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Biological and socio-economic implications of the inshore potting agreement.

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BIOLOGICAL AND SOCIO-ECONOMIC IMPLICATIONS OF THE INSHORE POTTING AGREEMENT

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SUMMARY

The Inshore Potting Agreement (IPA) is a fishery management system that was created in 1978 off the coast of south Devon, UK. The IPA was established after fishers who used towed fishing gears encroached onto the traditional grounds of fishers who used static fishing gears. Static gear loss or damage is almost inevitable when towed and static gears are fished in close proximity, and so an area of approximately 350 km^2 was designated for the use of static gear fishers only. An additional 150 km^2 area was designated for alternating use between static and towed gear fishers to allow individuals from both fishing sectors to target seasonally available resources.

Factors that facilitated the long history of cooperation between the fishing sectors were studied. The seasonal and exclusive use zones of the IPA allowed a fishery-scale investigation to be conducted into the effects on benthic communities of towed gear use. The availability of recreational angling catch data over the period of the IPA's existence provided an opportunity to determine the effects on temperate fish populations of restricting towed gear use. Finally, the existence of the IPA allowed an investigation to be conducted into the potential economic value of marine protected areas in the south-west UK.

This study showed that the IPA has provided benefits to the marine environment and to fishery stakeholders of the south Devon area. Fishers have operated safely and equitably because of the IPA, the benthic community has benefited from restrictions on towed-gear fishing, and scallops and a number of targeted fish species appeared to have benefited significantly from the potential for greater reproductive output and longevity respectively. Additionally, this study showed that the IPA and similar systems may help to generate economic benefits for coastal economies by improving the angling value of targeted fish stocks.

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CHAPTER 1

INTRODUCTION

1: INTRODUCTION

It has been estimated that the global production of fishery products in 1950 was 18M metric tonnes (FAO 2000b), and that by 2001 this had increased to 91.3M metric tonnes (freshwater and marine wild capture fisheries) (FAO 2002). During the same time period, it was estimated that the global human population increased from 2.5 Bn to 6.1 Bn, whilst the average consumption of fish increased from 8 kg to 16 kg per person per year (FAO 2002). Hence, the demand for fishery products has increased disproportionately to growth in the human population. Moreover, the global human population is predicted to increase still further, and may reach 8.9 Bn by 2050 (www.fao.org/sd/wpdirect/wpan0040.htm). It therefore seems likely that there will be greater demand for fishery products in the future. However, global production from wild capture fisheries has been relatively constant since the 1970s (FAO 2000b), despite massive increases in the amount of fishing effort exerted (Pauly *et al.* 1998).

As a result of increased fishing effort, many important fish and invertebrate stocks have been over-fished, and the resulting collapses in fishery production are well documented (Jackson *et al.* 2001). Such cases have included cod *Gadus morhua* on the Georges Bank (Hutchings 1996), herring *Clupea harengus* in the Atlantic (Stephenson 1997), Peruvian anchoveta *Engraulis ringens* (Csirke 1980) and white abalone *Haliotis sorenseni* off the Pacific coast of the USA (Malakoff 1997). However, over-fishing has had the greatest impact on high trophic level groups such as billfishes, sharks and groupers, leading to large reductions in their biomass and abundance (Myers & Worm 2003). In many cases fishers have been forced to target less valuable species at lower trophic levels in order to maintain yields (Pauly *et al.* 1998).

Some have argued that conventional fishery management regimes, that have aimed to maximise fishery output in the long term by employing models of stock dynamics, have failed to achieve their goals (Ludwig, Hilborn & Walters 1993; Acheson, Wilson & Steneck 1998; Hofmann & Powell 1998; Lauck *et al.* 1998). Conventional management is founded on stock-recruitment theory, which relies on the existence of a relationship between the number of adult fish in a stock and the number of recruits coming in to the fishery at a later date. However, an empirical relationship between stock size and recruitment has been demonstrated in only a few cases (Acheson *et* *al.* 1998). Logic determines that these factors are intrinsically linked, but the outcome (number of recruits) may be dependent on a large number of variables such as climate, predation pressure and food availability, for which predictive power is currently low. Hence, the assessment of the status and trends in the abundance of fish stocks is subject to considerable uncertainty and is now recognised as a major problem for both biologists and fisheries managers (Hall 1998; Lauck *et al.* 1998). This uncertainty is compounded as the falling biomass and abundance of target species reduces the analytical power with which changes in stock abundance may be determined.

Although fishery management models employ assumptions and, by necessity, greatly simplify biological systems [sometimes inaccurately (Hutchings 1996; Walters & Maguire 1996; Smedbol & Stephenson 2001)], it may also be argued that stock declines have rarely occurred as a result of inadequate advice from fishery scientists. More commonly, precautionary scientific advice has been ignored when managers have elected to allow catches that were subsequently proven to be excessive (Botsford, Castilla & Peterson 1997; Symes 1997a; Pitcher 2000). But for whatever reason, management systems that limit fishing effort by top-down management controls have failed to prevent numerous stock collapses.

Any lack of fishery management success may, in part, be attributed to the practice of discounting the future, whereby individuals prefer to collect benefits immediately, but bear costs later (Price 1993). For managers, these benefits and costs may be considered in terms of political success- they may prefer to satisfy the current demands of voting fishers by allowing fishing to continue at unsustainable levels, whilst politically dangerous quota cuts can be deferred for implementation by a successor in that political position. For fishers, these benefits and costs may be considered in terms of catches and profits (Hart 1998). Typically, the interest rate of capital investments are higher than the rate at which biological resources increase naturally (Turner, Pearce & Bateman 1994). Hence, waiting until the future to harvest may lead to a smaller monetary gain overall than if the harvest was taken now, and short-term wealth is thereby pursued at the expense of long-term sustainability[1]. The

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[1] Sustainability is here defined as, 'the pattern of social and structural economic transformations which optimise economic and other societal benefits available in the present, without jeopardising the likely potential for similar benefits in the future' (Goodland, Ledec & Webb 1989).

concept of over-harvesting because of individuals attempting to maximise their individual portion of a shared resource was termed the 'Tragedy of the Commons', and was described by (Hardin 1968). The evidence of stock collapses across the world's seas suggests that until discounting the future is fully recognised and accounted for in management regimes, fisheries may continue to decline (Charles 1998; Hanna 1998; Knudson & MacDonald 2000; Li 2000).

In addition to the increasing demand for fishery products and the practice of discounting the future, other factors have contributed significantly to the global decline in fishery production. In particular, advances in technology and capture methods have enabled fishers to fish successfully in marginal areas that previously acted as refuges for target species (Pitcher 1998; Jennings, Kaiser & Reynolds 2001a). Improvements in ship-board catch storage facilities have also enabled fishers to operate further from port, and there are now few places where fishing cannot and does not take place (Vitousek *et al.* 1997). Many studies have recognised that habitats and communities are impacted by fishing gears. Most of these studies have focussed on the effects of towed demersal (bottom-fishing) gear such as trawls or dredges (Bergman & Hup 1992; Auster *et al.* 1996; Currie & Parry 1996; Sainsbury *et al.* 1997; Fogarty & Murawski 1998; Kaiser *et al.* 1998a; Kaiser *et al.* 1998b; Thrush *et al.* 1998; Watling & Norse 1998; Norse & Watling 1999; Collie *et al.* 2000b; Eleftheriou 2000; Hall-Spencer & Moore 2000; Jennings *et al.* 2001b; Schratzberger, Dinmore & Jennings 2002), whilst relatively few have considered the impacts of static gears such as pots or anchored nets (Kaiser *et al.* 1996; Kinnear *et al.* 1996; Jennings & Kaiser 1998; Eno *et al.* 2001). These latter studies identified that static gears may capture unwanted species but that they have limited negative effects on benthic communities.

Towed demersal gears are generally considered to constitute the most environmentally damaging forms of fishing activity (Hall 1999). One aspect of this is that towed gears have the potential to impact much larger areas of seabed than static gears. In fact, it has been estimated that an area equivalent to all the world's continental shelves is trawled every two years by the global fleet (Safina 1998), although this is an average figure and some sites will never have been fished (Rijnsdorp *et al.* 1998). The damage caused by towed demersal gears results from dragging heavy ropes, chains or toothed bars across the seabed to herd or disturb fish and invertebrates into a following net. Saleable individuals of target species such as sole *Solea solea*, tiger prawns *Penaeus monodon* or scallops *Pecten maximus* may constitute as little as 10% of the total catch, with the remainder being made-up of non-target species, or undersize individuals of the target species (Alverson *et al.* 1994; Symes 1997b; Stobutzki, Jones & Miller 2003). Furthermore, a large proportion of the benthos detached or killed by towed gears may go unnoticed by fishers because small or soft-bodied individuals may pass through the nets before reaching the surface (Moran & Stephenson 2000).

In addition to the direct removal of target species, the degradation of habitats and removal of non-target species may have significant repercussions for targeted stocks and marine communities in general. Towed bottom fishing gears reduce the structural complexity of seabed habitats (Jennings & Kaiser 1998; Kaiser *et al.* 2002). Structural complexity has been identified as a key requirement for settlement, refuge, or feeding in a range of marine taxa, including scallops (Dare & Bannister 1987; Minchin 1992; Harvey, Bourget & Miron 1993; Stokesbury & Himmelman 1995), crustacea (Wahle & Steneck 1991; Egglestone & Armstrong 1995; Palma, Wahle & Steneck 1998; Stevens & Kittaka 1998; Herrnkind, Butler IV & Hunt 1999) and fish (Lough *et al.* 1989; Connell & Jones 1991; Bohnsack 1992; Gotceitas & Brown 1993; Tupper & Boutilier 1995; Auster, Malatesta & Donaldson 1997; Beukers & Jones 1997; Lindholm, Auster & Kaufman 1999). Importantly, it has been recognised that benthic communities in areas that are heavily fished tend to lower biomass and productivity than communities in areas that are not fished or are fished at low levels of effort (Jennings *et al.* 2001b; Kaiser *et al.* 2002).

HOW TO MANAGE FISHERIES?

It has been proposed that rather than attempt to manage a fishery or fish stock in isolation, managers should fully consider the ecosystem within which the fishery exists (Sherman 1991; Botsford *et al.* 1997; Langton & Haedrich 1997; McGlade *et al.* 1997; Hofmann & Powell 1998; Pitcher & Pauly 1998; Pitcher 2000). Essentially, because fish stocks are dependent on a range of environmental features for survival, including specific habitats, migration routes, spawning grounds or nursery areas, maintenance of those features may ensure that exploited stocks persist at sustainable levels. This concept has been termed 'parametric management' (Acheson *et al.* 1998) or, more generally, 'ecosystem based fisheries management' (Langton & Haedrich 1997). Irrespective of the terminology used, the consensus of opinion seems to be that sustainable exploitation may be more easily achieved by controlling 'how' fishing is undertaken, rather than 'how much' is caught (Murawski 2000).

Part of the assertion that controlling 'how fishing is undertaken' may help to achieve management targets is that it can be difficult to establish an optimum level of total allowable catch (TAC) from a fish stock (Acheson *et al.* 1998). Conventional fishery management relies on setting TACs, and traditionally these have been applied to whole fisheries as a global catch quota, or divided between fishers into non-transferable quotas (NTQs). However, even if a TAC has been set conservatively, both methods of limiting quotas have associated problems. Global catch quotas promote over-capitalisation and encourage fishers to go to sea in poor weather as they compete to secure as large a personal share of the catch as possible (Scott 1998). In contrast, NTQs encourage fishers to 'high-grade'; this is where small or low value individuals are caught but are then subsequently rejected in favour of larger or more valuable ones (Jennings *et al.* 2001a).

Individual transferable quotas (ITQs) are a development of the quota system, where shares in fish stocks are given to existing users, and the decision on how to use each share is then left to the individual (Wijkman 1982). ITQs may reduce deliberate overfishing by encouraging resource stewardship among share-holders (Hart & Pitcher 1998), and may increase economic efficiency by allowing the best performing fishers to purchase shares from other fishers (Arnason 1998). However, the ITQ system is still dependent on the establishment of TACs, may still lead to high-grading, and other social and economic issues may result from unfairly apportioning shares to users initially, or from excluding future entrants to the fishery (Exel & Kaufmann 1998; Fujita, Foran & Zevos 1998).

Finally, most demersal fishing gears are relatively unselective, and a broad range of species may be captured in multispecies fisheries (Jennings *et al.* 2001a). However, when different quota regulated species may be caught with the same gear, it can be difficult to avoid catching one species for which the quota has already been reached whilst in the pursuit of another species for which quota still remains (Jennings *et al.* 2001a). Usually, any resulting over-quota catch must be discarded at sea or sold illegally (Alverson *et al.* 1994). High-grading and discarding may lead to over-fishing, but these issues also make it difficult to estimate the total annual fishing mortality of a stock, so that the uncertainty in calculating subsequent TACs increases (Hilborn 1998; Hilborn & Liermann 1998).

MARINE PROTECTED AREAS

In concert with a reduction in overall fishing effort, the use of marine protected areas[2] (MPAs) has been proposed as a means to provide insurance against the uncertainty that is inherent in the management of exploited marine species (Roberts & Polunin 1993; Clark 1996; Auster & Shackell 1997; Hall 1998; Lauck *et al.* 1998; Fogarty 1999; Sladek Nowlis & Roberts 1999; Jennings 2000; Mangel 2000; Roberts *et al.* 2001; Rosenberg 2001; Gell & Roberts 2003). This insurance arises through protecting a portion of an exploited stock inside the MPA, so that a standing stock will remain even in the event of management failures in fished areas (Murray *et al.* 1999; Halpern 2003).

By protecting adults of exploited stocks and restricting the extent of fishing activities, MPAs may provide a range of advantages over conventional quota-based fishery management practices; these include, i) ensuring provision of recruits for surrounding areas, ii) restocking of fished areas through adult emigration, iii) maintenance of natural population structures, iv) maintenance of areas of undisturbed habitat, v) protection of intraspecific genetic diversity, vi) reduction in data-collection needs and vii) simplified enforcement (Bohnsack 1990). However, fishers may object to the introduction of MPAs if they are thereby excluded from areas where they have previously fished, or may wish to fish in the future (Jentoft, McCay & Wilson 1998; Suman, Shivlani & Milon 1999; Halpern & Warner 2003). Fishers may also have rejected MPAs as a management option because it has proved difficult to demonstrate that the benefits of MPAs for exploited stocks have translated into catches that exceeded levels prior to MPA implementation (Sladek Nowlis & Roberts 1999). However, this situation has changed, and a considerable body of evidence is now available to demonstrate the efficacy of MPAs as a fishery management tool that may be used in addition to other systems of management (Gell & Roberts 2003).

Much of the evidence for the fishery benefits of marine reserves has been collected in tropical regions, where fish may have specific habitat requirements and therefore small home ranges, and where visual census techniques may be utilised readily (Polunin & Roberts 1993; Roberts 1995; Russ & Alcala 1996a, b; Roberts & Hawkins

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[2] The term 'marine protected areas' will be used throughout this thesis to include marine reserves, closed areas, no-take zones, harvest refugia and other fishery management systems in which there is partial or total protection from fishing (FSBI 2001).

1997; Zeller & Russ 1998). Demonstrating benefits of MPAs in temperate waters has proved more difficult, as stocks are typically highly mobile, and visual census techniques cannot be applied in deep or turbid conditions. Despite the issues of data collection, small (on the order of tens of km^2) temperate MPAs have been shown to provide benefits to a variety of fish and crustacean species within their boundaries (Ballantine 1989; Bennett & Attwood 1991; Connell & Jones 1991; Carr & Reed 1993; Babcock *et al.* 1999; Kelly *et al.* 2000; Willis, Millar & Babcock 2003). In contrast, evidence of benefits from large (on the order of tens of thousands of km^2) temperate MPAs is somewhat equivocal; whilst impressive increases in the biomass of targeted scallop and fish stocks have been demonstrated from MPAs on the Georges Bank (Murawski *et al.* 2000), the establishment of seasonal MPAs in the North Sea may have resulted in considerable additional degradation of benthic communities in other locations as a result of forcing fishers away from traditional fishing grounds (Dinmore *et al.* 2003). Large MPAs may also disadvantage fishers unnecessarily by forcing them to fish far from port, and opportunity costs potentially increase with MPA size (Carter 2003). However, lack of evidence for fishery benefits subsequent to the implementation of an MPA may not mean that no benefit has accrued, because it may be difficult to determine what would have happened in the absence of an MPA.

Irrespective of potential benefits or the actual benefits that have been demonstrated already from MPAs, it is apparent that more evidence is required of their efficacy for temperate fisheries management generally if managers are to advocate their use more readily. However, few MPAs of moderate or large size (on the order of hundreds of km^2 or bigger) exist in European waters (Halfpenny & Roberts Unpublished manuscript). As such, it will clearly be difficult to determine the true implications of European MPAs. While waiting for more MPAs to be introduced, it may be necessary to study systems that have acted as *de facto* MPAs. These systems may include exclusion areas around oil and gas installations, military exclusion zones, or existing fishery management systems that prevent the use of certain types of fishing gears (Rogers 1997).

THE INSHORE POTTING AGREEMENT

A fishery management system known as the Inshore Potting Agreement (IPA) has existed off the coast of south Devon, England, since 1978. Fishing with static gears and recreational angling is allowed within the IPA, and the system operated as a voluntary agreement until 2002 when it was enshrined within legislation. The IPA has functioned as a form of MPA by preventing the use of towed demersal fishing gears in an area of approximately 350 km^2, and seasonally limiting the use of towed gears in a further 150 km^2. Whilst this total area may be considered insufficient in temperate regions for significant benefits to accrue to highly mobile stocks (Horwood 2000), the IPA has persisted voluntarily for more than 20 years (Woodhatch & Crean 1999). The IPA is therefore worthy of scientific attention because it offers an unique insight into the potential long-term outcomes associated with the implementation of MPA fishery management systems in temperate waters (Hart & Pitcher 1998; Woodhatch & Crean 1999; Kaiser, Spence & Hart 2000).

THE BIOLOGICAL AND SOCIO-ECONOMIC IMPLICATIONS OF THE IPA

The aims of this study were to investigate the biological and socio-economic implications of the Inshore Potting Agreement and, in particular, it was intended that the following questions were considered:

a) How has the IPA survived as a voluntary fishery management system, and what are the institutional arrangements that have contributed to its success?

b) Are benthic communities and habitats different within the IPA as a result of the exclusion of towed fishing gears, and to what extent do seasonal fishing arrangements benefit benthic communities?

c) Does the IPA act as a reserve of spawning stock biomass for targeted species?

d) To what extent does this management system alleviate fishing pressure on demersal fish species?

e) How has the existence of the IPA affected the economic value of the marine environment and the biological resources found off the south Devon coast?

THESIS FORMAT

In writing this thesis it was my intention that each experimental chapter (2-6) should be capable of standing alone in a format suitable for publication. As such, some duplication has inevitably occurred because of introducing the IPA in each of these chapters, but I have otherwise attempted to avoid repetition wherever possible.

CHAPTER 2

VOLUNTARY MANAGEMENT IN AN INSHORE FISHERY HAS CONSERVATION BENEFITS

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2: VOLUNTARY MANAGEMENT IN AN INSHORE FISHERY HAS CONSERVATION BENEFITS

SUMMARY

The management of fisheries in European Union (EU) waters has generally been regulated through government institutions and agreed quota allocations. This top-down management approach may have contributed to the continued decline of targeted fish stocks by forcing fishers to compete for limited resources without engendering a sense of resource stewardship. In attempting to reverse this decline, scientists and managers should examine management systems that do not solely depend on top-down approaches, and the Inshore Potting Agreement (IPA) is an example. The IPA is a voluntary fishery management system designed and operated by inshore fishers of south Devon, England. The IPA was conceived to reduce conflict between static-gear (pot and net) and towed-gear (trawl and dredge) fishers, and is regarded as a successful fisheries management regime by fishers and managers because it has effectively allowed fishers from both sectors to operate profitably on traditional fishing grounds. (Kaiser *et al.* 2000) determined that the IPA has incidentally protected benthic habitat complexity.

Fishers from the static-gear and towed-gear sectors were interviewed to determine the evolution and function of the IPA, and to establish the factors that ensure the high level of regulatory compliance amongst fishers from both sectors. Towed-gear fishers gave significantly different responses to the same questions asked of static-gear fishers, and were generally less satisfied with the existence of the IPA. Multivariate analyses of the interview data suggested that fishers who thought the IPA was a good system also thought the system provided pot protection, but had experienced inter-sector conflict. Fishers who thought the IPA provided no personal benefit also thought that static-gear fishers should be more restricted, and that towed-gear corridors or more seasonal-use areas should be established within the existing IPA area. However, fishers from both sectors agreed that the IPA has maintained traditional practices of the local fishing industry, and that the system has conserved target finfish and scallop species.

A number of factors were identified as critical to the success of the IPA. These included the voluntary nature of the agreement, the limited number of organizations representing fishers and very high level of membership of those organizations, and the simplicity of the system. Regulatory compliance is enhanced through the ability of fishers' organizations to respond rapidly to inter-sector conflict issues.

INTRODUCTION

It is widely accepted that fisheries globally are in decline (FAO 2000b). It therefore must be considered that conventional fishery management practices, based on predictive models of stock dynamics and aimed at maximizing or optimising fishery output in the long term, have not been working well (Acheson *et al.* 1998; Hofmann & Powell 1998; Lauck *et al.* 1998). In an effort to prevent further stock failures, and to prevent the demise of traditional fisheries, it may be beneficial to study and use management systems that have been successfully applied at a local scale.

The present paper focuses on a voluntary fishery management system established off the south coast of Devon, England, known as the Inshore Potting Agreement (IPA), that has to date been the focus of political (Woodhatch & Crean 1999), behavioural (Hart 1998) and biological (Kaiser *et al.* 2000) studies. The IPA was conceived and established by fishers to reduce conflict between those that operated static gears (pots and anchored gill nets) and those that used towed gears (trawls and dredges). At present, there is no legal recognition of the system, though the IPA is generally well adhered to by fishers from both sectors of the industry, and is an excellent example of a management system that takes account of the social and economic forces that drive the exploitation of living resources. These forces have been identified as factors that should be considered in fisheries management if sustainable exploitation is to be achieved (Langton & Haedrich 1997; Charles 1998; Hanna 1998; Murray *et al.* 1999; Knudson & MacDonald 2000).

The IPA is regarded as a successful fishery management regime by fishers and managers because it has effectively allowed fishers from both sectors to operate profitably on traditional fishing grounds, and because it has continued to function for several decades. In order to understand the reasons for its continuity it is necessary to record the historical development of the fisheries within the local area and the technological and biological changes that eventually led to its creation. This paper evaluates the attitudes and perceptions of fishers from the static-gear and towed-gear sectors in regard of (1) what the IPA achieves; (2) the reasons for the continuity of the IPA; (3) the operation of exclusive-use zones and seasonal-use zones within the IPA; (4) existing intra-sector and inter-sector conflict issues; and (5) the potential for further development of the IPA or the possibility of the system breaking-down. In addition, I have sought to characterize key features of the IPA that may be adopted by fishery managers in other areas.

HISTORY AND BACKGROUND OF THE IPA

Edible crabs *Cancer pagurus* have been harvested from the inshore waters of south Devon, England, for hundreds of years. Fishers from local communities with a strong crab- fishing tradition believe that the crab-fishing industry of the British Isles began in villages along the coastline of Start Bay (Fig. 2.1). Static-gear fishers that presently operate in Start Bay commonly maintain that they are at least third- or fourth generation crab-fishers. Evidence for this history is available from the 1891 Census, which indicated that of the 104 men between the ages of 15 and 65 living in the coastal villages of Beeson, Beesands and Hallsands, 63 (60.6%) listed fishing as their occupation.

Before the expansion and modernization of the crab fishing industry in south Devon, static-gear boats were commonly launched and retrieved by hand from beaches in front of fishing villages. The wooden sailing and rowing boats used were typically 5–6 m in length, and fishers worked in crews of two or three per boat, lifting 60–100 pots per day by hand (Table 2.1). Pots were constructed to an inkwell design from withy (thin woven willow branches), and were usually laid in strings of up to five below each marker buoy (Fig. 2.2). Crab fishing continued in a similar manner until the 1930s, when inboard engines were first employed on inshore boats (Table 2.1). The number of pots routinely operated remained small, essentially because the withy pots would disintegrate within one year, thus preventing the number of pots used being added to at the beginning of each season. The size of boat used did not increase during the 1930s and boats continued to be operated either from village beaches or local ports.

