to date it is and whether it is worth acting on), and associated costs (e.g. in terms of personal reputation, where asking for information may be considered a sign of weakness) may be important in fishers information-seeking behaviour.

Modelling of fishers' spatial behaviour and information sharing suggests that these mechanisms may also be moderated by resource scarcity. During periods of resource scarcity or increased group size, spatial similarity may have a local depletion effect on stocks, thus fishers switch between cooperative and autonomous behaviour in search of improved catch rates (Wilson & Yan 2009). While the present study has demonstrated an empirical link between social and spatial networks, further research would be useful in establishing how networks change over time in relation to resource availability. One study investigating effects of resource scarcity on information-sharing relationships did not strongly support the hypothesis that numbers of information-sharing links between and within groups would be greater in areas of resource scarcity (Ramirez-Sanchez & Pinkerton 2009). However, it may be that the frequency and extent of information changes with resource scarcity, thus longitudinal studies would be useful to investigate this further.

Communication networks were more strongly correlated with perceived spatial networks than with map-based measures of spatial similarity (Table 5.8). This may reflect a limitation of the data in that names recalled in perceived networks may have been biased by the consecutive nature of the questions, leading fishers to recall the same names and forget others. However efforts were made to ensure against this by using a follow-up recognition-based exercise. Alternatively, the weak correlation between perceived spatial networks and the map-based coefficient of overlap may suggest limitations of the measure of map-based spatial similarity used. The coefficient of overlap was calculated on the basis of presence or absence of fishing activity by each individual in each grid cell (i.e. fishing effort was assumed to be evenly distributed across fishing grounds), and did not account for the intensity of fishing effort in each cell. Consequently, similarity of fishers may appear to be different if the overall spatial extent of their fishing grounds differed, even if the majority of their fishing activity was concentrated in similar areas. The spatial distribution of fishing intensity was estimated at an aggregate level for each port in Chapter 2, but data were not considered to be sufficiently detailed at the level of individual fishers to incorporate here.

Despite these limitations, the Northumberland data suggest that social relationships among fishers have implications for the distribution of fishing activity. These findings support modelling work based on simple assumptions of information exchange between vessels which has demonstrated that the presence of information sharing can lead to differences in the spatial allocation of fishing effort over time, and may lead to greater efficiency of resource exploitation at the scale of fishing fleets in comparison to a situation with no information-sharing (Little et al. 2004).

5.5 Conclusion

This study has used social network analysis (SNA) to explore the relationships between fishers' information-sharing, fishing success, and spatial behaviour. Fishers' positions in information-sharing networks have implications at an individual level for fishing success and spatial behaviour. Furthermore, at a group level, the presence and structure of information-sharing networks has implications for resource management. Patterns of social relationships affect patterns of information availability and therefore influence patterns of resource exploitation, and the overall efficiency of resource use. In addition, the structure and function of information-sharing networks, which involve the development of trust and social capital among fishers, may have implications for the overall management of the fishery through encouraging collaboration and collective action. This study supports the contention that fishers' spatial behaviour and decision-making is conditioned by the social context in which they operate, and that this should be taken into account in order to understand and predict fishers' response to spatial management measures. Empirical studies using SNA may be useful to inform ways in which social interaction may be included in models of fishers' behaviour. Further study would be useful to investigate the response of fishers' information-sharing behaviour to changes in resource scarcity, and also to investigate the potential response of social network structure and function from displacement that may result from spatial management of the marine environment.

Chapter 6.

Disentangling drivers of fishers' behaviour in the Northumberland lobster fishery: synthesis and discussion

6.1 Synthesis

Sustainable management of natural resources requires an understanding of the factors that drive resource use behaviour, as these may influence changes in exploitation patterns and responses of fishers to resource management policies. A review of literature on fishers' spatial behaviour (Chapter 1) outlined the environmental, economic and social factors that may underpin fishers' decisions about where to fish, and highlighted questions concerning the social drivers influencing resource use behaviour. The original research elements of this thesis then investigated social and environmental drivers of fishers' decision-making in relation to their spatial behaviour in the lobster (*Homarus gammarus*) fishery in the Northumberland Sea Fisheries Committee (NSFC) district. Key gaps in the literature have been addressed through research centred around three themes: 1) investigating the comparability of different data sources (based on fishing vessel sightings and interviews with fishers) to indicate the spatial distribution of inshore fishing activity, 2) researching sources of variability in landings at different scales (individual vessels and fishing ports), and 3) exploring influences of social drivers (specifically information-sharing and territoriality) on the spatial allocation of fishing effort by individual fishers and fishing communities.