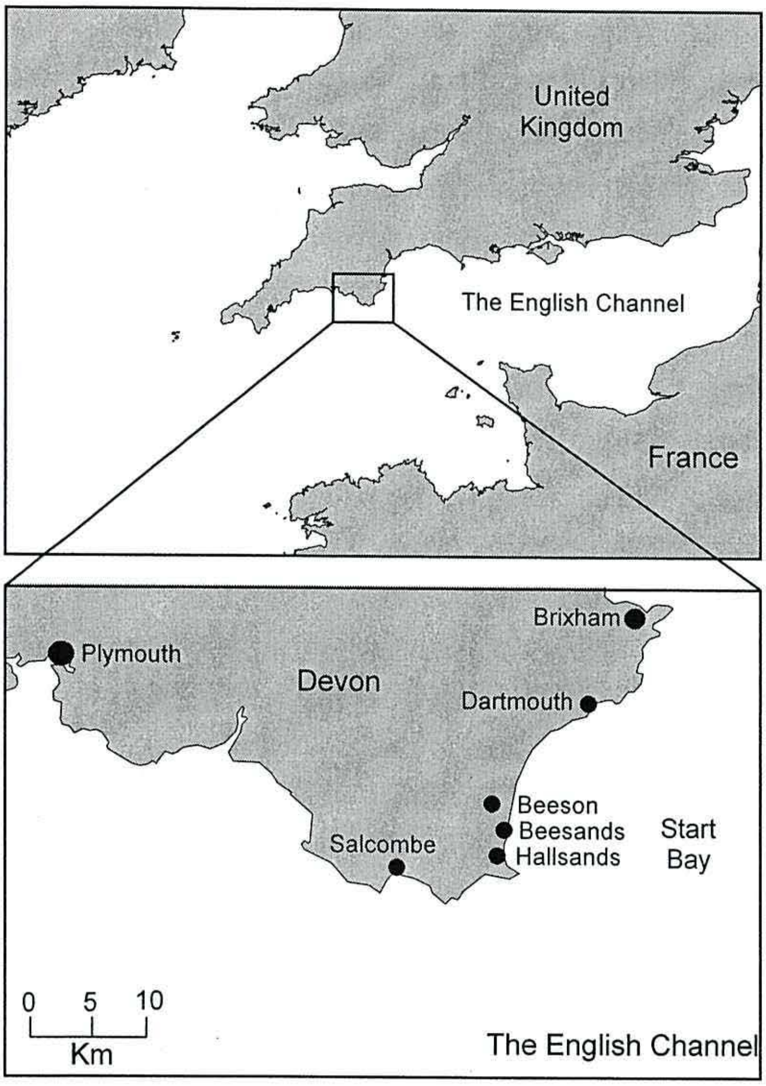

Figure 2.1: Fishing villages in South Devon, UK.

In the early 1950s, the materials from which pots were constructed changed to steel wire woven around a cherry-branch frame (Table 2.1). The inkwell design essentially remained unchanged, though wire pots were dipped in a mix of tar and creosote to improve their longevity. These pots typically lasted from one to two years, allowing each boat to operate up to 200. However, a small number of crabbing companies employed pot-makers, thus allowing a greater number of pots to be fished. By the mid 1960s, no commercial beach-launched boats remained in use, and the crabbing sector operated exclusively from ports such as Salcombe and Dartmouth. Pots assembled from plastic frames and nylon netting were finally introduced in the early 1970s, and fishers used boats of 10–12m length to typically operate up to 300 pots in strings of 30 per marker buoy (Table 2.1).

Table 2.1: Summary of the principle developments in South Devon fisheries.

Year	Developments
pre-1930	Static-gear fishers use wooden sailing and rowing boats of 5-6m length, 60-100 withy pots and two or three fishers per boat. Pots in strings of up to five below each marker buoy. Beach boats hauled ashore by hand.
1930-1950	Inboard motors introduced on beach boats early 1930s. Some larger boats (up to 10m) with motorised capstans for hauling pots operated from deep-water ports by 1950. Beach boats hauled ashore using motorised capstans.
1950-1960	Static-gear beach fishers began to move to larger deep-water port boats. Up to 200 cherry and wire pots operated from each boat, though sometimes more from port boats. Remaining beach boats equipped with motorised capstans for hauling pots.
1960-1970	Beach boats no longer in use. Typical static-gear boat size 10-12m. Improved gear designs and increasing engine power enabled towed-gear fishers to target rougher ground where only static-gear fishers had previously been able to operate.
1970-1980	Plastic pots introduced. 300 pots in strings of up to 30 commonly used. Navigation aids (Decca) as well as additional gear and power improvements enabled towed-gear fishers to further push into rough ground areas. Seasonal scallop dredging by static-gear fishers abandoned late 1970s. Inshore Potting Agreement (IPA) established 1978.
1980-1990	Increasing number of pots operated from each boat. Seasonal movement of pots within static-gear-only zones abandoned mid 1980s.
post-1990	Typical static-gear boat size 10-15m. Pot-locks and rubber skirts introduced on pots early 1990s. Up to 1600 pots operated from each boat, though average 600-700. Pots deployed in strings of 40-80.

THE MODERN CRAB FISHERY

At present, inshore boats are typically 10–15m in length, and are operated from deep-water ports by a skipper-owner and one to three crew. Up to 1600 pots are now worked from each boat, though the average number is 600–700 in strings of 40–60. The number of pots operated from each boat is no longer limited by the robustness of the pot construction, as modern pots constructed from man-made materials last many years, if routinely maintained.

Most skippers continue to use the inkwell design, although many have experimented with more modern 'soft-eyed creels' or 'parlour pots', both designs featuring non-return entries to prevent the escape of animals after entry (Fig. 2.2). Despite this apparent advantage, on the softer seabed substrates where female (hen) crabs are targeted, fishers commonly state that inkwell pots are more efficient than designs featuring non-return entries.

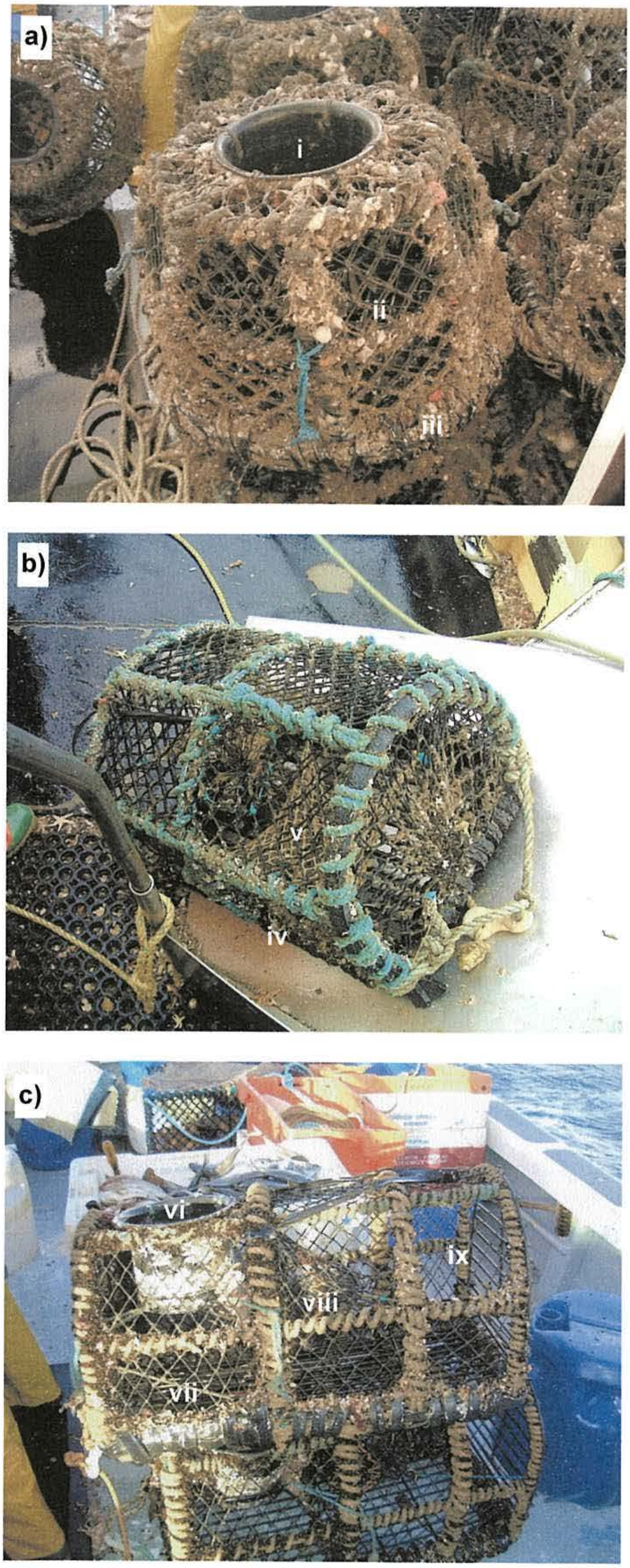

Figure 2.2: Different pot types used in the IPA: (a) Inkwell (diameter 65cm), (b) Soft-eyed creel (length 90cm), (c) Parlour (length 105cm).

i) Rigid plastic top entrance.
ii) Location of rubber skirt used to slow escape of captured animals.
iii) Heavily weighted base.
iv) Side entrance.
v) Soft mesh non-return valve.
vi) Rigid plastic top entrance.
vii) Baited chamber.
viii) Soft mesh non-return valve exit to parlour.
ix) Parlour chamber.

The only recent change to the inkwell design is that 'pot-locks' or rubber skirts were added to the funnels of the pots in the early 1990s, making it more difficult for captured animals to escape (Fig. 2.2). Fishers say that before these features were added, crabs would only stay in the pots for three to four days, or as long as bait remained. After this time, the crabs would climb out. Fishers believe that pot-locks or skirts slow the escape process, but state that even with these devices, few crabs will be caught unless pots are checked within seven to eight days of baiting. Lobsters are also generally believed to be able to climb in and out of inkwell pots, whether pot locks or skirts are used or not.

CONFLICT WITHIN THE STATIC SECTOR

Pots were traditionally left in the water to fish over winter, though withy pots tended to rot and disintegrate by this point in the fishing season. However, wire pots were repaired as required, and because of their greater longevity, fishers were able to increase the amount of gear used. This increase created competition for space amongst static-gear fishers, such that gear had to be continuously left in favoured sites to prevent other fishers moving their gear to the location. In the IPA system, occupation of an area of the sea (and hence seabed) traditionally signifies the right to fish in that location, but only as long as gear is retained there. The practice of leaving pots at sea over winter continues today. Space for additional static-gear within the IPA is very limited, and fishers wishing to enter the static-gear fishery are unable to do so unless they buy second-hand gear already positioned at sea. Vacant sites are also limited because some fishers leave weighted marker buoys in place to discourage other fishers from setting pot strings in unoccupied locations. As territories cannot be expanded, fishers can only create space for additional pot strings by moving existing strings closer together.

THE TOWED GEAR SECTOR

Towed bottom-fishing gears including otter trawls, beam trawls and dredges have been used in the inshore waters of south Devon for 500–800 years (Fox 2001). While some towed-gear boats were launched from beaches adjacent to villages, the majority operated out of deep-water ports such as Plymouth, Brixham, Dartmouth and Exmouth. There are now a small number of towed-gear fishers based in Salcombe and Dartmouth, but the towed and static sectors of south Devon tend to operate from different ports. Historically, scallop dredging was conducted on a part time basis by static-gear fishers from Christmas until the start of the crab-fishing season in April or May, when static-gear fishing restarted in earnest. Scallops rather than fish were targeted because the dredges used could be hauled by hand or with hand-operated capstans, while trawling required more specialized equipment. However, the use of towed-gear enabled static-gear fishers to 'make a living' over the winter when crab catches were low. In general, this practice stopped in the 1970s when scalloping became less profitable for part time fishers and potting became more time intensive. The inshore towed-gear sector now operates boats with dredges, beam trawls and otter trawls (for a review of towed gears see, (Jennings *et al.* 2001a). However, a local-area byelaw of the Devon Sea Fisheries Committee prevents non-local vessels greater than 15.24 m overall length operating within six miles of the Devon coastline. An annual closed season for scallops also occurs within the same area between July and September, and some boats seasonally use different towed gears to maximize potential earnings.

CONFLICT BETWEEN SECTORS

Conflict between the towed and static sectors has long existed within the south Devon inshore fishery, but it was uncommon prior to the 1970s simply because towed gears could not be used effectively or safely on the mixed or rougher ground where pot fishers operated. Catches were probably sufficient such that there was little need for boats to stray into areas typically fished with other gear types. In addition, static-gear fishers historically moved gear from one location to another as they followed movements of crabs, which allowed other fishers access to the grounds they vacated. The potential for conflict between towed-gear fishers and static-gear fishers has increased through time. As pots became constructed from more durable materials, static-gear fishers were able to operate more pots, and leave them in position year-round. The competition for space amongst static-gear fishers finally eliminated the traditional pattern of seasonal pot movement in the 1980s, and thus the towed-gear sector lost seasonal access to some sites. Most significantly, the development of towed gears such as rock-hopper trawls and spring-loaded dredges, in conjunction with higher market prices for scallops and whitefish, meant that it became cost effective for towed-gear fishers to target rough ground.

It may seem strange that fishers are unable to avoid each other's gear. However, while towed-gear fishers may attempt to avoid pot strings, static-gear loss or damage is almost inevitable when towed and static gears are fished in close proximity. In particular, strong and complex inshore tidal streams make accurate towing difficult, so even when towed-gear fishers are aware of pot positions, interactions with gear can occur. The strong currents also pull marker buoys down-tide and away from the pot strings, or may even submerge them during peak flows, making the accurate location of gear difficult or impossible. In addition, in inshore areas pot strings may be tightly packed together, leaving very little room for towed-gear use, and towed gears must be towed between banks, where static-gear may also be positioned to avoid being buried by movement of bottom sediments.

THE INSHORE POTTING AGREEMENT

In the mid-1970s, towed-gear fishers expanded the area over which they operated into areas where static-gear fishers had previously operated in isolation. Static-gear fishers suffered significant losses of pots as a result, which reduced catches and income, and necessitated the extra expense of gear replacement. In response to this, in 1978 the Ministry of Agriculture, Fisheries and Food was asked to mediate a meeting between representatives of the static and towed-gear sectors, the outcome of which was the Inshore Potting Agreement (IPA). It included areas designated for exclusive static or towed-gear use and for seasonal static and towed-gear use. The function of the agreement was to maintain the ability of static-gear fishers to operate on traditional grounds without the risk of losing gear to the towed sector (Fig. 2.3).

Subsequent to the creation of the first IPA, fishers suggested a number of modifications. In 1982 a new IPA was established, when temporal and spatial adjustments were made to reduce the complexity of the design, and the diamond-shaped seasonal zone outside the six-mile United Kingdom territorial limit was removed (Fig. 2.3). Further spatial and temporal adjustments were made in 1984 in response to requests for access to seasonal resources from towed-gear fishers, who gave up seasonal access rights in other areas as compensation (Fig. 2.3). The current version of the IPA was introduced in 1993, with further minor spatial and temporal changes (Fig. 2.3). There are now approximately 25 full-time static-gear boats that work within the IPA area, and approximately 15 towed-gear boats that regularly work in the vicinity of the IPA.

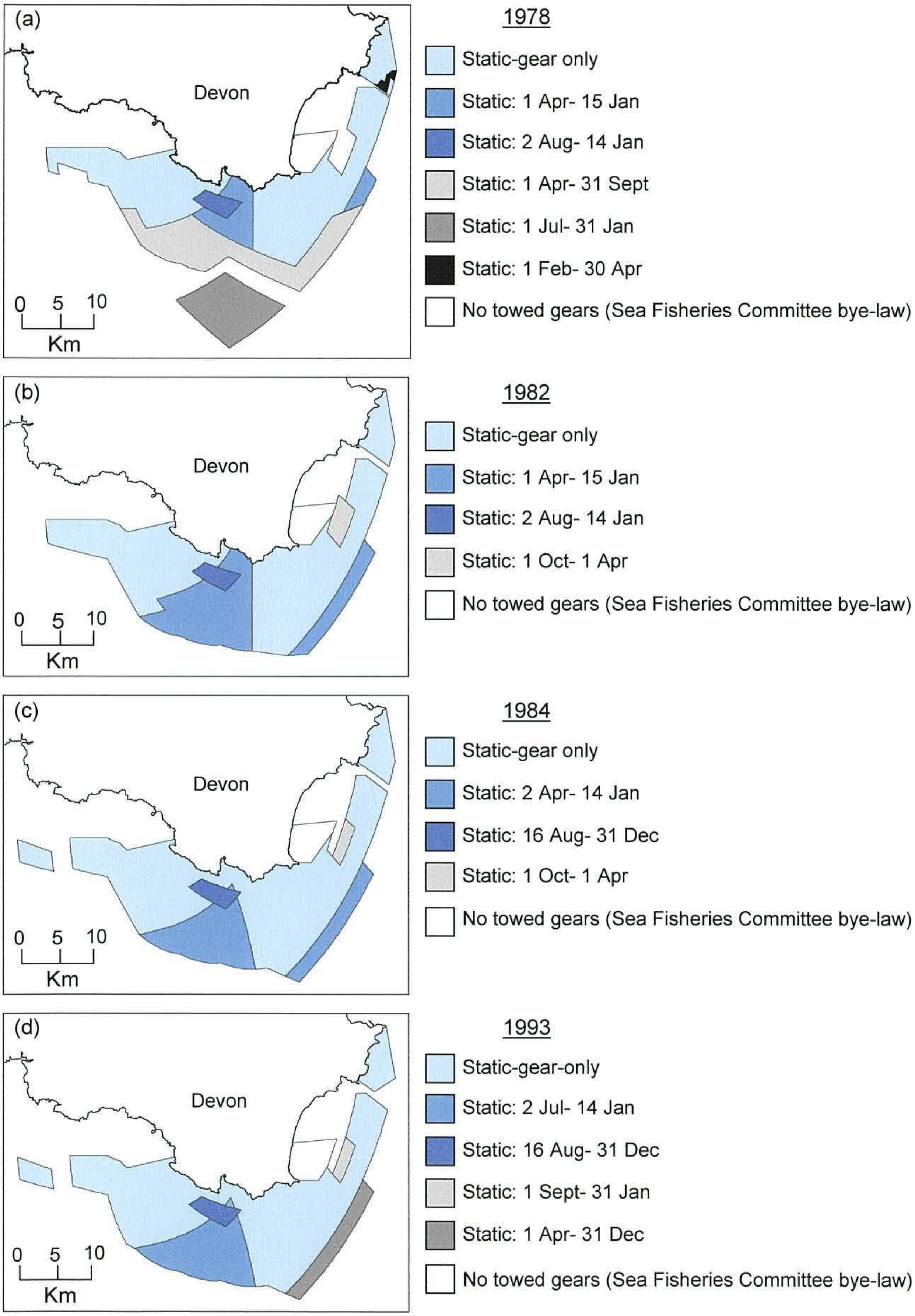

Figure 2.3: The Inshore Potting Agreements of a) 1978, b) 1982, c) 1984 and d) 1993.

METHODS

Copies of the 1978, 1982, 1984 and 1993 IPAs were obtained from the South Devon and Channel Shellfishermen's Association Ltd. These were digitised using Arc View V.3.2, and the total area of exclusive-use and seasonal-access zones were determined using the British National Grid map projection. The areas of zones for seasonal static-gear use were calculated as ([total size of each seasonal zone] x [proportion of the year the zone was allocated for static-gear use]). Hence a zone of 50 km^2 available for static-gear use during six months of the year was calculated as (50 x 0.5) = 25 km^2 yr^{-1}. In order to conduct interviews, towed-gear and static-gear fishers of the IPA were approached via their respective fishers' associations, the South Western Fish Producers' Organization Ltd. (SWFPO) and the South Devon and Channel Shellfishermen's Association Ltd. (SDCSA). Meetings were organized to introduce the project to fishers, and interviews were subsequently carried-out at sea under normal working conditions. If on analysis gaps in the data were found, fishers were re-contacted for additional questioning. (Neis *et al.* 1999) stated that fisheries researchers can greatly strengthen the quality of data gathered by conducting interviews on the fishing grounds and combining them with observation and follow-up interviews. Interviewing at sea also allowed fishers to provide additional non-elicited information regarding aspects of the fishery that would have been missed had interviews been land based.

The interview process followed a semi-structured system. Each fisher was initially re-informed of the project aims, and what was hoped to be achieved during the day. A series of questions were then posed to determine their position in the fishery, including age, experience, number of generations of fishers in their family and other socio-economic information. These included the value of the boat, types of gears used, number of crew, how much had been caught over previous seasons, where products were sold and from whom equipment or services were purchased. These questions not only served to establish each fisher's role within the fishery, but also began the questioning process on non-emotive issues. Finally, more contentious issues were covered, including what services the IPA provided to each fisher, whether they felt the IPA served other fishing sectors, and any means by which the IPA could be improved. Fishers were also asked if they had had conflict interactions with fishers of other industry sectors, or conflict with fishers of the same sector. By asking these questions last, it was hoped that more responses would be elicited, and that any responses would be more likely to be honest. However, notes were taken earlier in the day if these issues were covered without prompting.

During the course of the project, interviews were conducted with the skippers of twelve static-gear boats and five inshore towed-gear boats. These represented approximately half of the full-time static-gear boats operating within the IPA area, and a third of the full-time towed-gear boats regularly operating in the vicinity of the IPA. A member of the committee of the SDCSA, and two members of the committee of the SWFPO were also interviewed to elucidate the policy of each organization towards the IPA.

A multivariate analysis of fishers' responses to interview questions was undertaken to ascertain whether there were any significant differences in the responses made by the two sectors and to ascertain whether different responses were linked to each other in a consistent fashion. The PRIMER software package was used to undertake cluster analysis on the interview responses. Each interviewee was classed as a sample with their response to each question classed as either yes (1) or no (0). The Bray-Curtis index of similarity and the group average linkage technique were used to form a dendrogram of the relationship between the responses made by each interviewee. An a priori one-way analysis of similarity (ANOSIM) test (a multivariate nonparametric version of ANOVA) was performed for the differences that might occur between the different sectors that operate in the IPA (i.e. static versus mobile). The cluster analysis was then repeated, but on this occasion the data were examined for similarity between different questions. An *a posteriori* examination of the dendrogram indicated those questions that were answered in the most similar manner. The PRIMER software was further used to undertake BIOENV analysis (Spearman rank correlation) to search for the combinations of the fishing sector, home port, age, experience and membership of local fishing or village committees that best matched the responses that fishers gave to interview questions.

RESULTS

CHANGES TO THE IPA

The total area of seabed covered by the first Inshore Potting Agreement (1978–1981) was 527.3 km^2 (Table 2.2). In 1982, the total area covered by the IPA was reduced to

470.7 km^2. The majority of the reduction resulted from the removal of a diamond-shaped seasonal-access zone outside the six nautical mile United Kingdom territorial limit. Despite the loss of this seasonal-access zone, and the reduction in the total area of the IPA, the area available for static-gear use increased slightly to 444.2 km^2 yr^{-1} because the static-gear-only area increased in size from 291 km^2 to 330.7 km^2. In 1984 the total area of the IPA increased in size to 479.9 km^2, and the amount of ground exclusively available to static-gear fishers also increased to 357.1km^2. The amount of seasonally-accessible ground was reduced to 90 km^2 yr^{-1}, which continued the general evolutionary pattern of increased exclusive access in exchange for reduced seasonal access for static-gear fishers within the IPA. The current IPA has operated since 1993, and covers 478.4km^2, with 349.7km^2 reserved for static-gear use and 73.2km^2 yr^{-1} retained for seasonal access. Most of the loss of seasonal access area from 1984 to 1993 resulted from alterations to the temporal rather than the spatial access to seasonal zones.

Table 2.2: Area of the IPA and static-gear zones 1978-1993.

	1978	1982	1984	1993
Total IPA area (km^2)	527.3	470.7	479.9	478.4
Static-gear-only zones (km^2)	291.0	330.7	357.1	349.7
Seasonal static-gear zones [area x % of year] (km^{2}y^{-1})	135.7	113.6	90.0	73.2
Total static-gear area [static only + seasonal] (km^{2}y^{-1})	426.7	444.2	447.0	422.9

VIEWS OF FISHERS

Cluster analysis of the responses to interview questions (Fig. 2.4a) indicated that the responses of the towed-gear sector were significantly different from those of the static-gear sector (ANOSIM, $r= 0.34$, $p= 0.001$). BIOENV analysis of the responses to interview questions determined that the industry sector of the interviewees provided the best correlation of demographic variable and response ($r_s= 0.323$), followed by a combination of sector and experience ($r_s= 0.320$), and then a combination of sector, experience and home port ($r_s= 0.318$). Other demographic combinations of variables tested poorly represented the differences in responses observed ($r_s< 0.3$).

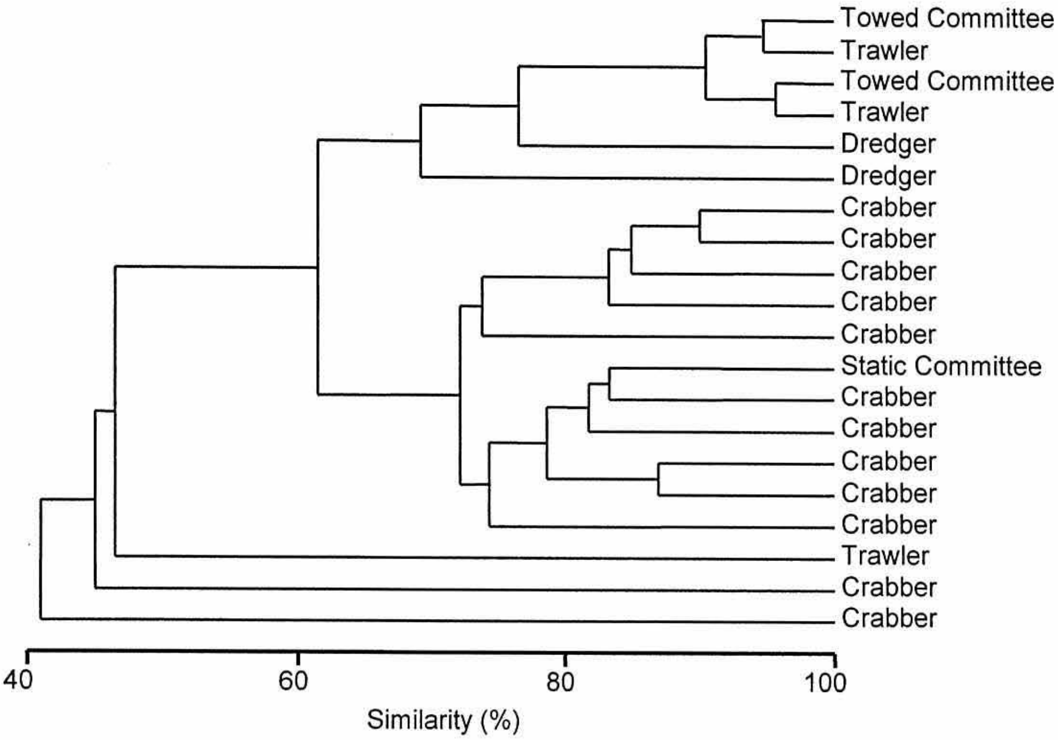

Figure 2.4a. Dendrogram showing the percentage similarity between the different fishers from the towed and static-gear sectors of the industry. Managers from each sector are also indicated.

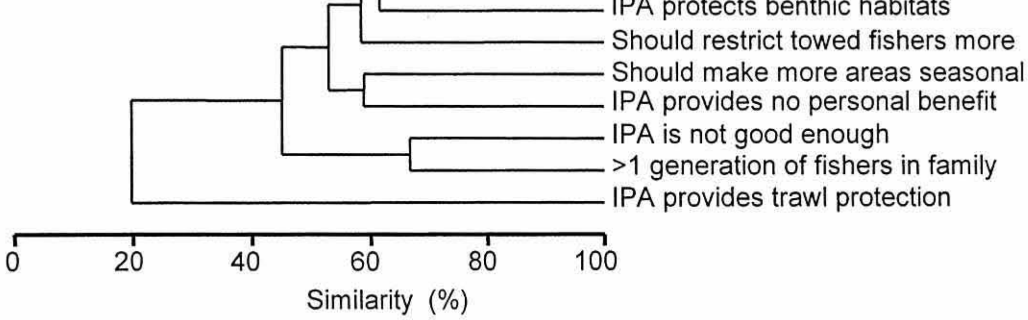

Figure 2.4b: A dendrogram of the same data analysed for the degree (percentage similarity) of association between different responses or opinions stated by all fishers.

The analysis of similarity between different questions indicated some associations (Fig. 2.4b). For example, the statement that 'the IPA is not good enough' was most strongly associated with fishers who confirmed that they had 'more than one generation of fishers in the family' and with the opinion that 'the IPA protects benthic habitats'. In contrast, the statement that 'our sector break IPA rules' was most strongly associated with the opinions that the IPA 'should restrict static-gear fishers more' and 'provides no personal benefit'. In addition, those that thought 'the IPA is a good system' also thought 'the IPA provides pot protection'.

IS THE IPA A GOOD SYSTEM?

In response to the question 'Is the Inshore Potting Agreement a good system?', all but one of the static-gear fishers responded positively (Table 2.3). The exception was a fisher with gear positioned on the edge of the system (referred to as an 'edge' fisher in Tables 2.3–2.7) that stated that the IPA provided no personal benefit. This fisher reported that the IPA did little to stop towed-gear fishers from working in static-gear-only zones, and that he was forced to cooperate with towed-gear fishers by occasionally moving pot strings to allow them access to the ground that he fished. Other static-gear fishers, including those that operated on the interior of the system (i.e. had at least one other fisher's gear between their gear and any edge of the IPA; 'interior' in Tables 2.3–2.7) stated that although they received no personal benefit from the IPA, it had generally protected the ability of the static-gear sector to operate. Seven of the ten static-gear fishers who said the IPA was a good agreement also said that the IPA was not good enough and that more protection should be afforded to the static sector.

Of the five towed-gear fishers interviewed, three thought the IPA was a good system, and two thought it disadvantaged them unfairly. The general difference in opinion was due to some defending the right of the static sector to access fishery resources, while some objected to the overriding principle that static-gear fishers had property rights to the ground governed by the IPA. All members of the towed-gear sector raised the property rights issue, particularly in regard of one static-gear fisher who on retiring had advertised his boat for sale 'with gear and ground'. Towed-gear fishers objected strongly to the sale of fishing territories.

Table 2.3: General function of the IPA. – = no strong opinion expressed or no comment.

Gear type	Area	Person	Generations of fishers in family	The IPA Is a good system	The IPA is not good enough	The IPA provides no personal benefit
Static	Interior	1	4+	Agree	Agree	Agree
		2	1	Agree	–	–
		3	3+	Agree	Agree	–
		4	3+	Agree	Agree	–
	Edge	5	2	Agree	Agree	–
		6	1	Disagree	–	Agree
		7	1	Agree	Agree	–
		8	2	Agree	–	–
		9	3	Agree	–	–
		10	1	Agree	–	–
		11	3+	Agree	Agree	–
		12	No data	Agree	Agree	Agree
	Committee	13	1	Agree	Agree	–
Towed	Inshore	14	1	Agree	–	–
		15	1	Agree	–	Agree
		16	1	Agree	–	–
		17	1	Disagree	–	–
		18	No data	Disagree	–	–
	Committee	19	No data	–	–	–
		20	No data	Agree	–	–

GEAR PROTECTION

Almost all members of the static-gear sector interviewed stated that the IPA afforded a degree of pot protection they would not have in the absence of an agreement (Table 2.4). The two static-gear fishers who felt that the IPA did not provide protection for their gear stated that despite the IPA, the towed sector regularly fished in static-gear-only zones anyway, except in areas in which it was technically too difficult to operate.

Two towed-gear fishers agreed that the IPA afforded static-gear fishers some protection for their gear. However, other towed-gear fishers claimed that the degree of loss that the static-gear fishers suffered as a result of the activities of the towed sector was minimal, and was frequently exaggerated in order to create the maximum controversy. One towed-gear fisher stated that if the IPA static-gear-only zones were opened to the towed sector, static-gear fishers would benefit because any pots lost in the past would be quickly recovered.

Table 2.4: The benefits of the IPA to fishers. – = no strong opinion expressed or no comment.

Gear type	Area	Person	The IPA provides pot protection	The IPA provides trawl protection	The IPA protects benthic habitats	The IPA acts as a reserve for target species
Static	Interior	1	Agree	Agree	Agree	Agree
		2	Agree	–	Agree	Agree
		3	Agree	–	–	Agree
		4	Agree	–	Agree	Agree
	Edge	5	Agree	–	Agree	Agree
		6	–	–	–	–
		7	Agree	–	Agree	Agree
		8	–	–	Agree	Agree
		9	Agree	–	Agree	Agree
		10	Agree	–	Agree	Agree
		11	Agree	–	–	Agree
		12	Agree	–	Agree	Agree
	Committee	13	Agree	Agree	Agree	Agree
Towed	Inshore	14	–	–	Agree	Agree
		15	Agree	Disagree	Disagree	Agree
		16	Agree	Disagree	–	Agree
		17	–	Disagree	Disagree	Agree
		18	–	Disagree	Disagree	–
	Committee	19	Agree	Disagree	Disagree	Agree
		20	Agree	Disagree	–	Agree

There is also a gear protection aspect to the IPA for the towed sector, and in particular for those using otter trawls. Essentially, if pots are snagged while trawling then considerable damage may be done to the belly and cod-end of a trawl net. In this regard, two static-gear fishers commented that the IPA benefited the towed sector considerably because the static sector operated only within the limits of the IPA. All towed-gear fishers interviewed mentioned that trawls may be damaged by static gears, but said that because towed-gear fishers would always attempt to avoid pot strings, the IPA zoning system did not provide any additional trawl protection.

HABITAT PROTECTION

Nine of the twelve static-gear fishers stated that the IPA functioned to protect benthic habitats within the IPA area. This was in contrast to interviewees from the towed sector, where only one fisher suggested that the IPA functioned in this manner. With the notable exception of one scallop-dredge fisher, interviewees from the towed sector generally accepted that towed gears caused damage to the seabed. However, they also said that the IPA did not protect benthic habitats because static gears also caused damage, in particular when ropes dragged across the seabed during hauling. Static-gear fishers commonly considered these factors, but generally thought that the damage caused by static gears would be less significant than the damage caused by towed gears and so stated that the IPA functioned to protect the seabed.

RESERVE FUNCTION

There was almost uniform agreement amongst interviewees that the IPA functioned as a reserve for species targeted by the towed sector. Therefore it was felt that the IPA improved the long-term viability of the local fishing industry. Despite this view, towed-gear fishers protested that some static-gear fishers used anchored gill nets to catch demersal fish species that they felt were protected by the existence of the IPA. Fishers from both sectors felt that the potential reserve benefits were therefore lessened.

INTRA-SECTOR CONFLICT

Almost all fishers from the static sector commented that they had conflict problems within their own sector, always as a result of competition for space (Table 2.5). The majority of these problems were said to have occurred as a result of newcomers entering the fishery, or with vessels that were fishing a large number of pots. The most commonly reported periods for conflict interactions to occur were at the start of the static-gear season in spring when additional pots were put out at sea after over-winter repair, and when seasonal zones were reopened after a period of towed-gear use. At these times, territory boundaries between fishers were re-established, with the potential for ground to be acquired from neighbours.

Towed-gear fishers less commonly stated that they suffered conflict within their own sector, but two commented that they were forced to be secretive when fishing within static-gear-only zones, in case other towed-gear fishers noticed where they were working and began to operate in close proximity. Both these fishers admitted that they were passed detailed information on the location of static-gear by the pot fishers who operated in the area worked. Both also feared that their personal agreements would suffer if static gear was damaged by other towed-gear fishers who had not been informed of the exact location of pot strings, but who attempted to fish nearby.

Table 2.5: Interactions between fishers of the same sector. – = no strong opinion expressed or no comment. n/a = not applicable.

Gear type	Area	Person	Have had conflict within own sector	Our sector break IPA 'rules'
Static	Interior	1	Agree	–
		2	Agree	–
		3	Agree	–
		4	–	–
	Edge	5	Agree	Agree
		6	Agree	–
		7	Agree	Agree
		8	Agree	Agree
		9	Agree	–
		10	Agree	–
		11	Agree	Agree
		12	Agree	Agree
	Committee	13	N/a	–
Towed	Inshore	14	–	Agree
		15	Agree	Agree
		16	–	Agree
		17	Agree	Agree
		18	–	Agree
	Committee	19	N/a	Agree
		20	N/a	Agree

INTER-SECTOR CONFLICT

All of the towed-gear fishers interviewed admitted to fishing inside the IPA static-gear-only zones, though accusations of static-gear loss were generally denied. One scallop-dredge fisher accepted that he regularly caught pots, but also said that he replaced them whenever damage occurred. A number of static-gear fishers that only used pots stated that the use of anchored nets by static-gear fishers represented a breach of the IPA. They commented that the IPA was established specifically to protect the right of pot fishers to operate, and that the use of nets was a considerable source of contention in dealings with the towed sector. All static-gear fishers who mentioned this issue thought the towed sector would be more likely to respect the IPA if anchored nets were not used inside the limits of the system. Two towed-gear fishers also commented that some static-gear fishers positioned gear outside the limits of the IPA (Table 2.6). One static-gear fisher confirmed that some fishers did place pots outside the IPA area, and a number of pot strings from another fisher were consistently found located outside the IPA during the period of the study.

Table 2.6: Interactions between fishers of different sectors. – = no strong opinion expressed or no comment.

Gear type	Fishing area	Person	Other sector violate the IPA	Cooperate with the other sector	Have had inter sector conflict	Worst sector
Static	Interior	1	–	–	–	–
		2	–	–	Agree	Scallop
		3	Agree	–	Agree	Scallop
		4	Agree	–	–	Scallop
	Edge	5	Agree	–	Agree	–
		6	Agree	Agree	Agree	Angling
		7	Agree	–	Agree	–
		8	–	Agree	Agree	–
		9	Agree	–	Agree	Scallop
		10	–	Agree	Agree	Scallop
		11	Agree	–	Agree	Scallop
		12	–	Agree	Agree	–
	Committee	13	Agree	Agree	–	–
Towed	Inshore	14	–	Agree	–	–
		15	Agree	Agree	Agree	Scallop
		16	Agree	Agree	Agree	–
		17	Agree	Agree	–	–
		18	–	–	–	–
	Committee	19	Agree	–	–	–
		20	Agree	–	Agree	–

Most static-gear fishers commented that they had experienced inter-sector conflict problems. The two exceptions were static-gear fishers with territories within the interior of the IPA. Despite this, only eight of the 13 interviewees from the static-gear sector felt that towed-gear fishers broke the spirit of the agreement by fishing in static-gear zones. Four static-gear fishers with conflict problems, including one who said he felt the other sector broke the IPA, still confirmed they worked with towed-gear fishers to allow them temporary access to the ground over which they worked.

Amongst those fishers who expressed an opinion with regard to which sector caused most conflict problems, there was almost universal agreement that scallop dredgers were most at fault. The exception was one fisher who stated that he had most problems with recreational anglers, as they frequently snagged ropes or pots while anchoring. Apart from dragging the pots away from their original location, which was said to reduce catches significantly, the interviewee claimed that the gear was almost inevitably cut off the anchors rather than untangled, thus making hauling the pots difficult and time consuming.

CAN THE IPA BE IMPROVED?

Predictably, most members of the towed-gear sector were opposed to any suggestion that static-gear fishers should be given more ground (Table 2.7). However, two members of the static sector who admitted to cooperating closely with the towed sector said that this was a means to improve the IPA. There was disagreement between respondents from both sectors when additional restrictions were considered for static-gear fishers. Of the respondents from the static sector who expressed a strong opinion, half were in favour of limiting static-gear fishers to pots only, and half were against. Further input controls, including banning the use of non-return pot designs and limiting pot numbers according to size and power of the boat, or number of crew, were mentioned by four of the static-gear fishers and all but one member of the towed sector. Output controls recommended by static-gear fishers included a total allowable catch (TAC) system, a raised minimum landing size for male and female crabs or increased quality standards. However, it was accepted that crab buyers and processors would have to participate fully in any output control system.

Table 2.7: How can the IPA be improved? – = no strong opinion expressed or no comment.

Gear type	Area	Person	Should give static-gear fishers more ground	Should limit static-gear fishers to pots only	Should put in corridors or seasonal areas	Should legalise the IPA
Static	Interior	1	Agree	Agree	–	–
		2	–	Disagree	–	Agree
		3	–	–	–	Agree
		4	–	–	–	Agree
	Edge	5	–	Agree	–	Agree
		6	–	–	–	–
		7	Agree	Disagree	–	Agree
		8	–	Disagree	Agree	–
		9		–	–	–
		10	–	–	Agree	Agree
		11	–	Agree	–	–
		12	–	Agree	–	–
	Committee	13	–	Disagree	Disagree	Agree
Towed	Inshore	14	–	–	–	Disagree
		15	Disagree	Agree	Agree	Disagree
		16	Disagree	Agree	–	Disagree
		17	Disagree	Agree	Agree	Disagree
		18	Disagree	Agree	Agree	Disagree
	Committee	19	Disagree	Agree	Agree	–
		20	–	Agree	Agree	Agree

Eight of the 13 members of the static sector interviewed, and one member of the South Western Fish Producers' Organization (SWFPO) committee, recommended that the IPA should be legalized to prevent towed-gear fishers operating in static-gear zones. All active fishing members of the towed sector rejected legislation however, as they claimed that it would do little or nothing to prevent towed fishers from breaking the IPA. In fact, fishers from both sectors commented that legislation could seriously harm the IPA, as towed fishers respected the agreement only because of its voluntary nature. In this case it was considered that legislative intervention would be counterproductive.

Interviewees from the towed sector most commonly suggested the IPA should be altered by the introduction of corridors through static-gear zones, or the implementation of further seasonal access arrangements in existing exclusive static-gear zones. The exception was one fisher who operated a small trawler, and regularly towed in pockets of open ground within the static-gear-only zones. He said he preferred the existing system because he would lose his advantage if larger vessels from the towed sector were to be allowed into restricted zones. The towed-gear fishers in favour of greater seasonal access commented that the static fishers commonly abandoned their gear at sea over winter to avoid losing the site to other static-gear fishers, but that this prevented towed-gear boats from operating in these areas.

Essentially, the right of all fishers to go fishing was accepted by every interviewee, but the suggestion that static-gear fishers held property rights over territories within the IPA was strongly condemned by every towed-gear fisher. In contrast, one member of the SWFPO committee and one towed-gear fisher commented that the area of ground within the IPA was tiny in comparison to the area available to towed-gear fishers who work in the English Channel.

DISCUSSION

FISHERY BENEFITS

Fishers perceived that the Inshore Potting Agreement serves a number of functions, and primarily that it limits conflict between the towed-gear and static-gear sectors. Though almost all fishers stated that they suffered conflict interactions, it was commonly considered that inter-sector conflict would be worse without the IPA. A typical comment was 'It works 90% of the time. It isn't perfect, but whatever is done, it isn't going to be perfect'.

By limiting conflict, it is likely that the IPA has served to protect a large portion of the pot fishing industry of south Devon, and fishers from the static and towed-gear sectors are able to operate effectively and profitably in relative harmony. In comparison, fishers from both sectors described a pot fishery that historically operated in the 'Exeter Roughs', a nearby area to the east of that of the IPA, which disappeared after scallops *Pecten maximus* were discovered there by dredge fishers in the mid-1980s. The substratum was composed of biogenic, coralline reef, but within a short period it was reported that the seabed had been flattened and the pot fishery ended. However, it was also reported that the scallop fishery had been very short lived, and that there was little sign of a recovery in the substratum, or crab or scallop fisheries.

Scallop dredges are considered to be among the most damaging towed bottom-fishing gears (Dayton *et al.* 1995; Collie, Escanero & Valentine 2000a), although the use of other towed gears may also lead to long-term changes in benthic community structure (Bradstock & Gordon 1983; Kaiser & Spencer 1996; Collie, Escanero & Valentine 1997; Jennings & Kaiser 1998; Kaiser *et al.* 1998b; Auster & Langton 1999; Norse & Watling 1999). In this study, even towed-gear fishers generally accepted that damage occurred as a result of their fishing activities. However, the argument that the IPA does not protect benthic habitats because static gears also cause damage to the seabed is difficult to support. Studies by (Kinnear *et al.* 1996) and (Eno *et al.* 2001) indicated that potting caused little incidental damage to epibenthic fauna. A study by (Kaiser *et al.* 2000) also determined the species diversity within IPA static-gear-only zones was higher than in seasonal-access zones, which in turn was higher than in areas outside the IPA system where towed-gear fishers were able to operate year-round. Importantly, biogenic fauna such as soft corals and hydrozoans were also more prevalent in exclusive static-gear use areas of the IPA.

Larvae of *Cancer pagurus* tend to be less selective of seabed characteristics at settlement than those of crustacean species of lower fecundity (Robinson & Tully 2000). However, the post-settlement survival of some sub-tidal crustacean species is higher in more complex habitats (Pile *et al.* 1996; Palma *et al.* 1998; Stevens & Kittaka 1998; Robinson & Tully 2000). Towed bottom fishing gears physically damage crustaceans (Hill *et al.* 1996; Kaiser & Spencer 1996), and it has been shown that crustacean densities decreased with increased towed-gear use (Eleftheriou & Robertson 1992; Veale *et al.* 2000). Pot fishers commonly maintained that if towed gears were occasionally worked near but not alongside or over their gear, then catch rates could increase, as crabs were attracted to dead or dying by-caught animals. The rapid attraction of scavenging megafauna, including *C. pagurus*, to dredge tracks has been well documented (Caddy 1973; Kaiser & Spencer 1994). However, pot fishers also stated that it took several months for catch rates to recover when towed-gear boats had worked repeatedly around their gear, and concluded that this was because the seabed had been damaged extensively. However, no published evidence was found to support this.

Of the species targeted with towed bottom fishing gears, scallops in particular may benefit from increased benthic heterogeneity within the IPA system. The presence of filamentous flora and fauna was identified as a critical factor in spat settlement in the scallop *Pecten maximus* (Dare & Bannister 1987; Minchin 1992), giant scallop *Placopecten magellanicus* (Stokesbury & Himmelman 1995) and Iceland scallop *Chlamys islandica* (Harvey *et al.* 1993). As sessile emergent epifauna are at risk from towed gears (Collie *et al.* 1997; Sainsbury *et al.* 1997; Moran & Stephenson 2000), limits on towed-gear use within the IPA may have important implications for spat settlement and later recruitment of adults to nearby fisheries. In addition, spat or undersized scallops may be damaged when in direct contact with towed gears (Caddy 1973; Brand, Paul & Hoogesteger 1980). Spat may preferentially settle on structures to avoid being smothered by sediment (Brand *et al.* 1980; Thouzeau 1991; Harvey *et al.* 1993), and high concentrations of suspended silt have been shown to cause mortality in larvae and spat of different scallop species (Naidu & Scaplen 1979; Stevens 1987). Trawling may be a significant contributing factor to sediment resuspension in shelf seas (Churchill 1989; Piskaln, Churchill & Mayer 1998; Auster & Langton 1999; Hall 1999), and consequently the reduction in sediment resuspension by trawlers inside the IPA may also benefit scallop recruitment. Furthermore, the possibility exists that some commercially important scallop beds are self-seeding, with only occasional spatfalls originating in other areas (Sinclair *et al.* 1985; Darby & Durance 1989; Brand 1991; Young, McLoughlin & Martin 1992). For example, it was determined that the scallop (*P. maximus*) spat settlement in the Bay of Saint-Brieuc reflected the status of the local parent stock (Buestal, Dao & Lemaire 1979). Therefore, if a scallop bed is fished to commercial extinction, there may only be limited potential for its resettlement and rejuvenation, and a reserve of mature scallops within the IPA could be vital to the continuation of the local scallop-fishing industry. Moreover, significant increases in scallop biomass have been demonstrated clearly in other closed area systems (Turner, Tammi & Rice 1996; Brocken & Kenchington 1999; Murawski *et al.* 2000).

Most interviewees thought the IPA had functioned to improve the long-term viability of the towed-gear sector, though it was almost always in regard of protecting populations of demersal fish species such as rays (*Raja* spp.), turbot *Scophthalmus maximus* and anglerfish *Lophius piscatorius* rather than scallops. The possibility that the IPA may act as a reserve for fish species is uncertain. Fishery benefits in areas adjacent to reserves have been demonstrated infrequently, and it has been questioned whether a limited access system of only 480 km2 would protect a population of mobile demersal fish such that any net benefits would result (Horwood 2000). However, much smaller reserves have proved to be beneficial for some relatively mobile species in both temperate and tropical systems (Dugan & Davis 1993; Roberts & Hawkins 1997; Roberts *et al.* 2001). In the case of the IPA, the benefits for demersal fish species of preventing towed-gear fishing may be limited because these fish are taken within the system in anchored nets and by recreational anglers. However, most fishers in the towed sector believed that the system protected valuable and scarce target species and wanted access to the restricted ground within the IPA; for example, fishers reported that unusually large rays are caught on banks within the IPA by both anglers and commercial netters.

DEVELOPMENT OF THE IPA

Few regulations exist to control the level of fishing effort exerted on crustacean stocks in European waters. Crab fisheries are yet to come under a total allowable catch (TAC) or quota system, and currently catches are only restricted by a minimum landing size and subjective quality assessment. There is also no statutory limit on the number of pots that a fisher may use, and the only effective limits on effort are the number of pots that a fisher is able to operate, and the space on the seabed in which the pots may be placed. The establishment of the IPA, and subsequent changes to its shape and size over time resulted from proposals originating from users of the inshore system. Fishers were driven to form the IPA because of significant conflicts and the system has worked effectively to maintain the ability of fishers from both the towed and static sectors to operate. However, the diamond shaped seasonal access zone outside the United Kingdom territorial limit was less likely to have functioned successfully because there are few access restrictions for fishers from the European Union to waters beyond the six-mile limit. In the absence of statutory protection, or without enforcement of fishery regulations, any part of the IPA that operated outside the six-mile limit could only function with the consent of other fishers within the European Union. This consent would be open to accidental abuse through lack of knowledge of the system, or deliberate intent. However, healthy fish stocks are a collective good, and in most common property situations it is difficult to exclude people from such goods (Jentoft *et al.* 1998). Hence, without conventional fishery management measures such as the six-mile territorial limit, or power and effort limitations on towed-gear use within six miles of the coastline where the bulk of the IPA exists, it is unlikely that the IPA would have survived.

Property rights refer to the entire range of rules, regulations, customs and laws that define rights over appropriation, use and transfer of goods and services (Kula 1992). It has been suggested that property rights must be established before any other fishery management regulation can be successfully applied (Acheson *et al.* 1998; Walters 1998). Towed-gear fishers were vehemently opposed to an official system of territory ownership within the IPA, and maintained that access should be equal for all fishers. However, informal ownership arrangements do exist between static-gear fishers. These arrangements have allowed static-gear fishers to reduce the risk of operating in an open-access system, though because of the number of pots fished, ensuring access to seasonal grounds is problematic. One informant maintained that pots were historically fished close inshore early in the season, when male crabs were targeted on rough ground. During this period, towed-gear vessels would cover ground further offshore. Over the summer and autumn, pots were moved further offshore onto softer ground to target female crabs, enabling the towed-gear fleet to fish any suitable ground inshore. The informant stated that the system operated successfully because it allowed both sectors to cover all areas. In addition, when the pots became degraded or were removed from the water over the winter period, towed boats were further able to target areas normally fished with static-gear.