This chapter summarises the findings of the research, and aims to integrate these and discuss their importance in the context of literature on fishers' behaviour. In keeping with an interdisciplinary approach, the research in this thesis has drawn on both qualitative and quantitative methods from social and natural science disciplines to inform the current state of knowledge on fishers' decision-making and spatial behaviour. In separate discussions of independent research chapters it is difficult to draw interdisciplinary conclusions. This chapter therefore commences with a summary of results, before attempting to draw together and integrate the key findings under the themes identified above. Implications of the research for the management of marine resources are then discussed in terms of both the study area and wider implications for fisheries management and marine spatial planning. Finally, priorities for further research are outlined.

6.2 Key findings and contribution to knowledge

6.2.1 Distribution of inshore fishing activity

Increasing interest in the spatial aspect of marine resource use worldwide has led to a growing demand for rigorous approaches to triangulate sources of data on the distribution of fishing activity, yet limited research has been undertaken in this area to date. With few sources of information available on the spatial distribution of inshore fishing activity in the UK, a methodology was developed to compare and integrate existing data sources on the distribution of potting activity in the NSFC district (Chapter 2). A statistically significant similarity was demonstrated between fishing effort distribution patterns indicated by fishers' perceptions (interview data) and NSFC observations (vessel sightings data) within 6 nautical miles (nmi) of the coast, providing further evidence to support the value of low-technology, cost-effective interview based methods to indicate the distribution of small-scale inshore fishing activity, and the utility of GIS systems to integrate and compare different datasets (Scholz et al. 2004; Hall & Close 2007; St. Martin & Hall-Arber 2008; Hall et al. 2009). The analysis further identified a number of factors influencing the relationship between the datasets compared, with the strength of correlation between the two datasets found to be greater where a) fishing activity was more highly aggregated, b) a greater proportion of fishers were interviewed, and c) the spatial scale of analysis was broader. These findings represent a starting point for an improved assessment of the spatial distribution of inshore fishing activity.

Analysis of interview sampling intensity in mapping perceived fishing areas (Chapter 2) found that the extent of fishing grounds increased with greater numbers of fishers interviewed, indicating that individuals to some extent fished distinct areas. However, interview data did not suggest that fishers maintained individual territories (Chapter 4). A possible explanation for this apparent contradiction is that the extent of mapped fishing grounds does not reflect fishing intensity. While the majority of fishing effort may be in fishing hotspots (likely to be determined by habitat availability), individuals may fish more diverse areas when it comes to more marginal grounds, particularly outside of peak lobster season. This may be motivated by the desire to avoid gear congestion, which was one of the factors commonly prioritised in individual decisions about where to fish (Chapter 4).

6.2.2 Sources of variability in lobster landings

Understanding sources of variability in landings and catch rates is important given past criticism of fisheries management for failing to take account of the spatial complexity of resource use (e.g. Hutton et al. 2004; Wilen 2004). Chapter 3 found significant variability in lobster landings both at a broad spatial scale (among ports) and among individual vessels. Spatial variability among ports was correlated with mean vessel density within port home range, suggesting that differences in inferred catch rates may be related to differences in fishing effort (though this was not supported by data on density of fishing gear). These findings provide an initial insight into the sources of spatial variability in the context of the Northumberland lobster fishery.

Variability in lobster landings among vessels was greater than that among ports, with differences among vessels only weakly correlated with vessel length and engine size, suggesting variation may be related to unmeasured factors, for instance relating to skippers' knowledge and experience. This was investigated in Chapter 5, which explored fishers' position in communication and information-sharing networks in relation to their performance. Perceived fishing success was negatively related to ties representing outgoing information, and positively related to ties representing incoming information from others, providing empirical support for models that suggest individual performance is related to patterns of social relationships (Little & McDonald 2007).

6.2.3 Social drivers of spatial behaviour

Through qualitative analysis of interview data and social network analysis (SNA), this study has highlighted ways in which fishers' decisions about where to fish were influenced by the social context, in addition to environmental and economic drivers. The application of SNA in fisheries to date has been extended to empirically assess links between fishers' social relationships, spatial behaviour, and fishing success. While fishers perceived secrecy to be common in relation to information about fishing location and catches (Chapters 4 and 5), fishers' spatial behaviour appeared to be related to information-sharing networks, with communication networks among fishers positively correlated with patterns of spatial interaction at sea (Chapter 5). These findings support other studies suggesting that interactions between fishers (e.g. observation, imitation and information-sharing) may have implications for both individual behaviour and the exploitation patterns of fishing fleets (e.g. Allen & McGlade 1986; Little et al. 2004; Wilson & Yan 2009).