The movement of pots between sites probably worked in the past because effort was limited. It is likely that the reduction in the amount of seasonal access ground from 1978 to 1993 resulted from two factors, namely the difficulty that static-gear fishers have in reacquiring ground when areas are seasonally reopened, and the difficulty of ensuring regulatory compliance in seasonal access zones. Not only is it logistically difficult to move a large number of pot strings from one place to another, there is also little to prevent a fisher from positioning gear in a site occupied by another the previous season. Occupying a territory continually prevents an annual race to position gear at the start of the season. It is also easier to manage and enforce a single use system than a multiple-use, seasonally-changing system. Enforcement is a key factor leading to successful fishery enhancement from reserves (Roberts *et al.* 2001).

Importantly, as a voluntary agreement, the IPA is based on goodwill, and the use of anchored nets by static-gear fishers to target demersal fish species has the potential to affect the long-term viability of the IPA adversely. Essentially, this is because the towed-gear sector perceived only limited benefits of abiding by the IPA. Towed-gear fishers stated that they did not feel trawl protection was achieved through the IPA, and that beam trawls and scallop dredges were in any case not damaged when they came into contact with pots. Further, because fishers of the different sectors do not generally use the same home ports, there is little social advantage for one fisher in avoiding conflict with another fisher of a different sector when there is no possibility that they will have to tie up alongside each other in port. However, towed-gear fishers stated that the benefit of the IPA to their sector was that the area acted as a reserve for demersal fish species. When static-gear fishers used anchored gill nets within the IPA area, towed-gear fishers felt that the benefit to them of adhering to the IPA was reduced, goodwill between sectors inevitably suffered, and the potential for the further development of the IPA also diminished.

CONCLUSIONS

A number of authors have proposed that rather than attempt to manage a fishery or fish stock in isolation, managers should take into consideration the ecosystem within which the fishery exists. Proponents suggest that if an ecosystem is sustainably managed as a whole, the individuals within will also be sustainably managed (Sherman 1991; Botsford *et al.* 1997; Langton & Haedrich 1997; McGlade *et al.* 1997; Hofmann & Powell 1998; Pitcher & Pauly 1998). Essentially, it may be critically important to include the management of fishers in the management of marine ecosystems, and it may be that the maximum long term fishery production will be more easily achieved by controlling 'how' fishing is undertaken, rather than 'how much' is caught. The shift in emphasis towards non-technical fishery management measures stems in part from the failure of existing management programmes to meet biological goals (Murawski 2000).

The IPA represents an interesting example of how fishing should be undertaken. Furthermore, the system has evolved in modern society, despite the increasing pressures of lower catches but higher expectations of earnings and living standards. Probably the most noteworthy features of the IPA are that it was conceived relatively recently and has the general backing of both fishery sectors, but has protected the traditional practices of the local fishing industry, and benthic habitats that have been recognized as important to the long term maintenance of some marine fisheries. Because of these features, fishers and managers should be commended for the creation and function of the IPA, and characteristics of the system that may be successfully adopted in other locations may be noted. These are:

(1) Management may be more successful if all existing uses of the managed area are taken into account. The IPA is an agreement between fishers over a fishing ground that historically had been used for the same purposes as it is today.

(2) Management may be more successful if all existing users of the managed area are taken into account. The IPA has been reduced in size to lie mostly within the six-mile territorial limit of the UK, thus reducing potential conflict with non-local fishers not party to the management system.

(3) When existing use of the seabed permits, exclusive-use zones have the greatest potential for management success. It is easier to enforce exclusive-use systems, and reallocating seasonal territories has the potential to create conflict within sectors. Further, exclusive-use zones may allow the effects of management strategies to be more easily quantified and related to changes in fishery use, and may provide the basis for adaptive management experiments, the results of which could be applied to a wider region.

(4) Seasonal limitations on gear types have the potential to work effectively, as different fishing sectors may wish to target the same areas at different times of the year. However, seasonal changes in use should not be overly complex in time or space. Care may also be required to ensure that on reopening an area to a sector, fishers that previously occupied sites are able to subsequently return to the same sites.

(5) Within a management zone, long-term regulatory compliance may be more likely if users are restricted in their ability to switch methods to take advantage of increases in abundance of species targeted by other fishing sectors, but protected and enhanced by the change in management. The use of anchored nets by static-gear fishers has reduced the potential for long-term viability of the IPA.

(6) If gear types and effective effort are limited at the inception of a new system, conflict between users is less likely to develop. In the present case, conventional fishery management regulations exist such that within six miles of the United Kingdom coast, towed-gear fishers are limited to 12 dredges and power of no greater than 300 hp. This has prevented large or non-United Kingdom vessels from fishing inside the IPA.

(7) Regulatory compliance is more likely to result when managers are able to meet regularly to discuss events occurring in a fishery, and when management is flexible and adaptable. When features of the IPA were found to be unworkable, changes were quickly made.

(8) Conflict avoidance and regulatory compliance is more likely if negotiation can be between bodies that represent fishers en masse. Two fishers' associations represent all of the static-gear fishers and most of the towed-gear fishers operating in the IPA. Information is rapidly disseminated within associations and peer group control may be applied.

ADDENDUM

After a number of 'illegal' incursions into the IPA by towed-gear fishers, the Department for Environment, Food and Rural Affairs (DEFRA) created national legislation to protect the IPA in March 2002. The maximum fine for breaking this legislation was set at £50,000. Whilst this may seem to have been a retrograde step after advocating the benefits of voluntary management in the IPA, the system of legislation that was created still allows fishers to determine the rules of the fishery. Managers and representatives of all fishing sectors impacted by the IPA are required to meet on a management panel once every three months. At each panel meeting, fishers are able to submit requests for changes to the IPA. Any recommendations for change that are decided by the panel can be then submitted to DEFRA annually. Importantly, whilst the IPA can change, the IPA that is protected by the legislation is then the one depicted by a chart of the system that hangs in the office of the Chief Fisheries Officer of Her Majesty's Sea Fisheries Inspectorate in Plymouth.

Although the IPA was no longer a voluntary system, static gear fishers responded positively to the introduction of legislation, and few losses of static gear were reported. Towed-gear fishers also reported being satisfied with the legislation, highlighting the parity that was created in the IPA for all fishers of their sector, and the benefits of having a forum in which they could have requests for changes to the IPA heard. The longer-term impact of this legislation is difficult to envisage, but it is hoped that it will provide the potential for enforcement of the IPA, whilst maintaining the ability of fishers to manage the fishery.

CHAPTER 3

IMPLICATIONS OF A ZONED FISHERY MANAGEMENT SYSTEM FOR MARINE BENTHIC COMMUNITIES.

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3: IMPLICATIONS OF A ZONED FISHERY MANAGEMENT SYSTEM FOR MARINE BENTHIC COMMUNITIES.

SUMMARY

The impacts of trawls and dredges on marine benthic habitats and communities have been extensively studied, but mostly at small scales and over short time periods. To investigate the large-scale chronic impacts of towed fishing gears, zoned commercial fishery management systems allow comparison of habitats and communities between areas of seabed subjected to varying levels of towed-gear use.

The Inshore Potting Agreement (IPA) was implemented in 1978 to restrict the use of towed gears in inshore areas that had traditionally been used by static-gear (pot and net) fishers. In this study, scallop dredges were used to sample benthic communities at sites within and adjacent to the IPA that had been subjected to four different commercial fishing regimes since the inception of the system. These were: a) towed-gears only, b) annual, seasonal towed-gear use, c) temporary towed-gear use but reverting to static-gear use 18-24 months prior to sampling, and d) static-gears only.

There were no significant differences in the total species richness or biomass of benthic communities between sites under regimes a) and b). There was significantly greater total species richness and biomass of benthic communities at sites of regimes c) and d) than at sites of regimes a) and b). The benthic community biomass under regime d) was significantly greater than under all other regimes.

The IPA has maintained benthic species that are important for the settlement and survival of others. The cessation of towed-gear fishing for a period of greater than two years would be necessary for benthic communities in areas adjacent to the IPA to recover such that they were indistinguishable from areas where towed gears had not been used. However, fishers may object to the creation of permanent closed areas because harvestable stocks can move in space and time. This study indicates that zoned fishery management can allow some sectors of the fishing industry to maintain access to fishery resources, whilst protecting benthic species and habitats.

INTRODUCTION

Advances in technology have enabled fishers to harvest resources from a progressively greater proportion of the marine environment. There are now few places where marine stocks are not targeted, and overfishing is commonplace (Dayton *et al.* 1995; Vitousek *et al.* 1997; Pauly *et al.* 1998; Pitcher & Pauly 1998; Roberts & Hawkins 1999; Pitcher 2000). To address the resulting problems there is a drive to adopt fishery management systems that incorporate temporal and spatial restrictions on fishing effort (Dugan & Davis 1993; Roberts & Polunin 1993; Roberts 1997; Allison, Lubchenco & Carr 1998; Lauck *et al.* 1998; Babcock *et al.* 1999; Auster & Shackell 2000; Mangel 2000; Rosenberg 2001; Willis *et al.* 2003). These restrictions are usually intended to protect significant portions of the stocks of targeted species such that spawning events and genetic variability may be at least partially ensured (Malakoff 1997; Roberts 1998).

As well as benefits for targeted species, other important biological benefits may accrue from fishery management systems that restrict the use of certain types of fishing gear. These include the prevention of habitat degradation that inevitably accompanies the use of towed bottom-fishing gear such as trawls or dredges (Dayton *et al.* 1995; Auster & Shackell 1997; Jennings & Kaiser 1998; Norse & Watling 1999; Kaiser *et al.* 2002; Schratzberger *et al.* 2002). Benthic communities in areas that are heavily fished with towed gears tend to be less complex and have lower biomass and production than communities in areas that are not fished in this way, or are fished at low levels of effort (Jennings *et al.* 2001b; Kaiser *et al.* 2002). In contrast, benthic communities are relatively unaffected by static fishing gears (fish or crustacean pots, long-lines or anchored nets) because of the relatively small area of seabed directly affected (Kinnear *et al.* 1996; Jennings & Kaiser 1998; Eno *et al.* 2001). Hence, the use of static gears might enable some exploitation to occur without negative effects on benthic communities. Few direct comparisons exist of the long term impacts of static gears and towed gears on benthic communities (Kaiser *et al.* 2000). In addition, few studies have focussed on the implications for benthic communities of management strategies that incorporate temporal zonation of fishing effort (Sainsbury *et al.* 1997; Murawski *et al.* 2000)

The Inshore Potting Agreement (IPA) is a zoned fishery management system located off the south coast of Devon, UK (Fig. 3.1). The IPA has operated since 1978 over an area of approximately 500 km^2 to reduce conflict between different sectors of the fishing industry. The IPA includes areas for the exclusive use of static gears (principally crab pots), and areas for seasonal static-gear use. Towed-gear fishers are able to work in seasonal areas during periods when these are free from static gears (Chapter 2, this thesis). The success and longevity of the IPA provides a unique opportunity to investigate the characteristics of benthic communities that have been subjected to varying levels of towed and static fishing gear use.

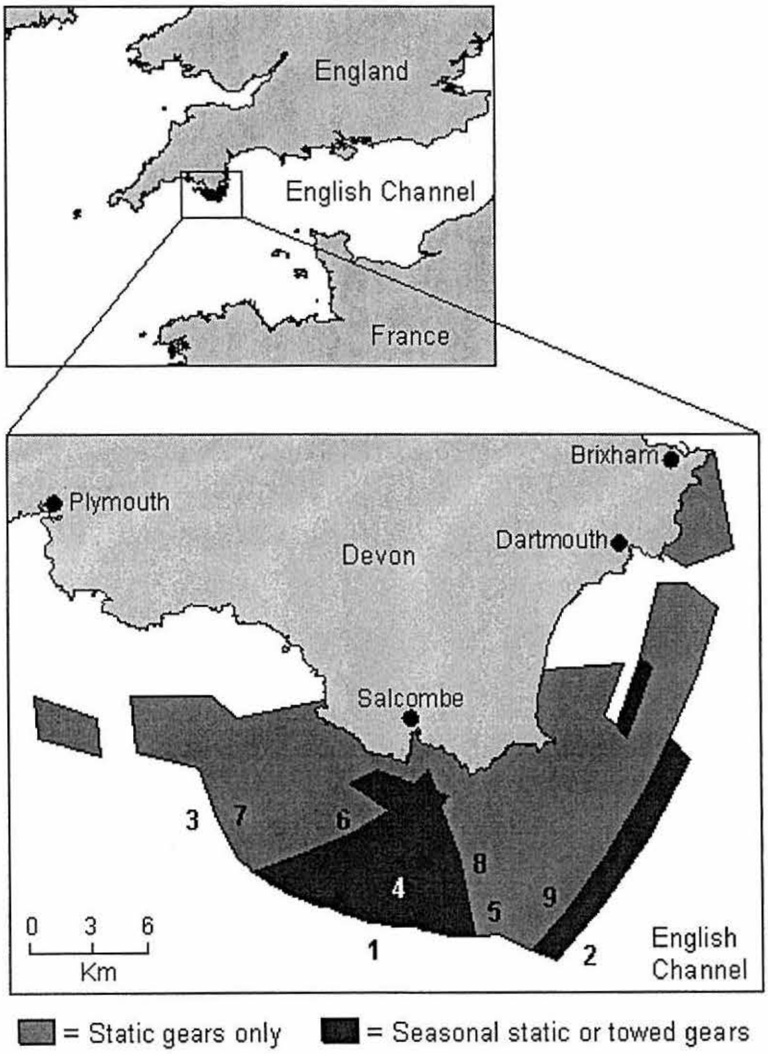

Figure 3.1: The location of the Inshore Potting Agreement. Shaded areas denote the officially recognised fishery management system. Numbers denote locations of sampling sites in areas subjected to different fishing regimes. Sites 1,2,3: 'trawl', 4,5: 'seasonal', 6,7: 'ex-trawl' and 8,9: 'untrawled'.

Here, the IPA was used to investigate the impact of different commercial fishing regimes on benthic communities. Two factors were of particular interest in assessing species richness and biomass of the benthic community: first, the effect of static-gear fishing in comparison to towed-gear fishing; second, the effect of annual, seasonal rotation of fishing regime.

METHODS

Fishers of the South Devon and Channel Shellfishermen's Association Ltd. were approached in summer 2002 to provide details on the extent to which towed gears had been used in the vicinity of areas where they maintained static-gear territories. Charts of the IPA were provided to 22 static-gear fishers, who were asked to indicate areas where towed gears had never been used, areas where towed gears had been used, but not within the previous year, areas where towed gears were used seasonally on an annual basis, and areas where towed gears were used regularly. Importantly, these sites did not have to correspond exactly with the boundaries of the IPA management system, as towed-gear fishers occasionally infringed the IPA (Chapter 2, this thesis). Without the input of fishers, these infringements could have unknowingly confounded attempts to attribute different fishing regimes to sites. Towed-gear fishers were not consulted on the use of towed gears in the IPA, as it was thought unlikely that they would cooperate honestly, or be willing to incriminate other fishers operating in static-gear areas. In contrast, it was considered that static-gear fishers had no motivation to provide misleading information regarding the illicit use of towed gears inside static-gear areas.

In comparison to other potential sources of data on the use of towed-gears (i.e. fisheries enforcement agency over-flight data or GPS monitoring), fishers' information was considered to provide the most detail and accuracy in the area of the IPA. This was because the small spatial variation between sites and the lack of daily agency monitoring precluded the use of fisheries over-flight data. Furthermore, the small boats that prosecute towed-gear fisheries within 6 miles of the UK coastline are not required to carry Differential GPS automated position recorders. Importantly, IPA static-gear fishers operate in small territories, and they typically maintain precise knowledge of all fishing activities in these areas because of conflict issues arising with other fishers (Chapter 2, this thesis). Finally, charts were cross-referenced between fishers to avoid potential sources of deliberate bias and to corroborate information on towed-gear use at the sites selected for sampling.

Using information provided by fishers, 9 sites that had been impacted by fishing gears to varying degrees, and situated as close to each other as possible, were selected and sampled in August 2002 (Fig. 3.1). Two of these sites were reported as never having been fished with towed gears (termed 'untrawled' sites), and two sites were last used by towed-gear fishers 18 months and 2 years prior to sampling (termed 'ex-trawl'). Two of the other sites selected were seasonally trawled on an annual basis and were last used by towed-gear fishers 3 months and 6 months prior to sampling (termed 'seasonal' sites). Three further sites, located just outside the IPA system, were regularly used by the towed-gear fleet (termed 'trawl' sites) (Table 3.1).

Table 3.1: Environmental characteristics and fishing history for Inshore Potting Agreement sample sites.

Site	Fishing Regime	Mean Depth (m)	Total Tow Length (m)	Substrate Grade (Φ)	Fisher Information
1	Trawl	66.4	4548	0.00	Towed gears used regularly, all year round
2	Trawl	64.4	3951	0.00	Towed gears used regularly, all year round
3	Trawl	56.6	4659	0.00	Towed gears used regularly, all year round
4	Seasonal	63.8	4059	2.81	Towed gears used annually Feb-May Towed gears last used 3 months previously
5	Seasonal	66.0	4635	2.81	Towed gears used annually Jan-Feb. Towed gears last used 6 months previously
6	Ex-Trawl	49.8	3888	3.81	Towed gears used 18 months previously
7	Ex-Trawl	49.2	3963	1.00	Towed gears used 22 months previously
8	Untrawled	62.3	5340	2.58	Only static gears used in living memory
9	Untrawled	65.7	4632	3.32	Only static gears used in living memory

No data on the precise frequency of fishing gear use at each sampling site was obtained for this study. However, little space exists inside the IPA for additional static gear (Chapter 2, this thesis), and so it was assumed that crab pots were regularly fished at the 'untrawled' and 'ex-trawl' sites, and at the 'seasonal' sites during periods when these were accessible. Due to the perceived catch benefits of operating in the proximity of the IPA, it was reported that the perimeter of the IPA, and hence the 'trawl' sites, were targeted by the towed-gear fleet throughout the year. 'Seasonal' sites were reported to be targeted regularly by the towed-gear fleet when accessible. Both of the 'ex-trawl' sites had been fished regularly over a period of one-two months. At the time of sampling, the 'untrawled', 'ex-trawl' and 'seasonal' sites were occupied by lines of crab and lobster pots.

The substratum at each site was assessed visually, as the mixed coarse substrata encountered within the IPA precluded the use of grab-sampling. At each site, a video camera was lowered to the seabed and suspended from the R.V. Prince Madog for 30 minutes. During this period, the vessel was allowed to drift with the tide, so that the camera moved across the seabed. iMovie© V.1.0.2 video software was used to capture a still image on every occasion that the camera came to rest on the seabed during each 30 minute deployment. The substratum type in 20 images, selected at random from each site, was allocated a score based on the Φ scale (Buchanan 1984). Using a scale bar mounted on the camera frame, scores of between 0 and 5 were allocated for sediments that varied from sand particles of less than 2 mm diameter to gravel of approximately 30 mm diameter (Table 3.1). Water depth was obtained at the start and end of every tow using the ship's echo-sounder. The mean water depth at each site was calculated as the average of the start and finish depths recorded for all tows at each site (corrected to chart datum). The mean depth across all sites was 60.5 m ±1.3 m S.E. (Table 3.1).

Following the video surveys, three replicate tows were undertaken at each site using a gang of four Newhaven commercial scallop dredges (each dredge was 850 mm wide). To maximise the collection of smaller organisms, two of the dredges were fitted with 50 mm belly rings and teeth positioned 35 mm apart (termed 'scientific' dredges). The other two dredges had 100 mm belly rings and teeth positioned 85 mm apart (termed 'standard' dredges). Tows were limited to 10 minutes bottom time, and were conducted perpendicular to the direction of the main tidal flow to run parallel to any lines of static gear. The distance the dredges travelled over the ground was calculated from DGPS positions recorded at the time the trawl winch was stopped at the beginning of each tow, and at the moment hauling commenced. Only great scallops *Pecten maximus* were collected from the two 'standard' dredges, whilst benthos (benthic macro-epifauna) for the community analyses was sampled only from the starboard-most 'scientific' dredge. This dredge was chosen randomly to be used for sampling on the first tow, and then to ensure consistent catchability it was used on all subsequent tows. The catch from the 'scientific' dredge was sorted and identified, and the shells of hermit crabs (Paguridae) and other substratum fragments were removed before all species were separated, patted dry with paper and then weighed on a motion-compensated balance (±1 g). Individuals of each species were not weighed separately due to the difficulty of counting colonial animals.

STATISTICAL METHODS

Biomass data for each species was standardized to the mean total tow length at all sites of 4408 m ±160 m S.E. (Table 3.1). The species richness per tow was not standardised. Data for fish species incidentally caught were excluded from any analyses.

UNIVARIATE ANALYSES

Univariate statistical analyses of the biological data were carried out to determine gross differences in species richness and the biomass of the benthic community between sites subjected to different fishing regimes. All univariate statistics were conducted using Minitab V.13.2. Biomass data for each species and the total numbers of species collected at each site were transformed ($x' = \log_{10}(x+1)$) to stabilise variance. Nested (fishing regime x site(fishing regime)) general linear model (GLM) ANOVA were then undertaken on these data. This model accounts for the enforced lack of orthogonality in the survey design (i.e. the design is not balanced with all treatments (fishing impacts) occurring at all sites) (Underwood 1997). Bonferroni pair-wise multiple comparison tests were undertaken when significant differences were found between the fishing regimes. In a further analysis, benthic taxa were then categorised as either 'attached' or 'free' according to their adult life mode. 'Attached' species included bryozoans, hydrozoans and other species that are fixed permanently to the substratum. 'Free' taxa included crabs, starfish, bivalves and other species that are able to move freely (Appendix 1). For both life modes, nested GLM ANOVA were undertaken on the numbers of species and biomass of species collected at each site. Bonferroni pair-wise multiple comparisons were also undertaken when significant differences were found between fishing regimes. Finally, nested GLM ANOVA and Bonferroni pair-wise multiple comparisons were undertaken on $\log_{10}(x+1)$ transformed data for the numbers of scallops greater than 100 mm shell height (the minimum legal-landing size in Devon waters) collected at each site using the two 'standard' dredges.

MULTIVARIATE ANALYSES

Multivariate statistical analyses of the biological data were carried out to determine differences in the structure of the benthic community between sites subjected to different fishing regimes. All multivariate analyses were performed using the PRIMER© V.5 software package. Data were initially averaged over the three tows conducted at each site. To examine the overall similarity of the benthic communities between sites, a non-metric multidimensional scaling (MDS) ordination plot was created from the community biomass data. This used the Bray-Curtis index of similarity on square root transformed data (the default PRIMER transformation to down-weight the contribution of common species in relation to rarer ones), and the group average linkage technique. Because of the low number of replicate sites, an *a priori* one-way analysis of similarity (ANOSIM), a multivariate analogue of ANOVA, was then performed on aggregated data. The 'untrawled' and 'ex-trawl' sites were grouped as 'inside' sites, and the 'seasonal' and 'trawled' sites were grouped as 'outside' sites. A SIMPER analysis was conducted to determine the species that contributed most to the within-fishing-regime similarities and between-fishing-regime dissimilarities. Finally, a RELATE test was conducted to determine the extent to which patterns observed in the biological community were correlated with abiotic variables resulting from the survey design. This test undertook an element-by-element correlation of a similarity matrix constructed from the square root transformed community data, with a second similarity matrix constructed from data for the tow length, water depth and substratum type at each site.

RESULTS

UNIVARIATE ANALYSES

Significant differences were determined among different fishing regimes for both the mean total species richness and the mean total biomass of the benthic community (Table 3.2). Pair-wise comparisons showed that a greater total species richness and community biomass was observed at the 'ex-trawl' and 'untrawled' sites than at the 'trawl' or 'seasonal' sites (Table 3.3). The total community biomass was also significantly greater at the 'untrawled' sites in comparison to the 'ex-trawl' sites. Pair-wise comparisons of total species richness or community biomass were not different between other combinations of fishing regimes.

Table 3.2: Nested General Linear Model ANOVA results for comparisons of a) total number of species, and b) biomass of species (kg) per standardised sample area, of the total benthic community, 'attached' species, and 'free' species observed at sites subjected to different fishing regimes. Bold italics indicate significant comparisons.

a) number of species

Total

Source	DF	Adj MS	F	*P*
Fishing regime	3	0.25	25.52	***<0.001***
Site (Fishing regime)	5	0.03	2.96	***0.040***
Error	18	0.01		
Total	26			

Attached

Source	DF	Adj MS	F	*P*
Fishing regime	3	0.14	9.49	***0.001***
Site (Fishing regime)	5	0.06	3.64	***0.019***
Error	18	0.02		
Total	26			

Free

Source	DF	Adj MS	F	*P*
Fishing regime	3	0.30	35.27	***<0.001***
Site (Fishing regime)	5	0.05	5.84	***0.002***
Error	18	0.01		
Total	26			

b) biomass

Total

Source	DF	Adj MS	F	*P*
Fishing regime	3	0.72	42.63	***<0.001***
Site(Fishing regime)	5	0.04	2.11	0.111
Error	18	0.02		
Total	26			

Attached

Source	DF	Adj MS	F	*P*
Fishing regime	3	2.29	17.13	***<0.001***
Site(Fishing regime)	5	0.55	4.09	***0.012***
Error	18	0.13		
Total	26			

Free

Source	DF	Adj MS	F	*P*
Fishing regime	3	1.49	33.99	***<0.001***
Site(Fishing regime)	5	0.08	1.87	0.150
Error	18	0.04		
Total	26			

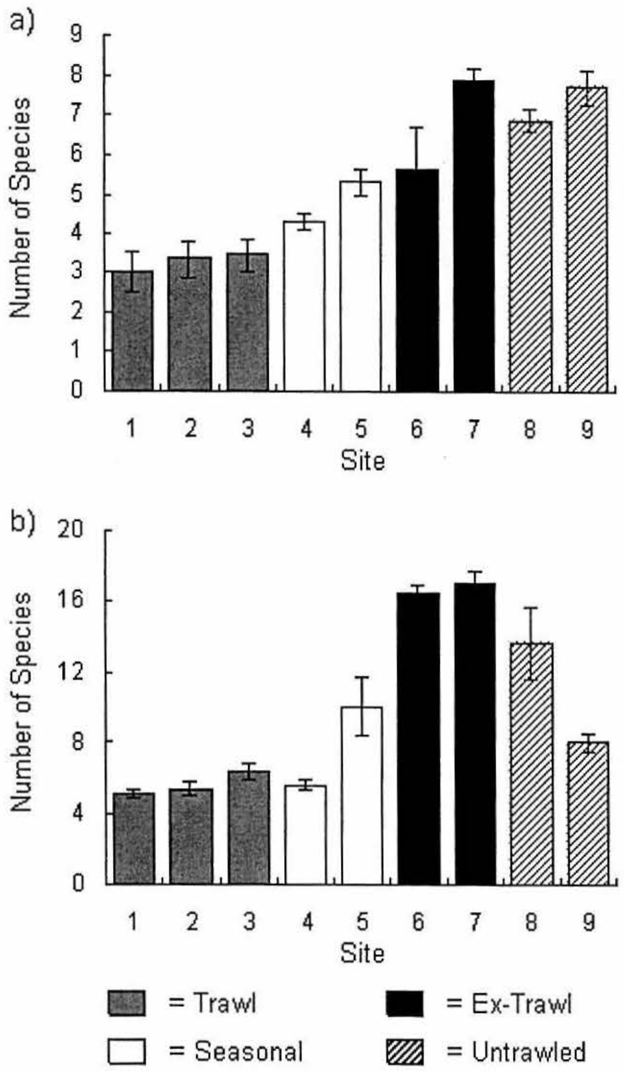

Figure 3.2: Mean (±1 S.E.) of a) total number of 'attached' species, and b) number of 'free' species observed at sites subjected to different fishing regimes.

An examination of the life mode components of the benthic community revealed significant differences among fishing regimes for the mean number of species of 'attached' and 'free' animals (Table 3.2a, Fig 3.2). Pair-wise comparisons showed that the mean number of 'attached' species at the 'ex-trawl' and 'untrawled' sites were significantly greater than that at the 'trawl' sites (Table 3.3a). In addition, the mean number of 'free' species at the 'ex-trawl' and 'untrawled' sites were significantly greater than at the 'trawl' and 'seasonal' sites (Table 3.3a). There were also significant differences among fishing regimes in the mean biomass of 'attached' and 'free' species (Table 3.2b, Fig. 3.3a,b). Pair-wise comparisons showed that the mean biomass of 'attached' species at the 'untrawled' sites was significantly greater than at other fishing regimes (Table 3.3b). The biomass of 'attached' species at 'trawl' sites was also greater than at the 'seasonal' sites. In addition, the mean biomass of 'free' species at the 'ex-trawl' and 'untrawled' sites were significantly greater than at the 'trawl' and 'seasonal' sites. Other comparisons among fishing regimes of the mean number or biomass of 'attached' or 'free' species did not differ significantly.

Table 3.3: Bonferroni multiple comparisons of differences in a) total number of species, and b) biomass of species (kg) per standardised sample area of the total benthic community, 'attached' species, and 'free' species observed between sites subjected to different fishing regimes. Bold italics indicate significant comparisons.

a) number of species

Total	Seasonal	Ex-Trawl	Static
Trawl	0.519	***<0.001***	***<0.001***
Seasonal		***<0.001***	***0.003***
Ex-Trawl			1.000

Attached	Seasonal	Ex-Trawl	Static
Trawl	0.088	***0.017***	***<0.001***
Seasonal		1.000	0.252
Ex-Trawl			0.922

Free	Seasonal	Ex-Trawl	Static
Trawl	1.000	***<0.001***	***<0.001***
Seasonal		***<0.001***	***<0.001***
Ex-Trawl			0.165

b) biomass

Total	Seasonal	Ex-Trawl	Static
Trawl	0.347	***<0.001***	***<0.001***
Seasonal		***0.012***	***<0.001***
Ex-Trawl			***0.002***

Attached	Seasonal	Ex-Trawl	Static
Trawl	***0.012***	0.070	***<0.001***
Seasonal		1.000	***0.030***
Ex-Trawl			***0.006***

Free	Seasonal	Ex-Trawl	Static
Trawl	0.459	***<0.001***	***<0.001***
Seasonal		***0.004***	***<0.001***
Ex-Trawl			0.099

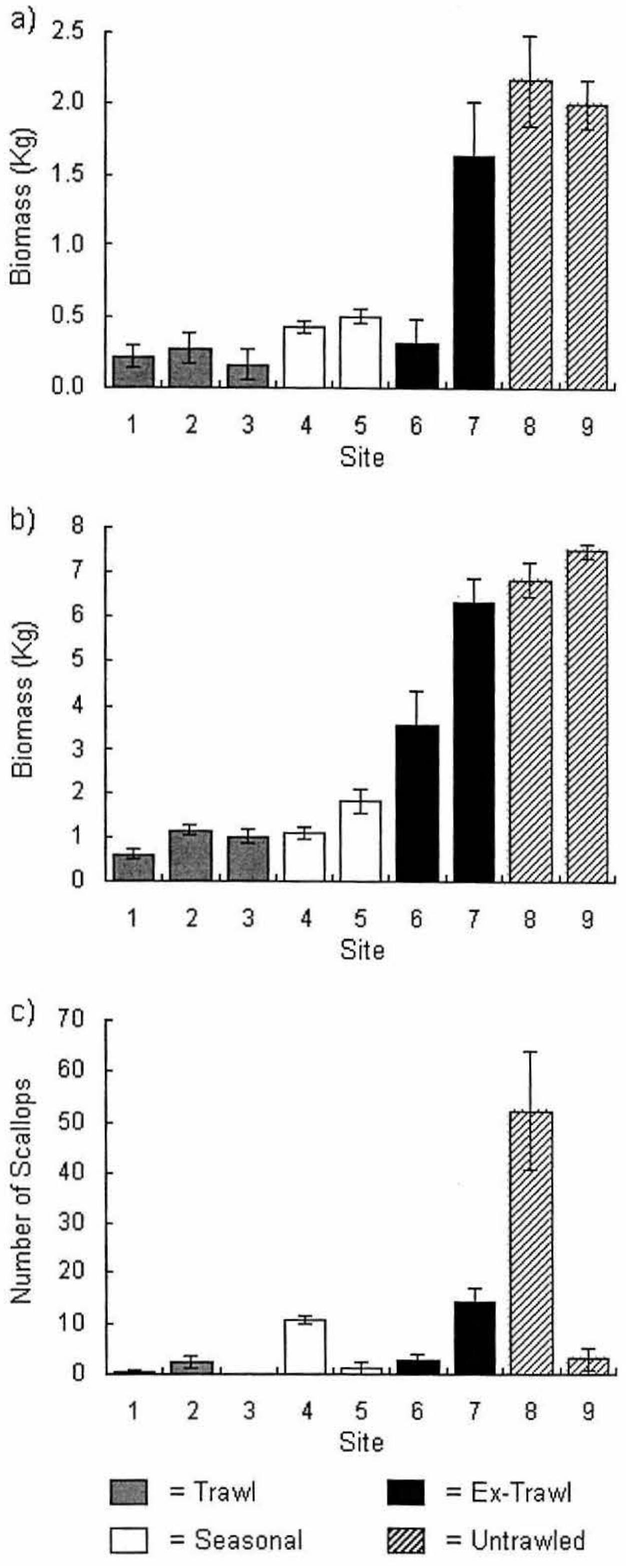

Figure 3.3: Mean (±1 S.E.) of a) biomass of 'attached' species, b) biomass of 'free' species, and c) total number of legally-sized scallops observed per standardised sample area at sites subjected to different fishing regimes.

The number of legal-sized scallops caught in the 'standard' dredges differed significantly among areas subjected to different fishing regimes (ANOVA, $F_{3,26}$= 9.40, *P*= 0.001) (Fig. 3.3c). Pair-wise comparisons revealed that fewer scallops were caught at the 'trawl' sites than at either the 'ex-trawl' (*P*= 0.009) or 'untrawled' sites (*P*= <0.001). The comparisons of the numbers of scallops caught at sites subjected to other fishing regimes were not significantly different.

MULTIVARIATE ANALYSES

The relative similarity between the observed composition of the species assemblage of each site is represented by the MDS ordination plot of square root transformed species data (Fig. 3.4). The 'untrawled' and 'ex-trawl' sites grouped discretely, whilst the groupings of the 'trawl' and 'seasonal' sites were less well defined. However, *a priori* defined aggregations of 'inside' and 'outside' sites were significantly different at the 10% level (ANOSIM, r= 0.375, *P*= 0.06). SIMPER analysis determined that the overall mean similarities within the 'trawl', 'seasonal', 'ex-trawl' and 'untrawled' sites were 10.5%, 16.8%, 24.5% and 40.0% respectively. The greatest overall mean dissimilarity occurred between the 'trawl' and 'untrawled' sites (89.4%) and the lowest overall mean dissimilarity was between the 'trawl' and 'seasonal' sites (73.9%).

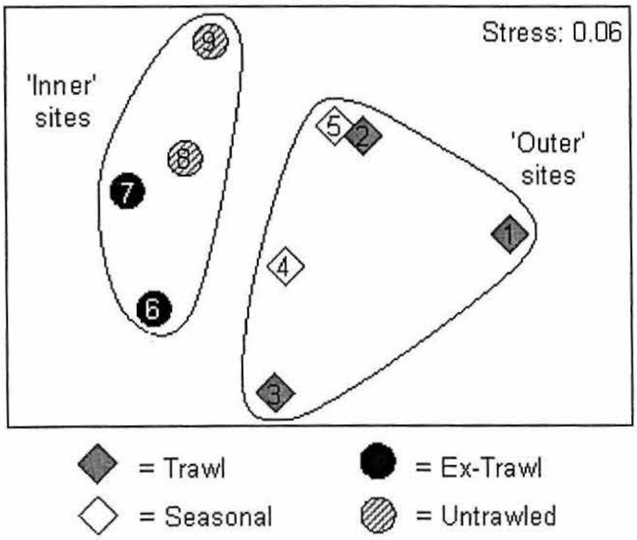

Figure 3.4: Multi-Dimensional Scaling ordination plot showing square-root transformed community biomass data for IPA sites subjected to different fishing regimes (numbers indicate site). 'Inner' and 'Outer' groupings indicate *a priori* defined site groupings used in the associated Analysis of Similarity (ANOSIM) test.

Common taxa that made the greatest contribution to the similarities within sites of all fishing regimes were the attached colonial anthozoan *Alcyonium digitatum*, hydroids, and the tube building bristle worm *Chaetopterus variopedatus* (Table 3.4). The sea urchin *Echinus esculentus* was also found frequently at the 'ex-trawl' and 'untrawled' sites. However, this species contributed greatly to the between-fishing regime dissimilarities because it was not recorded at the 'trawl' or 'seasonal' sites (Table 3.5). *Alcyonium digitatum* also contributed greatly to the dissimilarities between these combinations of fishing regimes because relatively large quantities of this species were found at the 'ex-trawl' and 'untrawled' sites. The brittle star *Ophiothrix fragilis* was only found in abundance at the 'ex-trawl' sites, and made the greatest contribution to the dissimilarities between these sites and those of the other fishing regimes.

Table 3.4: SIMPER results: relative contribution to within site similarities of the four most common taxa observed at each site.

	Mean Abundance (g)	Mean Similarity	Contribution (%)	Cumulative Contribution (%)
Trawl				
Hydroids	18.4	2.59	24.6	24.6
Atelecyclus rotundatus	48.3	2.41	22.9	47.5
Nemertesia	15.6	1.07	10.1	57.6
Asterias rubens	10.6	1.01	9.6	67.2
Seasonal				
Alcyonium digitatum	222.8	6.42	38.3	38.3
Chaetopterus variopedatus	53.0	2.86	17.1	55.4
Hydroids	23.4	2.27	13.6	69.0
Aequipecten opercularis	18.9	1.19	7.1	76.1
Ex-Trawl				
Marthasterias glacialis	649.1	8.02	32.8	32.8
Echinus esculentus	813.9	7.15	29.2	61.9
Aequipecten opercularis	777.4	2.85	11.6	73.5
Hydroids	123.4	2.53	10.3	83.8
Untrawled				
Alcyonium digitatum	1583.7	25.96	64.9	64.9
Echinus esculentus	589.6	6.40	16.0	80.9
Maia squinado	104.5	1.84	4.6	85.5
Chaetopterus variopedatus	107.4	1.60	4.0	89.5

Table 3.5: SIMPER results: relative contribution to between site dissimilarities of the four most dissimilar species observed between each site.

	Mean Abundance Regime 1 (g)	Mean Abundance Regime 2 (g)	Mean Dissimilarity	Contribution (%)	Cumulative Contribution (%)
Trawl v Seasonal					
Alcyonium digitatum	108.9	222.8	15.59	21.1	21.1
Nemertesia	15.6	186.2	12.48	16.9	38.0
Marthasterias glacialis	158.5	92.5	12.44	16.8	54.8
Pecten maximus	62.9	42.2	5.47	7.4	62.2
Trawl v Ex-Trawl					
Aequipecten opercularis	41.0	777.4	24.70	28.5	28.5
Echinus esculentus	0.0	813.9	18.03	20.8	49.3
Marthasterias glacialis	158.5	649.1	13.10	15.1	64.4
Chaetopterus variopedatus	3.5	203.9	4.17	4.8	69.2
Trawl v Untrawled					
Ophiothrix fragilis	0.0	1782.4	27.70	31.0	31.0
Alcyonium digitatum	108.9	1583.7	26.14	29.2	60.2
Echinus esculentus	0.0	589.6	10.75	12.0	72.2
Nemertesia	15.6	309.1	5.57	6.2	78.4
Seasonal v Ex-Trawl					
Aequipecten opercularis	18.9	777.4	23.89	27.7	27.7
Echinus esculentus	0.0	813.9	17.43	20.2	47.9
Marthasterias glacialis	92.5	649.1	12.04	14.0	61.9
Alcyonium digitatum	222.8	3.7	5.77	6.7	68.6
Seasonal v Untrawled					
Ophiothrix fragilis	6.6	1782.4	27.09	33.8	33.8
Alcyonium digitatum	222.8	1583.7	23.49	29.3	63.1
Echinus esculentus	0.0	589.6	10.47	13.0	76.1
Nemertesia	186.2	309.1	4.80	6.0	82.1
Ex-Trawl v Untrawled					
Ophiothrix fragilis	86.2	1782.4	19.76	25.5	25.5
Alcyonium digitatum	3.7	1583.7	19.11	24.6	50.1
Aequipecten opercularis	777.4	10.4	10.12	13.1	63.2
Echinus esculentis	813.9	589.6	6.61	8.5	71.8

The RELATE analysis determined that there was no similarity in the patterns observed between the benthic community, and the tow length, substratum type and water depth at each site (Rho= -0.116, *P*= 0.73). This result indicates that the abiotic variables tested were not able to predict the variation observed in the biological community.

DISCUSSION

Comparative studies of fishing impacts are prone to the confounding effects of variables such as substratum type that may be auto-correlated with the fishing treatment. In this study, the substrata at the 'trawl' sites were less coarse than those at the sites of other fishing regimes. However, the RELATE analysis indicated that 'fishing' was the only variable that corresponded with the observed differences in the benthic communities between the sites of different fishing regimes. The inference that 'fishing' rather than 'substratum type' brought about the observed differences was further supported by our data, because whilst the substrata at the 'seasonal' and 'trawl' sites were different, the communities were almost indistinguishable. If it is assumed that the communities at the 'trawl' sites were the most impacted by commercial fishing, then the cessation of towed-gear fishing could enable the communities at all sites around the IPA to recover towards those of the 'untrawled' state.

The benthic communities in areas that had been open only to static gears in the year preceding sampling were richer and of greater biomass than those in areas that were impacted by towed fishing gears during the same period. However, the benthic communities at the 'ex-trawl' sites remained different to those at the 'untrawled' sites. The lower community biomass but greater species richness at the 'ex-trawl' sites is consistent with the 'intermediate disturbance' theory (Connell 1978). This suggests that regular trawling disturbance would result in a community dominated by a small number of rapidly colonizing and maturing species. In contrast, occasional trawling disturbance may enhance species richness because of opportunities for slower developing species to become established in addition to the fastest colonizers. In the long-term absence of vigorous disturbance at the 'untrawled' sites, a community of moderate species richness but greater biomass appears to have become dominant. This finding is not necessarily mirrored by results from other studies. For example, (Thrush *et al.* 1998) found that the an increase in trawling frequency resulted in a decrease in species richness. The present study was limited in that the dredges used would have been unlikely to sample small species consistently. If additional sampling had been conducted using fine-mesh liners inside the dredges, then it is possible that greater numbers of small species would have changed the observed pattern of benthic community richness between sites.

Arguably the most significant result from this study is that the benthic communities found at the 'seasonal' sites were almost indistinguishable from those found at the 'trawl' sites. Only the biomass of the 'attached' community was greater at the 'seasonal' sites. This indicates that in the area of the IPA, a 6 month cessation of towed-gear use is insufficient for the benthic community to recover. In contrast, some studies conducted at shallow, coastal sites have reported that the benthic communities in fishing-impacted areas recovered within a short period post-disturbance, and have suggested that natural disturbance events such as storms or tidal scour are likely to have a relatively greater impact than fishing disturbance (Currie & Parry 1996; Kaiser & Spencer 1996; Kaiser *et al.* 1998b; Collie *et al.* 2000b). However, these were experimental studies, and the reported responses of benthic communities to localised experimental fishing may not represent the effects of fishing on a large scale and regular basis that occurs by commercial fleets.

In short-term impact experiments (days-months), communities may appear to recover as a result of immigration of fauna from nearby areas, as the recovery trajectories typically described are unlikely to result from the recruitment and growth of settling larvae (Kaiser *et al.* 2002). If towed gears affect a large area, then recovery may be much slower as immigration rates are reduced, and the process of recruitment then becomes increasingly important (Jennings *et al.* 2001b). In addition, attached epibenthic species such as *Alcyonium digitatum* and *Chaetopterus variopedatus* are slow growing (Rees 1987; Newell, Seiderer & Hitchcock 1998) and may take many years to attain former biomass (i.e. the pre-fishing state). Hence, at the larger scales of operation of commercial fisheries, benthic communities may take years, decades, or even thousands of years in deep water areas, to recover (Sainsbury *et al.* 1997; Hall-Spencer & Moore 2000; Hall-Spencer, Allain & Fossa 2002).

The significantly greater biomass of attached species at the 'untrawled' sites in comparison to all other sites is of particular interest because attached epifauna act as settlement sites for many benthic species (Walters & Juanes 1993). The presence of attached epifauna has been shown to increase the survivorship of commercially targeted species including silver hake *Merluccius bilinearis* (Auster *et al.* 1997), cod *Gadus morhua* (Tupper & Boutilier 1995; Lindholm *et al.* 1999), and spiny lobster *Panulirus argus* (Herrnkind *et al.* 1999). Scallops may be the commercially targeted species most likely to benefit from the IPA, and significant increases in scallop biomass have been reported after the establishment of other closed-area systems (Turner *et al.* 1996; Brocken & Kenchington 1999; Murawski *et al.* 2000). A number of factors may be implicated in this effect. Primarily, in addition to being captured, scallops may be physically damaged when contacted by towed gears, thereby reducing survivorship or requiring energy to be directed towards repair (Caddy 1973; Brand *et al.* 1980). The presence of attached epifauna has also been identified as a critical spat settlement cue for a number of scallop species (Dare & Bannister 1987; Minchin 1992); (Stokesbury & Himmelman 1995). Finally, fishery collapses of similar sessile species have been attributed to a reduction in the density of adults, so that mature individuals were too isolated to reproduce successfully (Tegner, Basch & Dayton 1996; Malakoff 1997; Orensanz *et al.* 1998; Roberts & Hawkins 1999; Jennings 2000). Hence, significant cumulative benefits may accrue for the IPA scallop population from greater reproductive output, spat settlement and subsequent juvenile survival. High density patches of scallops were present at the 'ex-trawl' and 'untrawled' sites within the IPA. However, the implications of these high density patches for the recruitment to the surrounding fishery remain unknown.

Within the IPA system, some areas are rotated seasonally to permit fishers from different sectors equitable access to resources (Chapter 2, this thesis). Area rotations present a potential problem for the maintenance of benthic communities because towed-gear fishers return regularly to areas that previously produced good catches and are known to be clear of seabed obstructions that could damage the fishing gear (Rijnsdorp *et al.* 1998). Area rotations may therefore relocate fishing effort by forcing fishers to operate away from favoured sites. For example, large scale seasonal closures in 2000, 2001 and 2002 in the North Sea, that were designed to protect spawning aggregations of cod, forced fishers away from traditional grounds. (Dinmore *et al.* 2003)) argued that the result of this fishery displacement may have had greater long-term impacts on fish-stocks and benthic communities, because fishers were forced to operate in areas that had rarely or never been fished before, than if the fleet had simply been allowed to continue operating in traditional locations. However, the greatest impact on the production and biomass of epibenthic communities occurs within the first few passages of towed, demersal gears (Sainsbury *et al.* 1997; Jennings & Kaiser 1998; Jennings 2000). Hence, in open-access systems where fishers are able to target virgin grounds, stable benthic communities may be impacted significantly by even single passes with towed gears.

Preventing towed-gear fleets from operating in closed-areas over sufficiently long periods has the potential to allow benthic communities in those areas to recover and be maintained. Findings from this study suggest that the cessation of towed-gear fishing in regions similar to those represented by the IPA, must be of a duration longer than two years if benefits for the benthic community are to accrue. A five year closure on George's Bank, Canada, resulted in significant recovery of the benthic community, including target species such as yellowtail flounder *Limanda ferruginea* and sea scallops *Placopecten magellanicus* such that a rotating closure system was subsequently proposed to increase fishery production (Murawski *et al.* 2000).

CONCLUSIONS

Fishers may object to the creation of permanent marine protected areas because harvestable stocks can move from place to place, and from season to season. In contrast, zoned management systems allow fishers from some sectors of the fishing industry to maintain access to marine resources, whilst having the potential to ensure that sensitive or important habitats, and a significant portion of targeted stocks, remain protected. The argument for adopting zoned systems will be strengthened if it can be shown that these regimes can provide economic benefits to local communities that depend on fishing, whilst helping to achieve habitat and stock management goals. However, if area rotations are incorporated into management plans, the length of time between switching usage from one area to another must be sufficient for the biomass and diversity of benthic communities to recover. This time period may need to be much longer than is predicted by benthic recovery trajectories constructed from short-term experimental fishing (Collie *et al.* 2000b), and will depend on factors that include the depth, tidal regime, susceptibility to weather, and substratum and fishery types (Dayton *et al.* 1995; Kaiser *et al.* 2002). In the present study, a cessation of towed-gear fishing for a 2 year period was insufficient for benthic communities to recover to the point that they were indistinguishable from communities found in adjacent areas that had been exclusively subjected to a static-gear fishing regime (i.e. no towed gear impacts). These results are important for fishery managers given the current drive for using spatial and temporal restrictions on fishing effort as fishery management tools.

CHAPTER 4

CHRONIC FISHING DISTURBANCE REDUCES REPRODUCTIVE OUTPUT

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4: CHRONIC FISHING DISTURBANCE REDUCES REPRODUCTIVE OUTPUT

SUMMARY

Marine Protected Areas (MPAs) are increasingly advocated as an essential management tool to ensure the future sustainable use of marine resources. Whilst the beneficial effects of MPAs are well documented in tropical and reef systems, as yet these effects are not well demonstrated in temperate waters. The Inshore Potting Agreement is a unique fishery management system located off the south coast of the UK. The system operates as a form of MPA by preventing the use of towed bottom fishing gears in a 350 km^2 inshore area. This study used the Inshore Potting Agreement to determine the effect that chronic towed bottom fishing had on the reproductive potential of great scallops *Pecten maximus*.

Scallops within areas protected from towed bottom fishing gear had gonads that were 19% to 24% heavier than those in fished areas, whilst other body characteristics were similar. The scallops within the protected area also occurred at a much higher abundance, hence the differences in gonad size occurred despite greater intra-specific competition. These results translated into a 9.1 fold increase in gonad density in legal-sized scallops between 'no-fishing' and 'fished' sites. The results provide compelling evidence that the use of towed bottom fishing gear can suppress the reproductive potential of intended target species.