Although many studies recognise potential social influences on fishers' behaviour, this thesis is one of few studies to explicitly set out to explore the influence of informal rules and norms on fishers' spatial decision-making in the UK. Interview data suggested territorial behaviour differed among ports, with defence of fishing grounds occurring through a) occupation of areas with fishing gear, b) damage to gear of other vessels, and c) discouragement of new entrants (Chapter 4). Differences in behaviour among ports were attributed by fishers to differences in resource distribution, degree of competition from adjacent ports, and norms of cooperation and conflict avoidance. Fishers' perceptions suggested changes in territorial behaviour over time were related to changes in fleet structure, technology, and the legal and political environment, and were mediated by social norms and community characteristics. Cooperation among fishers to engage in territorial behaviour appeared to be more likely in smaller, more socially cohesive fishing communities.

Interviewees perceived greatest territorial behaviour at the adjacent ports of Boulmer and Craster (Chapter 4). Interestingly, modelling of variability in lobster landings suggested baseline landings (and inferred catch rates) were higher at Boulmer and Craster than at other ports (indicated by highest port level random intercept effects; Chapter 3). This may provide circumstantial evidence that territoriality may yield economic benefits for fishers (as identified by Acheson (1990) in Maine). Overlap of port home range with other ports was high at Boulmer and Craster (Chapter 4), indicating territoriality may not confer exclusive use of fishing grounds. However, home range estimates did not account for differences in fishing intensity within home ranges, and overlap may be the result of a small number of vessels from other ports considered to be pushing the boundaries, while others may be deterred by higher travel costs or risk of conflict. Territoriality may be sufficient to deter enough vessels to maintain lower fishing pressure than in the absence of territorial behaviour.

6.3 Implications for management

6.3.1 Northumberland Sea Fisheries Committee (NSFC)

This research focused on the lobster potting fishery within the NSFC district as a case study in which to study fishers' behaviour; consequently, some specific implications are generated for this fishery. Firstly, the development of a methodology to map distribution of inshore fishing activity using data collected routinely by NSFC has provided an indication of fishing effort allocation within 6 nmi, which was previously lacking in the Northumberland region. Spatial bias in the data was identified as a result of differing patrol effort and a method proposed to standardise for this in future analyses of vessel sightings data. This could be used by other SFCs to adopt a uniform approach to analysis of SFC vessel sightings data in the UK. Patrol effort was pooled for several years due to limited availability of vessel sightings data in some locations. While analysis suggested that it was reasonable to assume consistent distribution of effort over this time, more even coverage and an increased volume of data collection in the future would allow for more detailed spatial analysis of temporal changes in distribution of fishing activity. However, given that patrol effort is targeted in areas of high fishing activity and expected enforcement needs, this may be difficult to achieve.

Data analysis undertaken in this thesis has highlighted some constraints with respect to data collection and administrative boundaries. Chapter 2 focused on fishing activity within the 6 nmi limit, yet this boundary represents the limit of SFC jurisdiction, and does not reflect fishing activity or target species distributions, which both extend beyond this limit in much of Northumberland (local fishers and NSFC fishery officers, *pers. comm.* 2009). Current reporting schemes do not require fishers to indicate a breakdown of their fishing activity within and outside 6 nmi, yet understanding this distribution of fishing activity may be important for NSFC to understand and interpret the relationships between fishing activity, catch rates and lobster abundance. For instance, quantifying and monitoring the proportion of fishing effort outside 6 nmi may help identify any changes such as expansion of fishing activity further out to sea, which could mask changes in catch rates occurring within the district (Hilborn & Walters 1992). Failure to understand the spatial extent of fishing activity and changes in fishers' behaviour may prevent managers from recognising problems; for instance even if resources are over-exploited, spatial expansion may mean that CPUE may not decline until fishing activity reaches the outer limits of target species distribution (King 1995). The recent NSFC pot limitation byelaw[13] has introduced a maximum of 800 pots per vessel to be worked within 6 nmi. Issuing of pot identification tags to fishers is envisaged to help track the quantity of gear being worked within the district, yet it will also be important to understand the impact of fishing effort that may be displaced outside the district, both as an immediate result of the byelaw and in the future. This information is also needed to inform MSP and MCZ designation, as activity of small vessels beyond 6 nmi is poorly represented by alternative data sources, but may be needed to assess impacts of spatial management measures for fisheries. Other than data collected directly from fishers, data on the distribution of fishing activity beyond 6 nmi are primarily available from satellite-based vessel monitoring systems (VMS) or Marine and Fisheries Agency (MFA) overflight data. However, VMS data currently cover only vessels >15 m in length, excluding all vessels in the NSFC potting fishery.