INTRODUCTION

Ecological benefits conferred by marine protected areas are typically measured as an increase in the biomass and abundance of species that that occur within the protected area (Jennings 2000; Halpern 2003). These effects have been demonstrated for a range of phyla including fish and molluscs (Gell & Roberts 2003). However, in most cases, the species that demonstrated a positive response to protection from fishing were tropical species that were strongly associated with a specific habitat such as coral or rock reefs (Roberts & Polunin 1991; Jennings, Grandcourt & Polunin 1995; Russ & Alcala 1996a). In temperate systems, where most fish species have much greater ranges and utilise a variety of habitats, there is some doubt that MPAs would out-perform adequate fishing effort control as a conservation measure (Horwood 2000; Jennings 2000; Steele & Beet 2003). As such, temperate species with a sedentary life-style, such as bivalve molluscs or certain crustacea, are those most likely to benefit from the exclusion of towed bottom fishing gear activities from discrete areas of the sea. For example, a fourteen fold increase in scallop biomass was demonstrated after a five year fishery exclusion off the northeast coast of the USA (Murawski *et al.* 2000).

In addition to removing harvesting pressure on the larger body-sized individuals within a population, the exclusion of towed bottom fishing gear also eliminates the associated negative ecological effects on non-target benthic biota and seabed habitats (Jennings & Kaiser 1998). Benthic communities in areas that are regularly fished with towed bottom gears tend to be less complex, and have lower biomass and production, than communities in areas that are not fished with towed gears (Sainsbury *et al.* 1997; Jennings & Kaiser 1998; Kaiser *et al.* 2002). However, the recruitment and subsequent survival of commercially targeted benthic species may also be dependent on habitat complexity (Walters & Juanes 1993; Herrnkind *et al.* 1999; Lindholm *et al.* 1999). The net accrued benefits of MPAs are therefore considered to be an increase in the proportion and density of large-bodied mature adults that have higher fecundity, resulting in spill-over into the adjacent fisheries, and greater future recruitment as a result of higher population fecundity (Gell & Roberts 2003).

The Inshore Potting Agreement (IPA) is a fishery management system located off the coast of south Devon, UK (Fig. 4.1). The IPA was established in 1978, but was originally supported only by a voluntary agreement between different sectors of the fishing industry. The system was enshrined in Government legislation in 2002, and operates as a form of MPA by preventing the use of towed bottom-fishing gear in a 350 km² area (Chapter 2, this thesis). This main area is used by static gear fishermen who mainly use pots to target crabs and lobster. A further 150 km² area is open seasonally to fishermen who use towed bottom fishing gear (trawls and scallop dredges) to target demersal fish and scallops. Fishing with towed bottom gear occurs throughout the year immediately adjacent to the IPA. The system has therefore functioned to subject areas off the UK coast to a range of towed bottom fishing gear regimes.

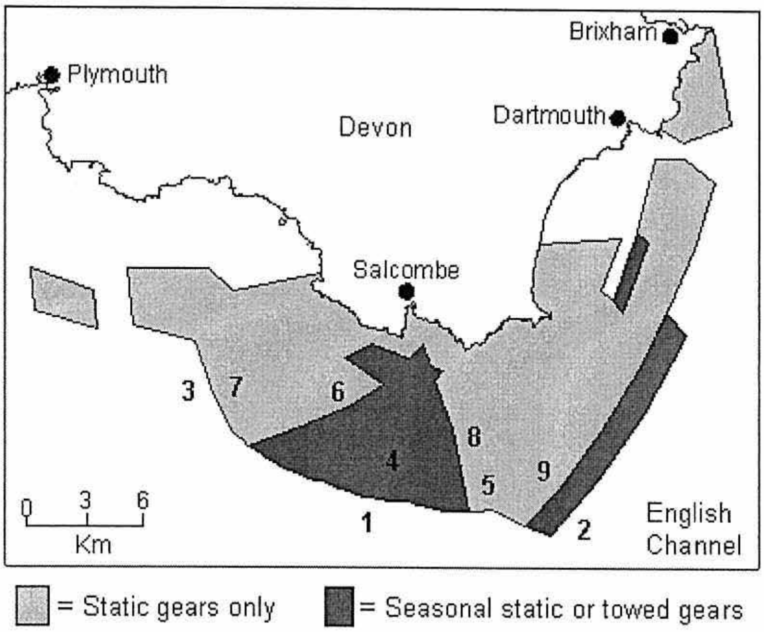

Figure 4.1: The Inshore Potting Agreement, located off the south coast of Devon, England. Shaded areas denote the officially recognised fishery management system. Numbers denote locations of sampling sites in areas subjected to different fishing regimes: sites 1,2,3,4,5 'fished', 6,7: 'ex-fished' and 8,9: 'no-fishing' for at least 25 years.

This study examined the effects of the exclusion of towed bottom fishing gear and harvesting on great scallops *Pecten maximus* found off the south Devon coast. The abundance and size of scallops, and their allocation of tissue-mass to gonads or soma, were determined between areas of the Inshore Potting Agreement subjected to different towed bottom fishing gear regimes.

METHODS

The history of towed bottom fishing gear use at sites within the IPA was ascertained from a survey of fishermen of the South Devon and Channel Shellfishermen's Association Ltd. This survey was important because, in some cases, the fishing regime described by the fishermen did not match the supposed conditions of the IPA. This was because towed-gear fishermen occasionally infringed the restrictions of the system in order to exploit the benthic resources in static-gear only areas. However, it was considered that the information supplied by the static-gear fishermen in regard of towed-gear use was accurate because those individuals maintained precise knowledge of fishing activities within small territories, and because static-gear fishermen had nothing to gain or lose by providing false information.

Following the survey of fishing history, scallops were collected from 9 sites within and around the IPA that had been subjected to a range of different fishing regimes (Fig. 4.1). These regimes were, i) fished regularly or seasonally with towed gears (termed 'fished' sites), ii) fished with towed gears previously but only with static gears 18-24 months prior to sampling (termed 'ex-fished' sites, and iii) fished with static gears only (termed 'no-fishing' sites) (Table 4.1). At each sample site, three replicate tows, each of 10 minutes duration bottom-time, were made with a gang of two Newhaven scallop dredges. These dredges had 100mm belly rings.

Table 4.1: Depth and fishing history of Inshore Potting Agreement sample sites.

Site	Fishing Regime	Mean Depth (m)	Fishermen's Information
1	Fished	66.4	Towed gears used regularly, all year round
2	Fished	64.4	Towed gears used regularly, all year round
3	Fished	56.6	Towed gears used regularly, all year round
4	Fished	63.8	Towed gears used annually Feb-May Towed gears last used 3 months previously
5	Fished	66.0	Towed gears used annually Jan-Feb. Towed gears last used 6 months previously
6	Ex-Fished	49.8	Towed gears used 18 months previously
7	Ex-Fished	49.2	Towed gears used 22 months previously
8	No Fishing	62.3	Only static gears used in living memory
9	No fishing	65.7	Only static gears used in living memory

Sample tow lengths were calculated from GPS position recordings, taken at the time the trawl winch stopped at the beginning of each tow, and again at the point at which the winch was started at the end of each tow. The abundance of scallops at each site was standardised to the mean total tow length at each site of 4408 m ±160 m S.E. To estimate gonad production per unit area at different sites, swept area for the gear was estimated from the mean tow length and using 1.7m as the width of the dredge gang. Scallop density at each site was and then converted to numbers per Hectare.

The shell height and clean shell dry weight (right valve mm and g, respectively) of all scallops was determined, and the adductor muscle and gonad were dissected out and returned to the laboratory preserved in 4% buffered formalin in seawater. The adductor muscle was chosen because it is used to close the valves of the shell, which is the scallop's primary defence mechanism against their main predator the common starfish *Asterias rubens.* The dry weights of these tissues were ascertained by drying to constant weight in an oven set at 90°C, and condition indices of flesh weight to shell weight and gonad weight were calculated to standardise for differences in body size-range that might occur among the different fishing treatments. All scallops were aged from annual growth checks on the shells using the methodology of Mason (1957), after the valves had been cleaned by soaking in mild household bleach solution for two days to remove dirt.

Data were subjected to either ANOVA or t-tests, after testing that the data met the appropriate assumptions. At each site, catch abundance of i) all scallops, and ii) scallops above the minimum landing size (100 mm shell height), were standardized to Log_e numbers per hectare. These data were then tested for significant differences among fishing regimes using a nested ANOVA with 'sample site' nested within 'fishing regime'. The amount of rock and dead shell (kg of inert material) collected at each site was also compared in the same way.

FURTHER ANALYSES

Subsequent to the initial analyses, dry weights of the shell, adductor muscle and gonad of only the legal-sized scallops were compared against shell height between just the 'no-fishing' and 'fished' sites (i.e. scallops from sites 6 and 7 were excluded from the analyses). These further analyses were conducted because the scallops at the 'ex-fished' sites were found to be significantly smaller and younger than the scallops sampled from the sites of other regimes. In this case, different allocation of energy into somatic or gonad tissues may have resulted because of maturation (Mason 1957). These further analyses consisted of analyses of covariance (ANCOVA). ANCOVAs were possible in this case because the assumption of equal covariance (shell length was used as the covariate term) was valid.

RESULTS

The mean abundance of all scallops was highest at the 'ex-fished' areas and lowest at the 'fished' areas (mean ± S.E. 'fished'= 11.59 ± 4.5; 'ex-fished'= 96.9 ± 29.2; 'no-fishing'= 84.5 ± 35.1, Table 4.2a), although there was a significant effect of site nested within fishing regime because the abundance also varied significantly among replicate sample sites. There was also a significant effect of site when only legal-sized scallops were considered, although in this case the highest abundance was observed in the 'no-fishing' areas (mean ± S.E. 'fished'= 5.9 ± 2.3; 'ex-fished'= 14.5 ± 4.6; 'no-fishing'= 75.7 ± 36.8, Table 4.2b). However, Bonferroni multiple comparisons determined that the abundance of scallops at the 'ex-fished' and 'no-fishing' sites were not significantly different (all scallops, T= -1.28, *P*= 0.650; legal-sized, T= 0.38, *P*= 1.00). In contrast, the abundance of all scallops and legal-sized scallops in the 'fished' areas was lower than that in both the 'ex-fished' and 'no-fishing' areas (all scallops, T= 7.32, *P*< 0.001 and T= 5.79, *P*< 0.001, respectively; legal-sized, T= 3.56, *P*= 0.007 and T= 4.02, *P*= 0.002, respectively).

The large number of undersized scallops sampled in the 'ex-fished' areas meant that mean size at these sites was smaller than in areas either protected from towed bottom fishing gear or areas open to fishing all year (Fig. 4.2), and the mean age was also lower (ANOVA $F_{2,191}$= 61.9, *P*< 0.001, fished 6.6 y, ex-fished 5.05 y, no-fishing 6.5 y).

The quantity of rock and dead shell collected in the dredges was highest in the 'ex-fished' areas and lowest in the 'fished' areas (mean weight (kg) ± S.E. 'no-fishing'= 19.0 ± 19.1; 'ex-fished'= 187.0 ± 97.5, 'fished'= 88.0 ± 24.3). Analyses of these data again showed that there were significant differences both between sites and between fishing regimes (Table 4.2c). Bonferroni multiple comparisons showed that the mean quantity of inert material was lower in the 'fished' areas than in the 'ex-fished' or 'no-fishing' areas (T=13.01, P< 0.001, and T= 9.97, P< 0.001, respectively). The amount of inert material collected at the 'no-fishing' sites was also less than at the 'ex-fished' sites at the P= 0.1 level (T= -2.59, P= 0.055).

Table 4.2: Results of general linear model nested ANOVA to determine variation in $\log_e$ abundance of a) all scallops, b) scallops > 100 mm shell height, and c) weight of inert material among different fishing regimes (fished, ex-fished and no fishing).

a) All scallops (abundance)

Source	DF	Seq SS	Adj MS	F	*P*
Fishing Regime	2	43.58	21.29	34.25	<0.001
Site (Fishing Regime)	6	39.47	6.58	10.34	<0.001
Error	18	11.45	0.64		
Total	26	94.49			

b) Legal-sized scallops (abundance)

Source	DF	Seq SS	Adj MS	F	*P*
Fishing Regime	2	19.82	9.91	11.27	0.001
Site (Fishing Regime)	6	45.84	7.64	8.69	<0.001
Error	18	15.83	0.88		
Total	26	81.50			

c) Inert material (kg)

Source	DF	Seq SS	Adj MS	F	*P*
Fishing Regime	2	35.96	17.98	106.50	<0.001
Site (Fishing Regime)	6	20.95	3.49	20.68	<0.001
Error	18	3.04	0.17		
Total	26	59.94			

There was a significant difference in the ratio of Log_e shell weight:shell height among the different fishing regimes (Fig. 4.2a, ANOVA, $F_{2,101}$= 9.48, *P*= <0.001), but a pair-wise t-test revealed that there was no significant difference between the fished and no-fishing regimes (t= -1.20, DF= 65, *P*= 0.23). This indicated that there was no difference in the weight of shell per unit length for these regimes. Similarly, there was no difference in the ratio of shell dry weight:adductor muscle dry weight (Fig. 4.2b, ANOVA $F_{2,103}$=1.06, *P*= 0.35) which indicates that the energy directed to the formation of muscle tissue per unit length of shell was similar among fishing regimes.

In comparison of all scallops, those individuals sampled from the 'no-fishing' areas had the highest mean ratio of gonad dry weight:adductor muscle dry weight. This was 19% and 24% higher than for the 'fished' and 'ex-fished' areas respectively (Fig. 4.2c, t-test, no-fishing v fished, t= -2.18, DF= 93, *P*= 0.015; no-fishing v ex-fished, t= -2.53, DF= 95, *P*= 0.006).

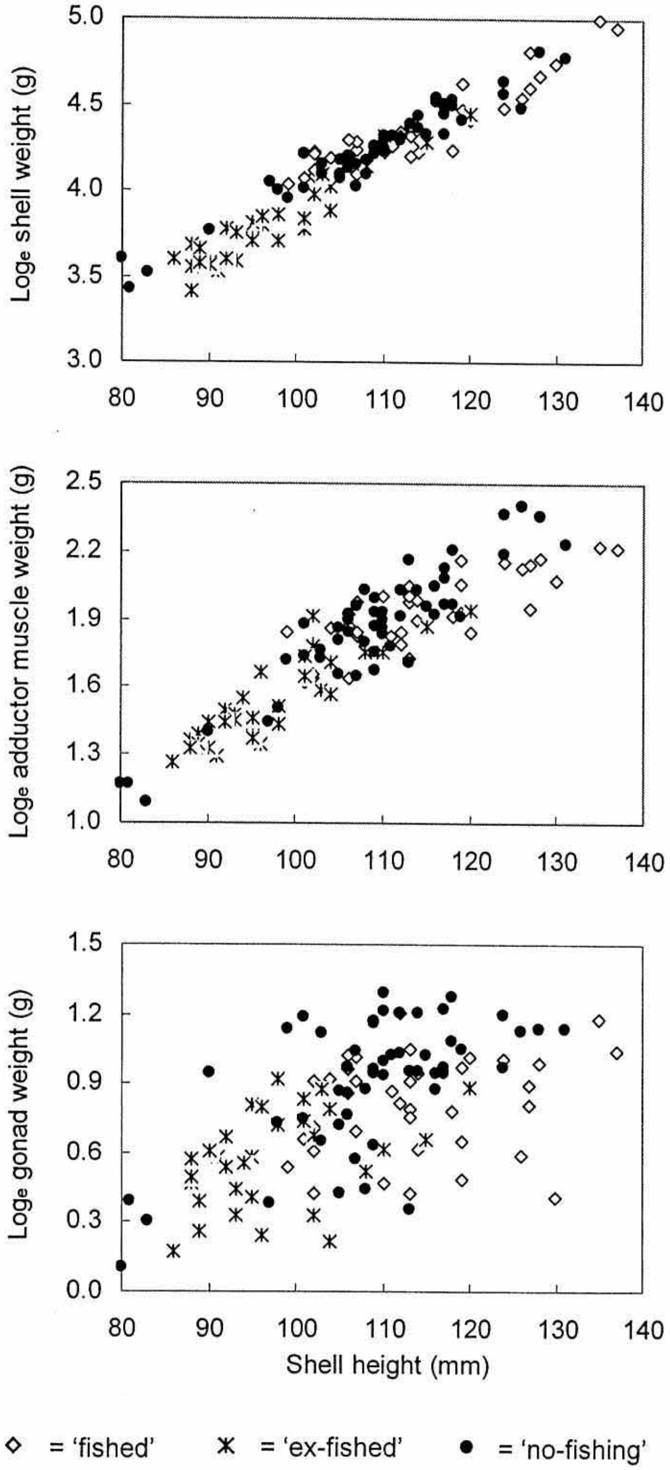

Figure 4.2: Comparison of shell weight, adductor muscle dry weight and gonad dry weight against shell height for all scallops at 'fished', 'ex-fished' and 'no fishing' sites.

RESULTS OF FURTHER ANALYSES

ANCOVAs comparing legal-sized scallops between 'fished' and 'no-fishing' sites showed that whilst the shell weights were not different, the increases in weight of adductor muscle and gonad per unit shell length were significantly different (Table 4.3). The difference in weight per unit length for adductor muscle was in contrast to the earlier comparison when data for all scallops were analysed. The covariate terms were always significantly different, which showed that across both sites the shell, adductor muscle and gonad weights increased with scallop size (Fig. 4.3). The differences in legal-sized scallop abundance and gonad dry weight between 'no-fishing' and 'fished' sites corresponded to a 9.1-fold difference in density of gonad dry weight (mean ± S.E.) between these site types of 112.76 g ± 85.7 and 15.46 g ± 12.5 per Ha respectively.

Table 4.3: Results of Analyses of Covariance comparing Log$_e$ shell dry, adductor muscle dry and gonad dry weights against Log$_e$ shell height for legal sized scallops at 'no-fishing' and 'fished' sites. Log$_e$ Shell Height was the covariate term, and bold italics indicate significant comparisons.

Log$_e$ Shell Weight

Source	DF	Seq SS	Adj MS	F	*P*
Log$_e$ Shell Height	1	3.09	3.03	427.6	***<0.001***
Fishing Regime	1	0	0	0.02	0.887
Error	79	0.56	0.01		
Total	81	3.64			

Log$_e$ Adductor Muscle Weight

Source	DF	Seq SS	Adj MS	F	*P*
Log$_e$ Shell Height	1	1.5	1.55	128.62	***<0.001***
Fishing Regime	1	0.05	0.05	4.53	***0.036***
Error	79	0.95	0.01		
Total	81	2.5			

Log$_e$ Gonad Weight

Source	DF	Seq SS	Adj MS	F	*P*
Log$_e$ Shell Height	1	0.21	0.29	6.47	***0.013***
Fishing Regime	1	0.51	0.51	11.24	***0.001***
Error	79	3.59	0.05		
Total	81	4.31			

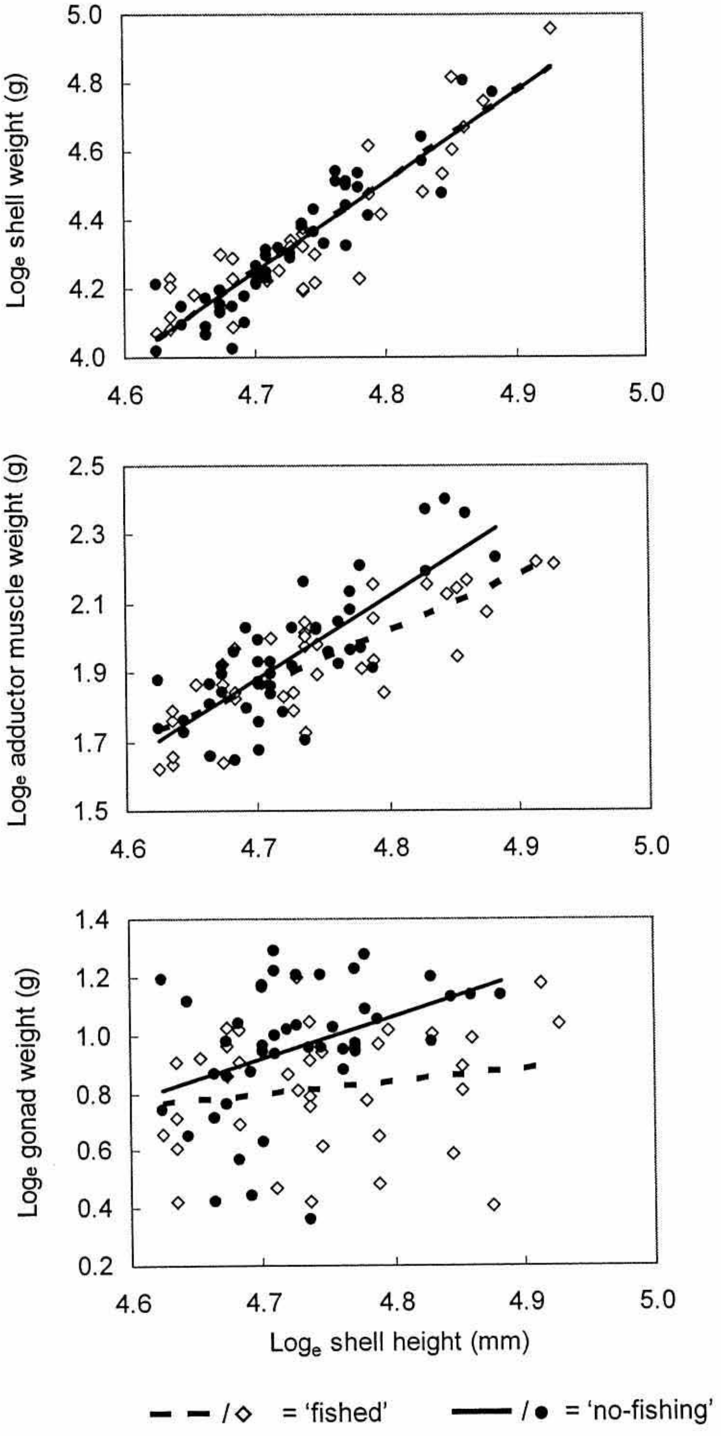

Figure 4.3: Comparison of shell weight, adductor muscle dry weight and gonad dry weight against shell height for legal sized scallops at 'fished' and 'no-fishing' sites. Trend lines show best fit linear relationships.

DISCUSSION

The mean abundance of scallops larger than the minimum legal landing size was c. 13 times higher in areas from which towed bottom fishing gear had been excluded compared to the areas where fishing occurred either year-round of or for six months of the year (fished sites). This result is remarkably similar to findings from large areas closed to fishing off the NE coast of the USA, where a 14-fold increase in scallop biomass was observed (Murawski *et al.* 2000). In this study, scallop abundance was also high in areas that had been protected from towed bottom fishing gear, but that had been fished illegally during a short period of intensive activity two years prior to sampling.

The variability in abundance of scallops at the 'no-fishing' sites may have been because 'illegal' fishing had occurred at site 9, where scallop abundance was low (Chapter 3). It seems unlikely that 'illegal' fishing occurred at site 9 though as, in other regards, the benthic community at that site was consistent with that of a site where towed gears had not been used for at least a number of years (Chapter 3). However, whilst the depths were similar, the substratum at site 9 was slightly more coarse than that at site 8, and this may have reduced the suitability of the site for spat settlement or for adult scallops. The differences in substrate grade may also have made the fishing gear less efficient at site 9, as could changes in the tidal strength or towing angle relative to the tide. It may also simply have been chance that the scallop abundance at site 9 was lower, but that in a different month or year the abundances at the 'un-fished' sites would be comparable.

The lower mean size and age in the 'ex-fished' areas was possibly related to a short burst of intensive and highly targeted illegal fishing at these sites, because scallop dredges preferentially select for only those individuals that meet the requirements of legal landing-size restrictions. However, it is also possible that the size of scallops selected for was reduced at the 'ex-fished' sites because the collection of large quantities of inert material clogged the belly rings of the dredges. However, the similar mean ages of scallops found in both 'fished' and 'no-fishing' areas indicated that the selectivity of the dredges was not affected at these sites, and that the scallops were recruited from similar cohorts.

Scallops are sedentary organisms that reproduce by broadcast spawning, hence reproductive success is likely to be highly density-dependent in this species (Levitan, Sewell & Chia 1992; Yund 2000). This may particularly true in areas where scallop densities are very low, as represented by the 'fished' areas sampled in this study. Perhaps the most significant finding is the previously unreported decrease in reproductive potential of scallops located in areas exposed to chronic fishing activity as represented by smaller gonad weight per unit body-size. Although it was not able to ascertain whether this reduced gonad size equated to fewer or smaller eggs, either scenario would result in lower potential successful spawning as egg size is directly related to egg survival (Martinez & Perez 2003).

There are a number of factors that might have affected the gonad production of the scallops sampled in this study. These include differences in the physical conditions or food availability between sites, or differences in the genetic structure of the scallop stocks between sites. However, it seems unlikely that an environmental gradient existed that could have caused the observed differences in growth between site because the sites were situated close together, and the depth and tidal regime were similar. Furthermore, it is unlikely that the scallop stocks at different sites were genetically distinct because scallop larvae are planktonic prior to settlement. During this dispersal period, the larvae from sites situated close together are likely to be well-mixed (Heipel *et al.* 1998). Hence, it is probable that the observed differences in the allocation of growth to different body tissues were due to differences in the fishing regimes between sites. However, to confirm this assertion it would be essential to undertake histological examination of the gonads of scallops from different sites, to confirm synchronicity of spawning. Whilst the analysis of the adductor muscle weights of scallops in 'fished' and 'no-fishing' sites suggested that there were real differences between the scallops at different sites, it is possible that sampling was undertaken prior to spawning commencing at the 'no-fishing' sites, but during or following release of gametes at the 'fished' sites.

The higher abundance of scallops and higher biomass of other sessile filter-feeding biota within the no-fishing areas might be expected to lead to density-dependent competition for food resources within and among species. If this was the case, the flesh weight of the scallops would be lower than in fished areas where the biomass of the benthic community was lower (Kaiser *et al.* 2000). Here, a result is reported that is entirely the opposite of what might be expected; scallops had larger gonad mass (and adductor muscle mass when only legal sized scallops were considered) in areas where competition for resources is highest.

Newhaven scallop dredges are highly inefficient, and a catch efficiency of 41% may be the best that can be expected (Beukers-Stuart, Jenkins & Brand 2001). Hence scallops located in areas subjected to chronic fishing may incur repeated stress or injuries from physical contact with fishing gear, which would divert energy from gonad production to the repair of body tissues. In addition, the resuspension of sediments that occurs as a result of bottom fishing can be equivalent to that which occurs during storm events (Churchill 1989; Planques, Guilen & Puig 2001). The latter have been shown to lower the availability of suspended particulate matter as a food source for scallops (Cranford *et al.* 1998; Planques *et al.* 2001). Both an increased incidence of physical damage and periodic reduction in the availability of food resources could explain the reduced gonad (and adductor muscle) development observed in the present study.

CONCLUSIONS

It would appear that areas protected from the effects of bottom fishing not only conserve the abundance and biomass of bivalve molluscs, but also allow the maintenance of population reproductive quality. The conservation benefits reported in this study were achieved through a voluntary agreement among different sectors of the fishing industry, that excludes certain users from access to certain areas of the sea (Chapter 2, this thesis). The successful implementation of MPAs is more likely to succeed with full participation of fishermen who are the main stakeholders (Hart 1998) and would appear to achieve much wider benefits than previously expected.

CHAPTER 5

CONSERVATION BENEFITS OF A MARINE PROTECTED AREA VARIES WITH FISH LIFE-HISTORY PARAMETERS

This chapter was submitted to Conservation Biology

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5: CONSERVATION BENEFITS OF A MARINE PROTECTED AREA VARIES WITH FISH LIFE-HISTORY PARAMETERS

SUMMARY

Marine protected areas reduce the exploitation of fish within specific areas of the sea. They have been proposed as tools to protect and enhance targeted fish stocks. As such, demonstrating benefits from these systems is crucial if they are to be used more widely for fishery management and conservation. However, demonstrating benefits can be difficult; indirect monitoring of population change via commercial catch data offers little potential because these data are rarely spatially explicit, and may be subject to mis-reporting. Commercial data also seldom includes details of individual fish, although changes in the abundance of above-average sized individuals may provide important information on general stock health. Recreational angling data may address these short-comings because anglers usually weigh fish individually, and records of angling catches from specific locations may be available over long time periods.

This study examined angling catches reported over the period 1973-2002 from within, and adjacent to the Inshore Potting Agreement (IPA), which is a fishery management system located off the south-west coast of England. The IPA functions as a form of MPA by restricting the use of towed bottom fishing gears in a 500 km^2 area. Analyses of recreational angling catch data from 1973-2002 determined that the mean reported weight of above-average sized individuals of two ray (Rajidae) species and three flatfish (Pleuronectidae and Scophthalmidae) species was greater within the IPA than in adjacent areas. The mean reported weight of the same flatfish species but two different ray species also declined more rapidly in the adjacent areas over the 30 year study period. Although benefits for commercially targeted fish species were identified, the results indicate that marine protected areas that restrict commercial exploitation in temperate regions would need to be much larger than the IPA to eliminate the wider effects of exploitation for both long-lived species and for those that undertake extensive migrations.

INTRODUCTION

It is widely accepted that globally, fisheries are in decline and that conventional fishery management practices have failed to arrest this trend. This failure has been attributed to uncertainty in the predictive models of stock dynamics, and inadequate political will to adhere to management advice (Acheson *et al.* 1998; Hofmann & Powell 1998; Lauck *et al.* 1998). To arrest this decline, the use of marine protected areas has been proposed as a method by which stocks may be protected and even enhanced (Pauly *et al.* 1998; Murray *et al.* 1999; Roberts *et al.* 2001; Gell & Roberts 2003).

Marine protected areas (MPAs) restrict fishing operations within specific areas of the sea, which may benefit targeted stocks in a number of ways. In particular, MPAs may reduce the overall fishing mortality of a targeted stock such that the average age and body-size of individuals within the protected population increases (Bohnsack 1992; Hutchings 1996). This can have important consequences for overall stock fecundity (Roberts 1995; Russ & Alcala 1996a; Babcock *et al.* 1999). Females that have spawned previously tend to produce a greater number of larger eggs per unit bodyweight than do first-time spawners (Auster & Shackell 2000). The survival of larvae from these larger eggs may also be greater, hence the genetic contribution of older females to subsequent recruitment can be considerable (Hutchings 1995). In addition, an increased number or density of mature individuals can be important for spawning success due to Allee (density dependent) effects (Gascoigne & Lipcius 2004). For example, a minimum critical density may be essential for some sessile invertebrate species to achieve egg fertilisation (Malakoff 1997) and to generate synchronous spawning behaviours (Dew 1990). Thus, MPAs may enable adults with spawning experience to survive in concentrations that disproportionately benefit the overall spawning success and sustainability of a stock (Jennings 2000).

Some MPAs may function by allowing only particular types of fishing gears to be used. These MPAs can work in a similar manner to other spatially defined management systems by reducing fishing effort on particular stocks. Population level benefits have been observed from large MPAs of this type in temperate waters, as with yellowtail flounder *Limanda ferruginea* in the Nantucket Lightship closed area, Georges Bank, (Murawski *et al.* 2000), and for plaice *Pleuronectes platessa* in the Plaice Box, North Sea (Anon. 1994; Piet & Rijnsdorp 1998), although the efficacy of the Plaice Box has recently been questioned (ICES 1999).

It has been argued that few MPAs in temperate waters are large enough to benefit mobile fish and crustacean species that are able to move 10s or 100s of kilometres in a relatively short time period (Horwood 2000). However, others argue that a portion of even highly mobile stocks can show strong site fidelity, such that benefits may accrue to populations from small MPAs (Gell & Roberts 2003). Determining these benefits in temperate waters has proved difficult. The visual techniques used to census fish in relatively shallow, tropical locations, cannot be applied in deep or turbid conditions. Commercial landings data may not be used as these are often unreliable, and catches may increase without a corresponding increase in stock size (Horwood 2000). Demonstrating the effects of MPAs is also confounded by natural population fluctuations that mask changes in population size. In fact, despite apparently having many conservation benefits, very few large (>1000 Km^2) MPAs exist in temperate waters. This perhaps suggests that evidence of beneficial effects (or otherwise) is required if this type of management is to be adopted more widely (Gell & Roberts 2003).

Commercial landings data rarely include the weight of individual fish, although these data can provide valuable information on the general status of fish stocks (Jennings 2000). Commercial data can also seldom be attributed to specific areas, which is unfortunate as spatial data are required to determine the effect on stocks of introducing a spatially defined management system such as a MPA. In contrast, recreational sea angling (angling) records usually include detailed information on the weight of individual fish, together with the location and date of capture. These records usually focus on above-average sized fish, so that trends may be determined in the component of the population that is likely to be most vulnerable to over-exploitation. Finally, angling records often extend many years into the past, and thereby provide a potentially valuable long-term data source. If this methodology could be proven then the information may prove useful in assessing the effect of MPAs on fish species (Bennett & Attwood 1991; Roberts *et al.* 2001).

The present study was focussed on the Inshore Potting Agreement (IPA) which is a spatially defined fishery management system established in 1978 off the coast of south Devon, UK. The system was designed to reduce conflict between fishermen that used static gears (principally crab/lobster pots), and those that use towed gears (otter trawls, beam trawls and scallop dredges) (Fig. 5.1). The IPA includes areas for the exclusive use of static gears (approximately 350 km^2), and other areas (approximately 150 km^2) where towed gears are permitted seasonally. Whilst static-gear fishermen are also able to use anchored nets to target demersal fish within the IPA, this practice is rare due to the strong tides in the area (RB, pers. obs.). Thus the IPA has functioned as a form of MPA because intensive commercial exploitation of demersal fish species within the IPA has been restricted for at least 25 years (Chapter 2, this thesis).

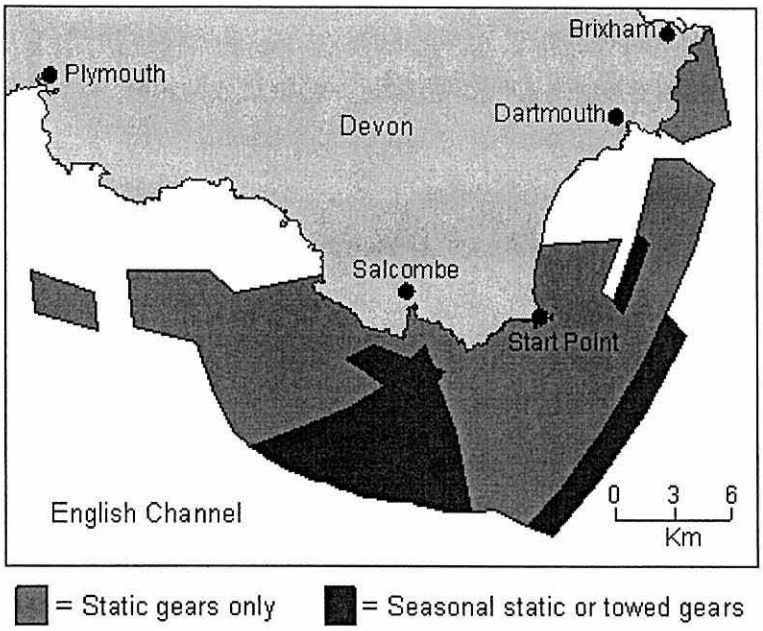

Figure 5.1: The Inshore Potting Agreement (IPA) system located off the southwest coast of England (2003 version of the IPA shown).

Angling is undertaken throughout the year in the UK; most harbours support an abundance of private angling boats, and at least 106 registered commercially-operated charter angling vessels operate along the south west coast of England (Professional Boatman's Association, http://www.pba.org.uk). Records of catches taken along the south west coast of the UK provided an unique opportunity to assess the implications of a marine protected area for local fish populations, because of the intensity of angling effort and the long time-scale over which angling has taken place. The aims of this study were to determine whether trends in the weights of fish recorded by anglers differed between the IPA system and the adjacent waters, and whether long-term trends in angling catches within the IPA reflect commercial landings for the same species in the wider vicinity.

METHODS

Records of angling catches were collected from the National Federation of Sea Anglers (NFSA) and 'Sea Angler' magazine (SAM). The NFSA is the UK government recognised body that represents recreational sea anglers. Since 1932, the NFSA has run an annual specimen award scheme that rewards anglers that catch fish heavier than a species-specific specimen weight with an official certificate. To qualify for the award scheme, an angler must be a member of an angling club affiliated to the NFSA. The certificates have no monetary value, and all fish submitted must be independently witnessed and weighed on calibrated scales. SAM has been published monthly since 1972, and includes catch reports of individual, notable fish. Any angler fishing in UK waters can submit details of captures to the magazine for publication. There is no reward for submitting details of fish to SAM other than for specific competitions, and in such cases photographs are required to authenticate capture. While such records undoubtedly under-report actual catches it was considered that both NFSA and SAM catch reports were valid data sets as they were subject to the same potential errors regardless of the exact location of any given angling event (i.e. under-reporting and measurement errors were both equally as likely within the IPA as outside it). Original catch reports are held at the NFSA headquarters, and SAM maintains a library of back issues.

Table 5.1: National Federation of Sea Anglers qualifying specimen weight, British record angling weight, and mean maturation length (L_{mat}), for the nine fish species studied. * indicate L_{mat} estimated from values for the similar species in this study.

Common Name	Species	L_{mat} (cm)	L_{mat} source	Specimen Weight (Kg)	British Angling Record (Kg)
Bass	*Dicentrarchus labrax*	35	FISHBASE	3.63	8.85
Spotted ray	*Raja montagui*	62	Dulvy *et al.* (2000)	2.27	3.54
Small-eyed ray	*Raja microocellata*	65*	Estimate	3.63	7.49
Thornback ray	*Raja clavata*	86	Dulvy *et al.* (2000)	3.63	16.80
Blonde ray	*Raja brachyura*	90	FISHBASE	9.08	17.71
Dab	*Limanda limanda*	13	FISHBASE	0.45	1.27
Plaice	*Pleuronectes platessa*	27	FISHBASE	1.82	4.77
Brill	*Scophthalmus rhombus*	30*	Estimate	2.72	7.26
Turbot	*Scophthalmus maximus*	35*	Estimate	8.17	14.76

Catch reports were collected for the period 1973-2002 from both the NFSA and SAM. Data were obtained for bass, spotted ray, small-eyed ray, thornback ray, blonde ray, dab, plaice, brill and turbot (Table 5.1). These species were those that appeared regularly in angling catches from the south coast of England, and are the subject of important commercial fisheries in the area. Only fish larger than the NFSA minimum qualifying specimen weight for each species were included in the study (Table 5.1). When any capture report was found to be duplicated in SAM and the NFSA (identified by manually cross-checking between capture date, capture location, and fish weight), the SAM record was removed.

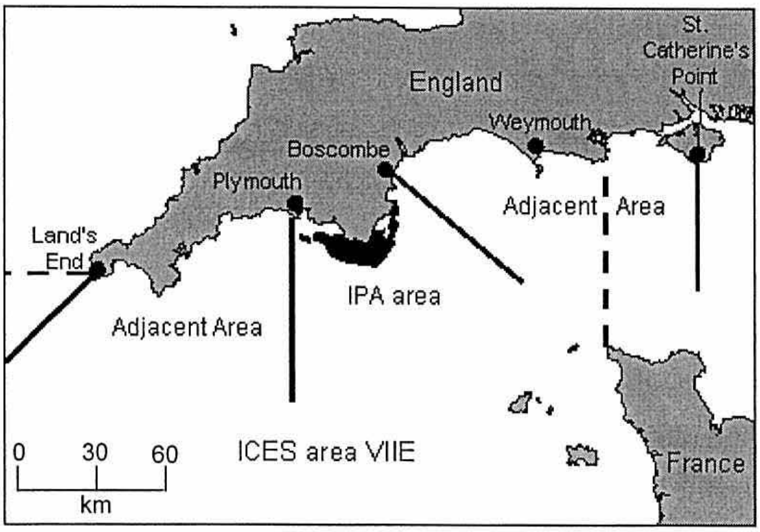

Figure 5.2: The English Channel showing the coastal extent of the IPA and 'Adjacent Areas' (AA) study areas (solid lines). The boundaries of the International Council for the Exploration of the Seas (ICES) fishing area VIIe is also shown (dashed lines).

Both the NFSA and SAM generally require that anglers specify where each fish was caught, but reports of catches was excluded from the study when these data were absent. Each fish captured was then attributed to either the IPA area or to 'Adjacent Areas' (AA). For the purposes of this study, the IPA area was defined as the zone between lines drawn to the south of Plymouth and to the south-east of Boscombe (Fig. 5.2). It was assumed that by defining the IPA area as a larger zone than the specific IPA system, a conservative estimate of the effect of the IPA would be determined. The AA were defined as the combined regions to the east and west of the IPA area (Fig. 5.2). The eastwards limit of the study area was St. Catherine's Point on the Isle of Wight, and the westwards limit was Land's End (Fig. 5.2). The seaward limit of the study area was assumed to be 20 km as few privately owned vessels operate further than 10 km offshore. Some commercial charter angling boats consistently operate further than 20 km offshore, but these vessels usually target demersal gadoid species that were not included in this study.

DATA ANALYSES

Data for each species were analysed between areas for homogeneity of variance, and to ensure that they met the assumptions of normality. Subsequent analyses for bass, thornback ray and blonde ray were conducted using untransformed data, whilst the data for the other species were Log_{10} transformed to meet the assumptions of ANOVA. General linear model analysis of covariance (GLM ANCOVA) procedures were undertaken to compare the mean weight of fish caught by anglers in each year over the period 1973-2002 within the IPA and the AA. The overall mean specimen weight of each species captured over the entire 30 year period in the IPA and the AA were then compared using two-sample T-tests.

For each species, the number of specimen-sized individuals caught within the IPA and the AA were aggregated into three year bins (1972-1974 inclusive, 1975-1977 inclusive, etc.). Pearson correlations were then used to compare the number of individuals caught between areas in each 3 year bin. The maximum weight of any individual of each species were also determined in both areas in the same 3 year bins. Paired t-tests were used to compare the maximum weight of any individual fish of each species caught in each area and within each year group.

Regression coefficients were calculated using the least mean squares procedure for the mean weight of each species caught in both areas over the 1973-2002 period, using Log_{10} transformed data for all species. These regression coefficients were plotted against estimates of the mean length at maturation (L_{mat}) for each species to determine if the rate of decline in the mean weight of reported species varied according to life-history parameters. L_{mat} was selected for this analysis because body length is a strong predictor of the intrinsic rate of population increase in fish (Denney, Jennings & Reynolds 2002) and these data were generally available from the FISHBASE website (http://www.fishbase.org), or reported by Dulvy *et al.* (2000). Some fish species had very large differences in the maximum length reported from different European regions, and so these data were not considered to provide reliable life history parameter data. L_{mat} data were more consistent between regions, but when L_{mat} data were obtained from FISHBASE, care was taken to ensure that only L_{mat} estimated for stocks from the English Channel, southern North Sea or Celtic Sea were used. However, L_{mat} data were not available for small-eyed ray, brill or turbot. Hence, estimates of L_{mat} for these species were derived by scaling values of L_{mat} for closely related species up or down according to the % differences in regional maximum length, as reported by FISHBASE (Table 5.1).

In order to compare angling catches against commercial landings for each species, fishery landings data was collated for International Council for the Exploration of the Seas (ICES) area VIIe (Western English Channel, Fig. 5.2) for the period 1973-2001 from Fishstat Plus V.2.3 (FAO 2000a). Commercial species-specific landings data were available for all species except blonde ray or small-eyed ray. Available landings data were aggregated into the same three-year bins as used for the angling catches. Three-year aggregated commercial landing data were then correlated against the total number of specimen sized fish reported for each species by anglers in the entire study area between Land's End and St. Catherine's Point in the same three-year bins (Fig. 5.6). All statistical analyses were conducted using Minitab V.13.2.

RESULTS

The number of bass and thornback ray caught over the period 1973-2002 followed similar patterns in the IPA and the AA, as evidenced by significant positive correlation coefficients (n= 905, r= 0.77, p= 0.01, and n= 480, r= 0.88, p = 0.001 respectively) (Fig. 5.3). There also appeared to be positive relationships between the numbers of spotted ray and dab caught between areas (Fig. 5.3), but these were non-significant (n= 196, r= 0.59, p= 0.08, and n= 964, r= 0.52, p= 0.13 respectively). However, significant negative relationships between the number of catches reported in both areas over time were found for plaice (n= 688, r= -0.66, p=0.04) and brill (n= 207, r= -0.69, p= 0.03) (Fig. 5.3). No other significant relationships were observed.

With the exception of spotted ray and small-eyed ray, GLM ANCOVAs conducted for each species between areas produced significant interaction effects (IPA to AA * Year). These significant results indicated that the mean weights of specimen fish caught in the IPA and the AA had declined at different rates over time (Table 5.2, Fig. 5.4). Visual inspection of the data was subsequently conducted.

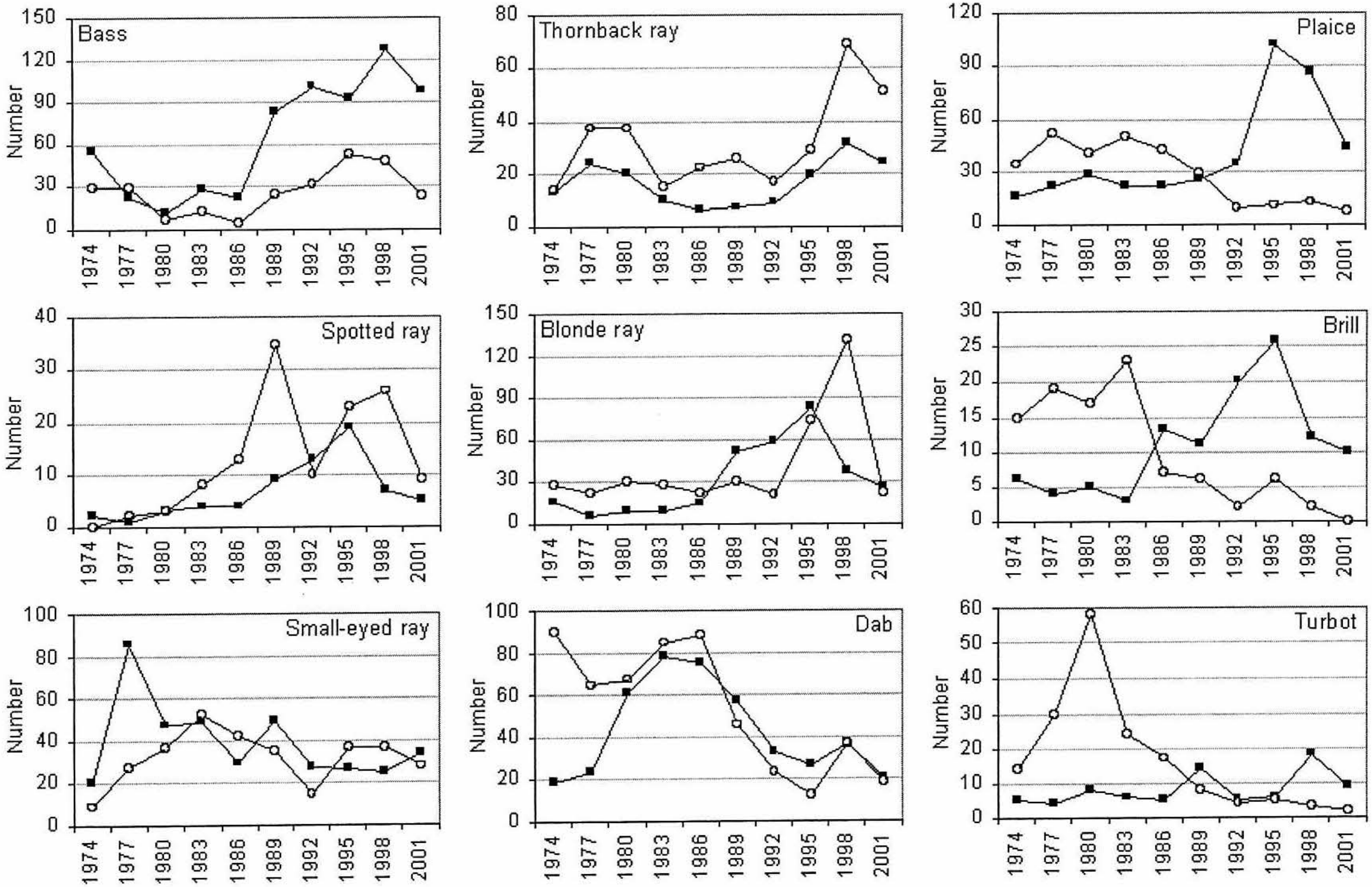

Figure 5.3: The number of specimens of nine fish species caught by recreational anglers in the IPA and the AA in three year bins from 1973-2002. -○- = IPA area, -■- = the AA.

Table 5.2: Results of GLM ANCOVA between weights of specimen fish caught in the IPA and the AA over the period 1973-2002. Terms modelled were capture area, year, and capture area * year. Bold italics indicate significant results.