Analysis of port home range has two advantages: firstly, it allows fishing grounds at sea to be linked to fishing communities ashore, and secondly, home port provided the most detailed level of spatial analysis possible with the available data (see Chapter 3). However, this analysis raises the issue of estimating the distribution of fishing effort within home ranges, in particular where there is overlap of home ranges at different ports. A starting point for verification of the resulting estimates of fishing activity distribution would be discussion with local fishers. Port home range estimates used in Chapter 3 to estimate fishing intensity were also based on data within 6 nmi, therefore more accurate home range estimates that include the full extent of fishing activity beyond this boundary may lead to a re-evaluation of the relationships between port random intercept effects and fishing intensity estimates. However it is likely that home range estimates beyond 6 nmi would be extended in particular in the ports in the north of the district, where suitable potting habitat extends further offshore; therefore it is not expected that this would contradict the findings presented here, which suggested that fishing intensity was generally lower in the north of the NSFC district.

The data analysed in Chapter 3 represents the most extensive source of information available on trends in the Northumberland lobster fishery, the analysis of which provides an improved understanding of sources of variability in lobster landings, and gives an indication of trends in landings, suggesting baseline landings have increased during 2001-2007. These data provide a useful baseline for NSFC monitoring, although future analysis of the data could attempt to integrate finer scale information on the distribution of fishing effort and catch. Such data could be collected by NSFC as part of a reporting scheme that was formerly a condition of shell-fishing permits within the district, and the re-introduction of which is currently being considered (NSFC, *pers. comm*. 2010).

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[13] NSFC Byelaw 15: Pot Limitation (www.nsfc.org.uk/byelaws.html)

6.3.2 Wider implications for fisheries management and marine spatial planning

The case study approach used in this thesis enabled a detailed analysis of the social aspects of fishers' decision-making. Furthermore, it is possible to generalise some of the insights made to show the wider relevance of the research in informing management of marine resources in a national and international context. The case study approach provides an opportunity to learn from examples of social processes in particular contexts, the value of which is often underestimated (Flyvbjerg 2006).

Marine spatial planning

Comparison of data sources available to assess the distribution of inshore fishing activity has implications for processes currently underway in the UK to inform the designation of a network of marine protected areas (MPAs), including new marine conservation zones (MCZs), by 2012. The designation of MCZs is principally intended to protect marine biodiversity, but decision-making is also required to consider socio-economic impacts on resource users (Natural England & JNCC 2010). Much of the work to designate MPAs and implement MSP worldwide relies on integrating various sources of spatial information using geographic information systems (GIS) as a medium in which to consider complex processes and interactions at different scales, in keeping with an ecosystem-based approach to planning (Ehler & Douvere 2007). Consequently, if the interests of inshore fisheries are to be fully considered, integrating the spatial representation of their activity into such a format is needed. This study has shown that in the UK both SFC vessel sightings data and data elicited through interviews with fishers can provide fine-scale information on the distribution of pot fishing activity. However, the accuracy of these data sources may depend on the underlying patterns of resource use (i.e. dispersed or aggregated), the sampling intensity, and the scale of analysis. Furthermore, vessel sightings are likely to better represent variable intensity of fishing activity, while interview data may more accurately capture the spatial extent of activity. These findings highlight the importance of triangulating data sources, and it is recommended that both data sources are used to inform MCZ designation and MSP in the UK.

In collating marine spatial data the human aspect of resource use at sea is often dissociated from communities on land (e.g. fishing activity may be represented by a GIS layer representing fishing intensity) (Ehler & Douvere 2007). Inclusion of social geography, such as linking fishing grounds to particular resource users, is important to help predict and minimise social impacts of spatial management measures, including possible conflict as a result of spatial displacement of fishing activity, increased congestion, and disruption of customary or informal allocation of fishing grounds (St. Martin & Hall-Arber 2008; Valcic 2009). The results presented in this thesis highlight that drivers of territorial behaviour are complex and change over time, and may be contested among fishers. In addition, it has been demonstrated that territorial behaviour among fishers need not necessarily lead to exclusive use of fishing grounds, which may result instead from a lack of competition for the resource from neighbours. Consequently, understanding fishers' perceptions of these and the forces that drive change in them is essential to the interpretation of the social significance of mapped fishing grounds, and to help predict how fishers might respond to spatial management measures. In addition, fishing grounds that appear less intensively used or more economically marginal may be important in terms of fishers' adaptive capacity and flexibility at certain times of year, as fishers use their experience and seasonal knowledge to adapt and respond to changes in resources and the environment (Salas & Gaertner 2004). Engagement with resource users is therefore essential to understand sources of variability and uncertainty, and drivers of change in behaviour.

Fisheries management

This thesis has demonstrated ways in which the social context of fishing activity may have generic implications for fisheries management. The research presented supports findings of other studies that performance of fishers (indicators of catch rates; Chapter 3) may be related to characteristics of fishers themselves rather than their vessels. While such differences may be in part a matter of luck, the knowledge and experience of individual skippers may also be important. The presence of social networks among fishers and social interaction in the form of information-sharing may have implications for fishers' spatial behaviour, in that social groups may share similar knowledge and thus make similar decisions about where to fish. The degree to which fishers rely on information from others may therefore have implications for the success of individuals. Furthermore, the presence of skilled individuals may have implications for the overall efficiency of exploitation by a fleet if the behaviour of successful fishers is imitated by others (Hilborn 1985). The findings of this thesis support suggestions that the study of fishers' decision-making and spatial behaviour should not focus only on individuals, but should consider the interactions among fishers that may affect overall patterns of resource exploitation (Hilborn 1985; Little et al. 2004; Wilson & Yan 2009).

Trust developed through social relationships among fishers may also be conducive to the development of social capital and increased cooperation to develop rules and norms concerning resource use behaviour. The implications of territoriality or informal systems of marine tenure for fisheries management can be considered in terms of the degree to which they contribute to sustainability of resource use, equity among resource users, and the functioning of institutions for fisheries management (Aswani 2005). Northumberland fishers associated the exclusion of fishers from local fishing grounds with issues of compliance with conservation measures in the lobster fishery (Chapter 4), and the benefits of territoriality were discussed in terms of long-term objectives of 'looking after' the resource. These findings support the contention that territoriality may confer a long-term interest in the sustainability of the resource among fishers, as the incentive to over-exploit resources and value current gains over potential future gains is reduced through the ability to exclude outsiders (Dietz et al. 2003). The presence of territoriality in Maine has been considered instrumental in the initiation of voluntary conservation measures (e.g. trap limitations, seasonal closures) which may ultimately be in the long-term interests of fisheries management, even where fishers are motivated by self interest rather than conservation (Acheson 1998; Acheson 2006).

On the basis that the development of territorial behaviour may be a result of distributional conflict over resources, informal systems of access to fishery resources may not be equitable among resource users, as they may allow some to maintain higher catches than others where they are able to collectively defend areas of productive habitat. A more economically optimal distribution of fishing activity may be achieved in the absence of factors such as territoriality which may constrain fishers movement as a result of costs incurred (e.g. through gear damage). However, locally agreed rules and norms of access may have greater legitimacy among resource users than those imposed centrally, and may lead to benefits in terms of lower enforcement costs (Jentoft 2004). For instance, there is a perception that the rules introduced under the Common Fisheries Policy (CFP) have led to unfair distribution of resources among fishers (Woodhatch & Crean 1999). Similarly, the introduction of an individual transferable quota system in the Tasmanian rock lobster fishery was seen to lead to the distribution of wealth away from fishing communities (Phillips et al. 2002). Recognition of local rules and norms and inclusion of resource users in management may improve legitimacy and compliance of fisheries management measures, lowering costs of enforcement and improving relations between fishers and managers (Hønneland 1999; Raakjær Nielsen 2003).

In summary, the findings presented in this thesis have shown that the social context is important in fishers' decision-making and spatial behaviour, and should be taken into account in marine resource use management. This has previously been recommended (e.g. Jentoft 2000; Salas & Gaertner 2004; Wagner 2004), but the challenge remains as to how social science might best be incorporated in marine resource management policy. Social objectives in European fisheries management policy have been largely neglected to date, with a focus instead on the institutional arrangements of the CFP to reverse declines in commercially important stocks (Symes & Hoefnagel 2010). European fisheries policy has focused on economic grown and wealth creation, marginalising small-scale inshore fishing communities (Symes & Phillipson 2009). While there has been increased attention to ecosystem-based management and economic modelling in recent years, social science has been integrated more slowly due to difficulties in generalising findings independently of local contexts (Jentoft 2006; Symes & Hoefnagel 2010).

Given that the social context influencing fishers' spatial behaviour may also have implications for the development of stewardship, social capital and local decision-making, fisheries managers may benefit from acknowledging local rules and norms, rather than considering them to be subsumed by contemporary fisheries management (Symes 1998; Aswani 2005). Understandings informal rules and norms, and the drivers of change in these, can help inform the development of governance systems that are suited to local conditions, supported by resource users, and compatible with modern resource management systems (Aswani 2005). Differences in territoriality among the communities studied in Northumberland highlight heterogeneity in the behaviour of fishing communities, which may be characterised by social stratification and conflict between groups. Some communities may be better equipped for constructive involvement in fisheries management than others, and a pragmatic approach is therefore needed to take account of local contexts (Degnbol et al. 2006). Thus, community involvement in fisheries management and the integration of informal rules and norms must be encouraged through policies that strengthen civil society and support the development of social cohesion, trust and networks to facilitate greater involvement of resource users (Jentoft 2000; Symes & Phillipson 2009). The Green Paper on the 2012 CFP reform recognises that maintaining coastal fishing communities and supporting their cultural and social identity are legitimate social objectives, providing greater impetus for the inclusion of social science in resource management (Commission of the European Communities 2009).

6.4 Future research

This study has highlighted several areas in which further research can further inform gaps in knowledge of fishers' spatial behaviour and decision-making. While this research has compared alternative sources of data to assess their comparability in describing the distribution of fishing activity, questions remain with respect to the use of such data in informing MSP and MCZ designation. For instance, understanding the comparability of different data sources would be further informed by similar data comparisons in relation to more mobile fishing gears (e.g. trawls). The methods used in this thesis could also be further developed to assess indicators of economic value of fishing grounds, which are commonly sought in assessing economic impacts of alternative management options. This could be achieved through developing ways to incorporate data on landings and market value of different species, or through assessing fishers' perceptions of the value of different fishing grounds. However, further attention should also be paid to incorporating the importance of fishing grounds to fishers' adaptability and flexibility (i.e. taking account of areas of apparently low fishing intensity or economic value that may be important for fishers at certain times of year). In addition, agreement between mapped fishing grounds and vessel sightings varied among a sub-set of individual skippers, indicating potential variation in fishers' abilities to accurately recall and map fishing grounds. This suggests further research is warranted into understanding how fishers recall information and how it can be best elicited and represented in formats compatible with other data sources. While the comparison of two datasets undertaken in Chapter 2 yields valuable insights into the strengths and limitations of both sources, further triangulation with other data sources that fishers may be willing to share, including personal records and electronic plotters, could also be explored.

Variability among fishing vessels in lobster landings was only weakly related to vessel length and engine power, and further investigation is therefore needed to improve understanding of the relationship between vessel and skipper characteristics, fishing behaviour and catch rates. Similarly, further investigation into variables that characterise differences among fishers in the factors driving decisions about where to fish (e.g. degree of short-term profit maximising behaviour, Abernethy et al. 2007; and longer-term strategic decision-making patterns that may be used to characterise fishers, Christensen & Raakjær 2006), could inform efforts to predict spatial behaviour. Differences in landings (and inferred catch rates) were identified among ports, but fine-scale analysis of vessel movement in responses to catch rates within port home ranges could provide further information on sources of variability in the fishery. A question that warrants further investigation is the extent to which differences in overlap among port home ranges are related to fishers' movements in response to variable productivity in different fishing grounds. Interpretation of spatial differences in catch rates could also be informed by fishery-independent data on lobster abundance throughout the study area, for comparison with measures of fishery-dependent data (e.g. standardised catch rates) that may be used to indicate relative abundance. Further indication of lobster abundance could be achieved through controlled fishing experiments, or fishery independent surveys such as diver based surveys, or baited underwater video (Miller 1990).

While lobster is the most economically valuable target species in the Northumberland potting fishery, other species (e.g. brown crab, velvet crab) are also targeted using pots, and some fishers also use other fishing gear at certain times of year (e.g. netting for salmon, trawling for white fish and prawns) or are seasonally engaged in different occupations. Interpretation of trends in fishing effort and landings over space and time could therefore also be informed by the consideration of the fishery as a multi-species fishery and in the context of wider livelihoods. An understanding of how fishers respond to additional environmental, economic and social drivers such as changes in price of alternative target species could help in interpreting fishers' spatial behaviour (e.g. Bene & Tewfik 2001).

Further knowledge of the social influences on fishers' behaviour could be enhanced by comparison of the findings presented here with similar case studies of other fisheries, and research into the potential benefits of incorporating informal rules and norms into formal management. A question of interest arising from the current work is to assess the degree of stewardship and compliance with formal and informal rules in communities with different degrees of territorial behaviour, in order to further understand the role that informal systems of access to resources may have in the context of contemporary resource management. In addition, while there are a number of studies modelling the response of fishers to spatial closures in the marine environment (e.g. Smith & Wilen 2003; Valcic 2009), there is a lack of research on the possible social impacts of these measures, and their implications for spatial behaviour of fishers. A study of fishers in the Gulf of Maine found that area-based closures, while leading to competition and congestion, had also in some cases led to new networks of communication and cooperation among fishers (St. Martin & Hall-Arber 2008). Further studies are warranted that explore the changes of social drivers of resource use behaviour in relation to spatial management measures. There is also potential for further application of SNA approaches for quantifying the properties of social interactions and their implications for resource use and management. For instance, further SNA studies of information-sharing and communication networks could help develop greater empirical knowledge of the influence of network structure on spatial behaviour and inform models of behaviour that aim to include interactions among individuals. Longitudinal studies of social networks could also inform how social relationships respond to environmental, economic or social change, or changes in management of the resource.

In conclusion, while there are many areas for future research, this thesis has made a contribution to the study of fishers' spatial behaviour, demonstrating the value of a mixed methods approach to understanding the inter-related factors that underpin fishers' decision-making, and attempting to draw together different data sources to reach an interdisciplinary understanding. The findings highlight the importance of understanding the social context in which decisions are made, and illustrate a number of implications for resource management. It is recommended that such approaches are built on in the future to develop a fuller understanding of the social dimensions of resource use and enable the development of resource management policies that are suited to local contexts and integrate social objectives.

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Appendix 1.

Interview schedule

Appendix 1. Interview schedule

Date & time ______________________________ Location___________________________

Interviewee ______________________________ Tel. no. ____________________________

Vessel name ______________________________ PLN ______________________________

A. Background and fishing practices

1. How did you get involved in fishing?

   a) What type of fishing do you do now? *(record gear type, target species)*

   b) What other types of fishing have you done in the past?

   c) How many years have you been fishing?

   d) How many years have you been potting *(if different to above)*?

   e) Why did you choose potting?

2. How many years have you worked as a skipper?

   a) Do you own or part-own the vessel you work on?

   b) Have you skippered other potting boats in the last 10 years? *(For each vessel record name, PLN, main fishing activity, dates owned, and home port)*

3. Which port(s) do you work from? (If more than one, which is the main one?)

4. How many people work on the boat?

5. Are you from this area? If not, how long have you lived here?

6. How many generations of your family have been fishing?

7. Do you have family currently involved in fishing? *(For each family member fishing record name, relationship, vessel name and registration number, port and main fishing activity)*

8. What types of fishing gear do you use now? (*For each gear record gear type, number owned, target species, seasonal use, and additional details – e.g. pots per fleet, typical soak time)*

B. Decision-making

9. How many days a week do you go to sea in a typical week?

   a) What factors influences this from one week to next? How?

10. On a day to day basis, what kind of things affect where you decide to put your pots?

11. How do you decide how long to leave your pots in, and when to move them?

12. When you go fishing do you tend to explore new areas, or stick to areas that you know well?

13. Do you fish in the same place from one month to the next? Why/why not?

14. Do you fish in the same place for the same species at the same time each year? Why/why not?

15. When deciding where to go fishing each day, how important is each of the following factors?

	V. important	Important	Less important	Not important
Own experience from **recent** fishing trips				
Own **long term** experience				
Information from observing other fishermen				
Information from talking to other fishermen				
Winds/weather				
Season (i.e. seasonal movement of species)				
Regulations				
Cost of fuel				
Travel time				
Capability of vessel				
Market conditions/prices				
Potential conflict with other vessels				
Tradition				
Number of vessels already fishing in an area				
Other…				

16. Were any of these more or less important in the past?

17. Do you think any will be more or less important in the future?

C. Fishing grounds

[Show example map and explain purpose of exercise]

18. Please draw on the map any features that are important to fishing in this area (e.g. this may include local landmarks, areas of different types of ground (hard/smooth), productive areas for particular species, deep/shallow areas, areas important at particular times of year)

19. Please draw on the map a line to enclose the areas commonly fished by potting boats from this port.

20. *[Show maps based on vessel sightings data]* These maps show observed fishing activity locally – please amend them where you think necessary to indicate areas that you think are fished by boats from this port and explain any changes.

    a) Have these patterns changed over time? If so, please indicate on map and explain how they have changed and over what time period.

    b) Are there any seasonal changes? If so please indicate them on the map and explain.

21. How do you know where the good fishing grounds are?

22. How do you navigate?

23. Of the areas already marked on the map, or other, which areas(s) do **you** personally fish?

    a) Which species do you catch in each site? Please indicate on map and explain.

    b) Are some sites more important than others? If so please indicate on map and explain why.

24. What are the minimum and maximum distances you travel offshore throughout the year?

25. Throughout the year, roughly what percentage of your time do you spend fishing outside the NSFC district (6 nmi line)?

D. Perceptions of access, ownership and territoriality

26. In your opinion, who owns the sea?

27. Who do you think has a right to go fishing from this port?

28. If someone is new to the potting fishery, can they fish anywhere? If not, please explain why.

29. Are there any formal rules or regulations about where people can fish with pots? If so, what?

30. Do fishermen have any unwritten rules or informal agreements about who fishes where? If so, what are they?

    a) How did these rules / agreements come about?

    b) Have they changed over time? If so, how and why?

    c) Do people follow these rules/agreements? What happens if they don't?

31. Are people protective of areas where they fish? If yes, in what way?

    a) If people are protective, are they protective of areas fished by individuals, or by groups?

b) Are people more or less protective over the areas they fish than in the past? Please explain any changes and the time period over which they have occurred.

c) Do you think this will change in the future? Why?

32. Are there any areas of conflict or competition for space at sea? If so, please mark them on the map.

    a) What are the sources of conflict?

    b) How frequent is conflict?

    c) How is conflict resolved?

E. Social networks and information sharing

33. Are you a member of any group or organisation related to fishing?

    a) If so, which?

    b) Why are you a member?

34. Are you part of any other social groups/organisations in the community?

    a) If so, which?

    b) Why are you a member?

35. In your opinion is this a close-knit community? Please explain why/why not.

36. In what situations and places do fishermen talk to each other?

37. Is your reputation among other fishermen important to you? Please explain why/why not.

38. Is there a sense among fishermen of how people should and shouldn't behave? If so, please explain/give examples.

39. Generally speaking, would you say that you trust other local fishermen from this port? Please explain why/why not.

40. In what kinds of situations would fishermen in this fishery tend to help each other out?

    a) If a fisherman asked others for advice to improve his fishing success, would they help?

41. Are fishermen secretive about where they fish and what they catch, or are they open about it? Please explain why/why not.

42. What's your main source of information about where other people fish and what they catch?

43. Could you please name the vessels or skippers you most regularly encounter at sea?

44. Could you name the vessels or skippers that you talk to generally about fishing?

45. Could you name the vessels or skippers that you would share detailed information with about your fishing location and catches?

    a) Why do you share information with these individuals?

46. *[Show port vessel list]* From this list of local vessels, are there any you've forgotten to mention?

47. In your opinion, who are the most successful fishermen you know?

    a) What makes you think they are successful?

F. Management and health of the fishery

48. Would you say that each of the stocks you fish are stable, increasing, or in decline?

49. In your opinion, what are the main factors that determine the abundance of lobsters?

50. What do you think about the number of fishers and number of pots targeting lobster (and crab)?

    a) Is there room for more fishing effort?

51. Which of the rules and regulations in place do you think are most effective for managing the lobster fishery?

52. In the last year have you broken any of these rules? If so which, and why?

53. Why do you personally comply/not comply with the rules?

54. For each of these rules please rate the level of compliance by local fishermen on a scale of 1 (very low) to 5 (very high).

55. Why do people comply/not comply with the rules?

56. If people see another fisherman break the rules, do they do anything about it? If so, what?

57. Are there any rules not currently in place that you think would be effective in managing the fishery?

58. In the last year how many times have you been inspected at sea or ashore by NSFC fishery officers?

59. Please say whether you agree or disagree with the following statements:

    a) The economic benefits of breaking the rules are high;

    b) The likelihood of being caught breaking the rules is high;

    c) When people are found breaking the rules the consequences are appropriate and fair;

    d) Breaking the rules could lead to gossip or confrontation from other fishermen;

    e) Fishermen are well represented in decisions made about regulating the lobster fishery.

G. Economics

60. How long do you *usually* (or *on average*) spend at sea each time you go out?

61. How far do you *usually* travel in one day?

62. Approximately how much fuel do you use each week?

63. Do you think you could catch more by travelling further? If so, what restricts how far you travel?

64. In the last 10 years has the usual distance you travel changed? If so how and why?

65. Apart from fuel, what other expenses do you have to account for? Do they affect your fishing practices? If so, how?

66. Do you earn income from anything other than fishing? If so, what? Is this income year-round or seasonal?

67. What percentage of your own personal income comes from fishing?

68. Of your annual fishing income, roughly what percentage does each target species contribute?

69. What percentage of your total household income comes from fishing?

70. How many more years do you expect to work in fishing?

H. Concluding

71. What's your age?

72. What was the approximate value of your vessel and licence in 2008?

73. Do you have any comments or questions on this interview? Are there any important issues that haven't been covered?