Species	Source	DF	Seq SS	Adj MS	F	P
Bass	Capture Area	1	6.8	3.5	5.4	***0.021***
	Year	1	1.7	0.4	0.6	0.45
	Capture Area * Year	1	3.6	3.6	5.4	***0.020***
	Error	901	592.6	0.7		
	Total	904	604.7			
Spotted ray	Capture Area	1	0.1	0.0	0.5	0.50
	Year	1	0.0	0.0	1.0	0.31
	Capture Area * Year	1	0.0	0.0	0.5	0.51
	Error	192	0.4	0.0		
	Total	195	0.4			
Small-eyed ray	Capture Area	1	0.1	0.0	0.0	0.97
	Year	1	0.0	0.0	0.3	0.60
	Capture Area * Year	1	0.0	0.0	0.0	0.99
	Error	709	2.6	0.0		
	Total	712	2.6			
Thornback ray	Capture Area	1	10.3	15.1	9.9	***0.002***
	Year	1	173.1	187.9	123.0	***0.000***
	Capture Area * Year	1	15.0	15.0	9.8	***0.002***
	Error	476	727.6	1.5		
	Total	479	926.1			
Blonde ray	Capture Area	1	1.4	11.2	3.9	***0.049***
	Year	1	10.2	18.3	6.4	***0.012***
	Capture Area * Year	1	11.1	11.1	3.9	***0.049***
	Error	656	1884.0	2.9		
	Total	659	1906.7			
Dab	Capture Area	1	3.4	0.1	24.2	***0.000***
	Year	1	0.0	0.0	0.1	0.73
	Capture Area * Year	1	0.1	0.1	25.1	***0.000***
	Error	960	4.7	0.0		
	Total	963	8.2			
Plaice	Capture Area	1	0.0	0.1	10.7	***0.001***
	Year	1	0.0	0.0	6.6	***0.010***
	Capture Area * Year	1	0.1	0.1	10.7	***0.001***
	Error	684	3.3	0.0		
	Total	687	3.4			
Brill	Capture Area	1	0.2	0.0	4.1	***0.044***
	Year	1	0.1	0.1	9.9	***0.002***
	Capture Area * Year	1	0.0	0.0	4.2	***0.042***
	Error	203	1.4	0.0		
	Total	206	1.6			
Turbot	Capture Area	1	0.0	0.0	6.9	***0.009***
	Year	1	0.0	0.0	0.4	0.52
	Capture Area * Year	1	0.0	0.0	7.0	***0.009***
	Error	241	0.6	0.0		
	Total	244	0.7			

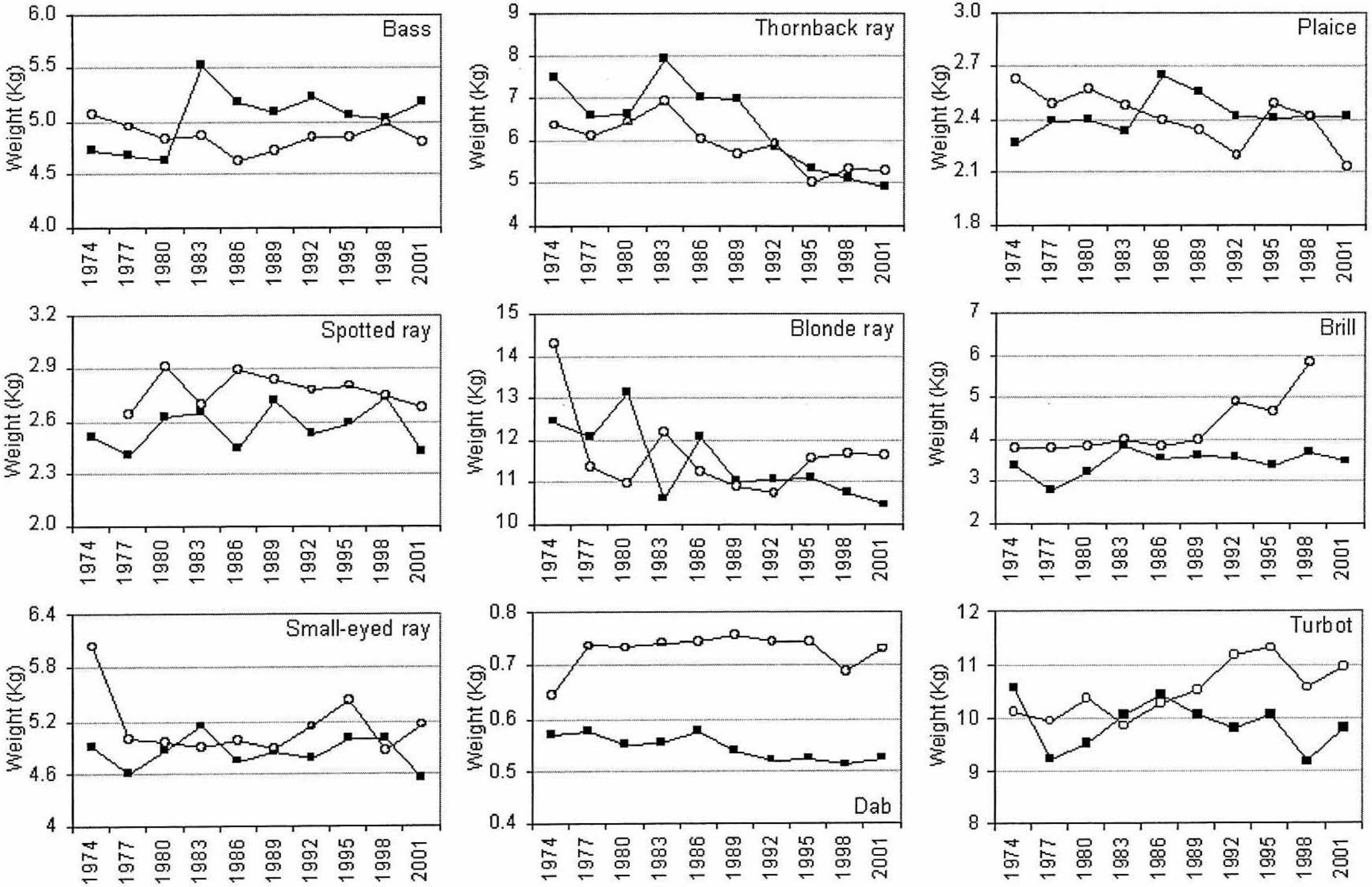

Figure 5.4: The mean weight of specimens of nine fish species caught by recreational anglers in the IPA and the AA in three year bins from 1973-2002. -○- = IPA area, -■- = the AA. Error bars have been omitted for clarity

The mean weight of specimen bass caught inside the IPA had remained relatively constant over 30 years, whilst in the AA the mean weight had increased slightly. The mean specimen weight of plaice caught in the AA had also remained stable in comparison to a fall in mean weight within the IPA. The mean specimen weight of thornback ray and blonde ray caught in both areas had decreased with time, although the decline was steeper within the AA than the IPA. The mean specimen weight of dab was maintained for the IPA area in comparison to a fall in the mean weight in the AA over the same period. Finally, the mean specimen weight of both brill and turbot had increased in the IPA area in comparison to remaining stable within the AA.

Table 5.3: Results of 2-sample t-tests between weights of specimen fish reported in the IPA and the AA over the period 1973-2002. Bold italics indicate significant results.

Species	IPA Mean Weight ± S.D. (Kg)	AA Mean Weight ± S.D. (Kg)	IPA Heavier?	T	P
Bass	4.88 ± 0.78	5.07 ± 0.83	***N***	3.30	***0.001***
Spotted ray	2.79 ± 0.28	2.59 ± 0.30	*Y*	-5.02	<
Small-eyed ray	5.04 ± 0.75	4.81 ± 0.62	*Y*	-4.19	<
Thornback ray	5.75 ± 1.29	6.06 ± 1.55	***N***	2.19	***0.030***
Blonde ray	11.55 ± 1.75	11.64 ± 1.62	-	0.71	0.481
Dab	0.72 ± 0.12	0.55 ± 0.09	*Y*	-26.16	<
European plaice	2.46 ± 0.39	2.42 ± 0.44	-	-1.69	0.092
Brill	3.99 ± 0.88	3.48 ± 0.66	*Y*	-4.71	<
Turbot	10.24 ± 1.38	9.77 ± 1.04	*Y*	-2.93	***0.004***

For most of the species, two sample t-tests revealed that the mean specimen weight reported by anglers over the entire 30 year study period were significantly different between the IPA and the AA (Table 5.3). The overall mean specimen weights of bass and thornback ray were significantly less in the IPA than in the AA. In contrast, the mean specimen weights of spotted ray, small-eyed ray, dab, brill and turbot were significantly heavier in the IPA area than in the AA over the 30 years. The overall mean specimen weights of blonde ray and plaice were not significantly different between areas.

Paired t-tests comparing the maximum weight of fish of each species caught in the IPA and the AA in three year bins from 1973-2002 also determined that the IPA had produced the largest individuals for small-eyed ray, dab, brill and turbot (Table 5.4, Fig. 5.5). In addition, larger individual spotted ray were caught in the IPA than in the adjacent area in nine of the ten three-year periods, and in seven of the ten three-year periods for blonde ray, although these results were not significant (Table 5.4, Fig. 5.5). No differences in the weight of the heaviest individuals were detected between areas for thornback ray or plaice, although for the seven most recent three-year periods, the heaviest bass were caught in the AA (Fig. 5.5).

Table 5.4: Results of Paired t-tests between the heaviest single fish caught in each three-year bin (1973-1975, 1976-1978, etc.) in the IPA and the AA over the period 1973-2002. Bold italics indicate significant results.

Species	IPA Heavier?	T	P
Bass	-	2.23	0.053
Spotted ray	-	-1.49	0.174
Small-eyed ray	*Y*	-2.85	***0.019***
Thornback ray	-	-0.20	0.843
Blonde ray	-	-1.53	0.265
Dab	*Y*	-5.02	***0.001***
European plaice	-	1.34	0.214
Brill	*Y*	-4.06	***0.004***
Turbot	*Y*	-3.73	***0.005***

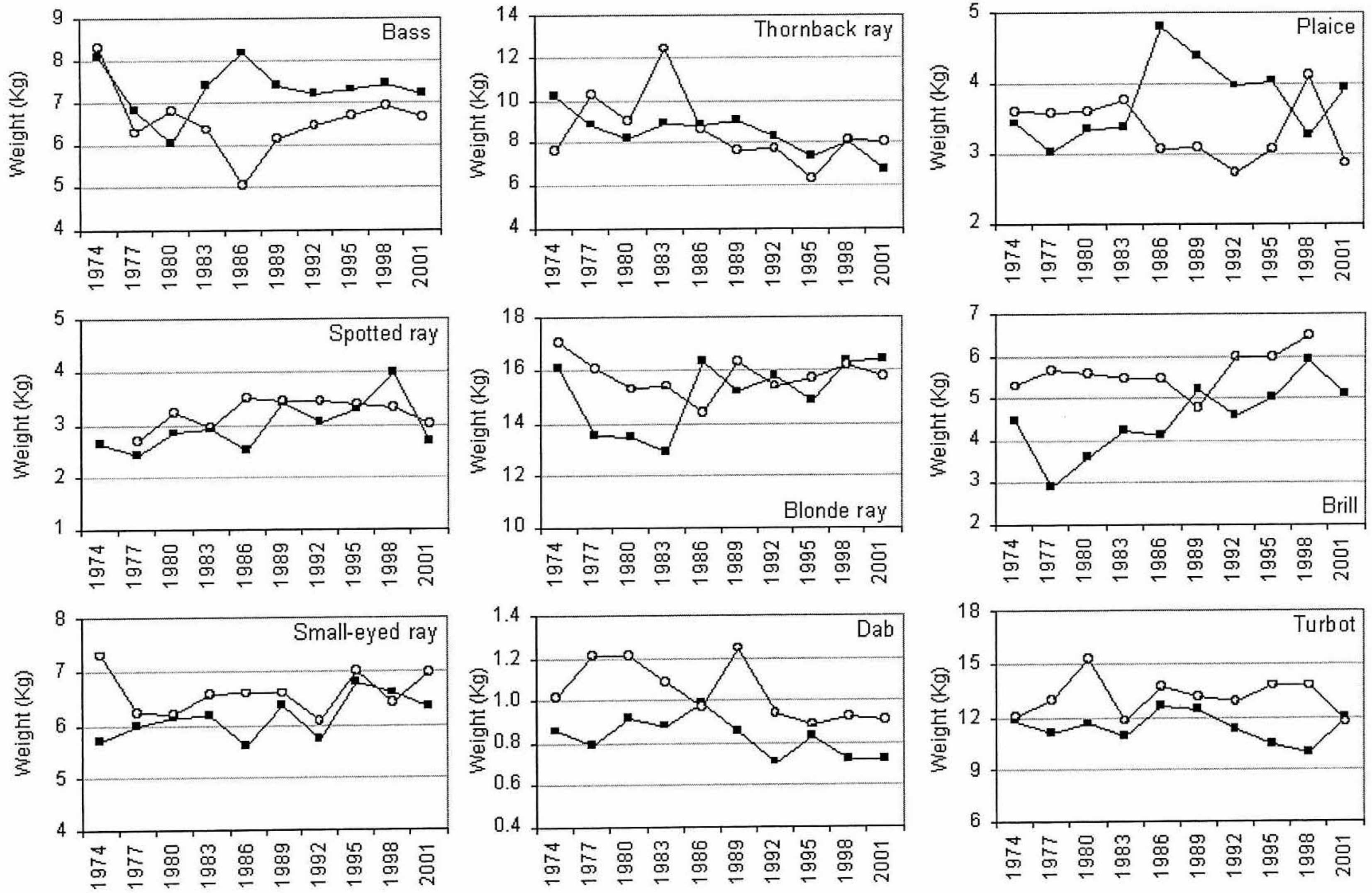

Figure 5.5: The maximum individual weight of nine fish species caught by recreational anglers in the IPA and the AA in three year bins from 1973-2002. -○- = IPA area, -■- = the AA..

To determine if there was a consistent pattern in the change in mean reported weight of all species over the period 1973-2002 in the IPA and in the AA, the regression coefficients derived for the changes in mean reported weights over time were plotted against the mean maturation length (L_{mat}) for each species (Table 5.5, Fig 5.7). In this analysis, non-significant regression coefficients were given '0' values to minimise the potential for erroneous results to confound the interpretation of the data. Significant regression coefficients were not adjusted, or weighted according to level of significance, to reduce the complexity of the analysis. This analysis indicated that the rate of decline of the weight of fish from 1973 to 2002 was more negative with increasing L_{mat} in both the IPA and the AA. However, whilst the slope of this relationship was similar both within and adjacent to the IPA (ANCOVA, $F_{1,17}$= 0.00, p= 0.95), the intercept of these relationships (decline in mean weight = 0) occurs at a larger L_{mat} within the IPA (ANCOVA, $F_{1,17}$= 4.81, p= 0.046) (Fig. 5.6). This suggested that the IPA has functioned to arrest the rate of decline of the mean size of specimen-weight fish reported by anglers.

Table 5.5: Regression coefficients and R^2 values for the Log_{10} transformed mean weight (Kg) of nine fish species caught by recreational anglers in the IPA and the AA in three year periods from 1973-2002. Bold italics indicate significant results.

		IPA			AA		
Species	L_{mat} (cm)	Regression coefficient	R^2	*P*	Regression coefficient	R^2	*P*
Bass	35	0.000	0.002	0.500	0.001	0.014	***0.002***
Spotted ray	62	-0.001	0.015	0.172	0.000	0.001	0.830
Small-eyed ray	65*	0.000	0.000	0.756	0.000	0.001	0.651
Thornback ray	86	-0.004	0.128	***< 0.001***	-0.007	0.323	***< 0.001***
Blonde ray	90	0.000	0.000	0.791	-0.002	0.036	***0.003***
Dab	13	0.001	0.023	***< 0.001***	-0.002	0.031	***< 0.001***
Plaice	27	-0.002	0.052	***< 0.001***	0.000	0.001	0.583
Brill	30*	0.005	0.092	***0.003***	0.001	0.008	0.346
Turbot	35*	0.002	0.028	***0.031***	-0.001	0.003	0.102

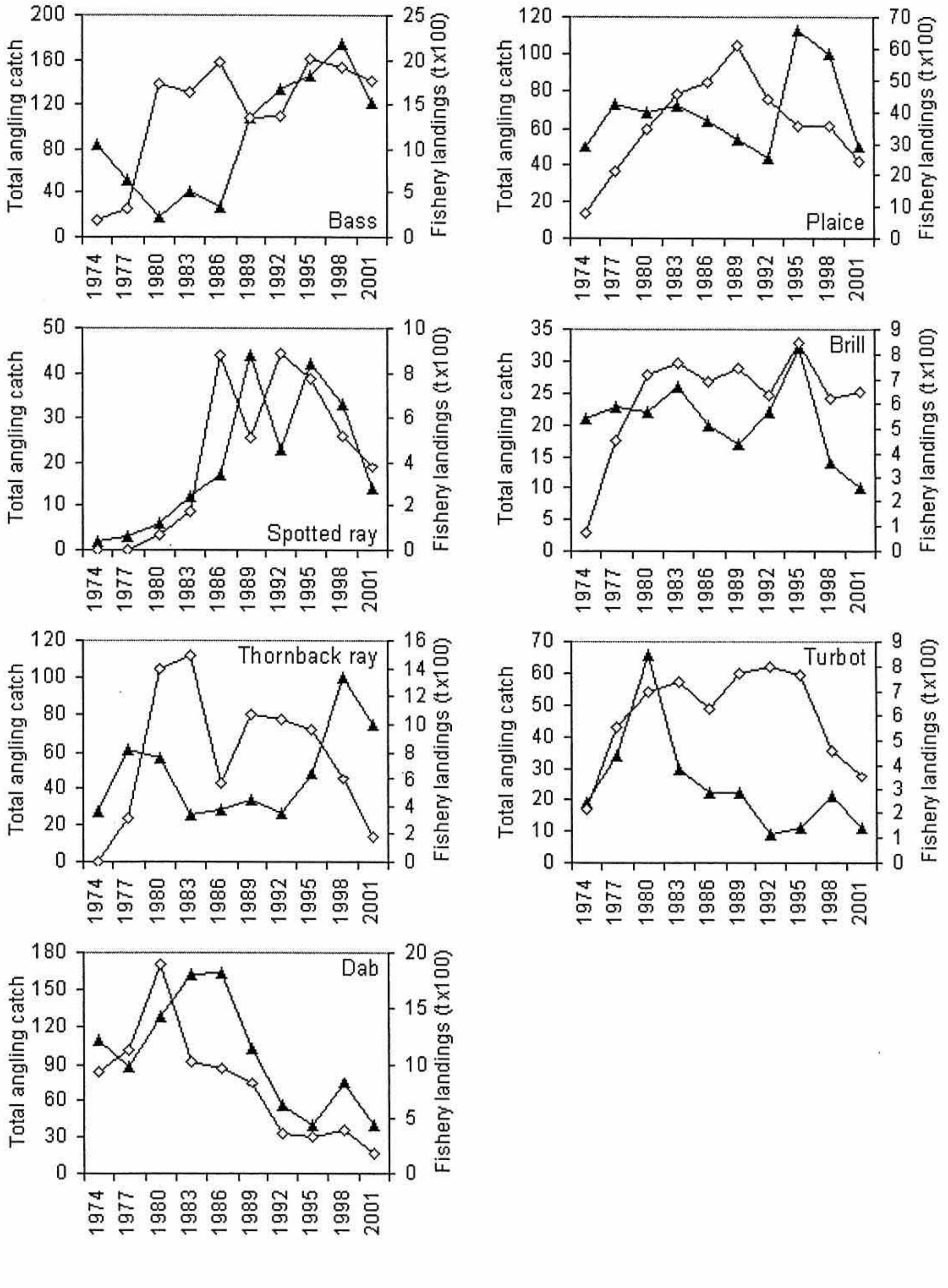

Figure 5.6: The total number of specimen-sized fish of seven species caught by recreational anglers in the area between Land's End and St. Catherine's Point in three year periods from 1973-2002, against commercial landings (tonnes). ▲ = Angling catch data, ◇ = Commercial landings data. No commercial landings data were available for small-eyed ray or blonde ray.

Correlations between the number of specimen fish of each species reported in angling catches over the entire study area (aggregated into three-year bins) and aggregated commercial landings data for ICES area VIIe (aggregated into the same three-year bins), were significant and positive for spotted ray (r= 0.68, p= 0.03) and dab (r= 0.71, p= 0.02) (Fig. 5.7). These results may indicate that recreational anglers and commercial fishermen were harvesting from the same general stock of fish. The comparisons of commercial landing and recreational catch data for other species were not significant (Fig. 5.6).

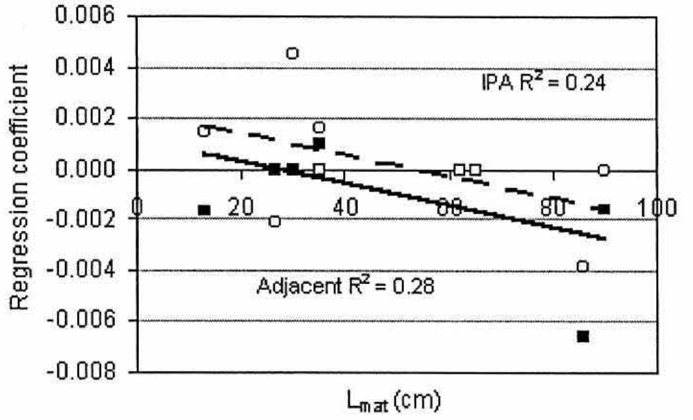

Figure 5.7: Regression coefficients of mean weight (Log_{10} Kg) of nine fish species caught by recreational anglers in the IPA and the AA from 1973-2002, compared against the maturation length (L_{mat}) of each species. L_{mat} for small-eyed ray, brill and turbot estimated from values for other similar species in study. L_{mat} for other species from FISHBASE. Non-significant regression coefficients are represented by a zero value. ○ and dashed regression line = IPA area, ■ and solid regression line = the AA.

DISCUSSION

The present study has capitalised upon a management system that has been in place for a sufficient length of time (25 yrs) for ecological effects to become apparent. However, such studies are by their nature comparative. Hence the present study might be open to criticism that physical characteristics within the IPA area have allowed individuals of a variety of fish species to grow more rapidly than in nearby areas, or have encouraged large individuals to aggregate. Thus, the observed differences between the mean and maximum weights of fish caught by anglers in the IPA area and the AA may not be attributable to the IPA fishery management system. However, this study has attempted to avoid latitudinal bias in catches by comparing fish caught from within the IPA area with fish caught from either side, and has ensured a conservative estimate of benefit by defining the IPA area as a larger zone than just the IPA system. Additionally, although the biomass and diversity of the benthic community is greater within static-gear fishing areas of the IPA than in surrounding areas, this has been attributed to the absence of the impacts of towed fishing gears (Kaiser *et al.* 2000). The absence of these impacts is a fundamental characteristic of the IPA system. Hence, these analyses suggest that the IPA has acted to benefit a number of commercially important fish species.

The benefit of the IPA has been expressed by fish species in a number of different ways. The mean specimen weights of spotted ray and small-eyed ray were consistently greater in the IPA area than in the AA. The heaviest individuals of these two species were also reported from the IPA. The mean weight of all thornback ray reported was greater in the AA than in the IPA, but the rate of decline of mean weight over time was slower in the IPA area. For the larger blonde ray, no difference in overall mean or maximum weights between areas was determined, but the rate of decline in mean specimen weight over time was slower in the IPA than in the AA. The difference in response to the IPA by these species reflects other data that suggest the abundance of blonde ray and thornback ray decreased between the periods 1901-1902 and 1989-1997 in the South Devon area, whilst the abundance of spotted ray and small-eyed ray increased slightly over the same time period (Rogers & Ellis 2000).

Flatfish species also appear to be afforded some protection within the IPA area. The individual maximum and overall mean reported specimen weights for dab, brill and turbot were significantly greater within the IPA area than the AA. The declines in mean weight over time were also significantly greater for these species in the AA than in the IPA. These data also reflect findings of Rogers and Ellis (2000), who reported that the overall abundance of brill and turbot had remained relatively constant, and dab abundance had increased slightly, over the course of the 20th Century in the area of the IPA. However, direct comparison of these data with those from the present study cannot be conducted because the weights of individuals of each species were not reported in the Rogers and Ellis (2000) study. In addition, no data concerning the angling effort exerted between areas over time was available to the present study.

The benefit that fish receive from the IPA area appears to be dependent on their life history parameters. Those species that showed the strongest response have either a relatively localised distribution, or do not undertake long distance spawning or feeding migrations. The species that showed a response to the IPA are also those that typically associate with sand or gravel habitats, and their presence within the IPA is likely to be at least partially linked to the Skerries Bank. This is a 7 km long series of sand and gravel banks located entirely inside the IPA system off Start Point (Fig. 5.1). Spotted ray are limited to a small number of locations around the UK coastline (Walker & Heesen 1996) and do not appear to migrate significant distances (Walker, Howlett & Millner 1997). In northern European waters, small-eyed ray have a restricted distribution and are confined to particular sandy bays and sandbanks (Wheeler 1969). Brill and turbot are strongly associated with sand and gravel habitats, and whilst dab is abundant in northern European waters, the adults do not appear to undertake spawning migrations (Wheeler 1969). In combination with the presence of suitable habitats, life history characteristics may have allowed these species to gain refuge benefit from the existence of the IPA.

The species that appeared to either benefit from the IPA to a lesser extent, or did not appear to benefit at all, generally had either less site fidelity, or were long-lived and late maturing. Thornback ray are found in a wide variety of habitats, from mud substrata through to rough ground (Wheeler 1969), and were widespread in European waters prior to intensive trawling (Walker & Hislop 1998). However, this species does not appear to migrate long distances (Walker *et al.* 1997). In contrast, blonde ray appear to be patchily distributed (Walker & Hislop 1998), but are associated with sand habitats (Wheeler 1969). The general decline in mean weight of these two species within both the IPA and the AA is probably linked to their longevity and late maturation. Essentially, long-lived species have a greater chance of being caught by anglers, or randomly straying beyond the limits of the IPA into a commercially fished zone. Whilst plaice and bass mature earlier and are less long-lived than most rays, both species undertake long spawning migrations and are widespread in European waters (Pawson, Kelley & Pickett 1987; Rijnsdorp & Pastoors 1995; Hunter, Metcalfe & Reynolds 2003). The characteristics of these species limit the potential for the IPA to provide any refuge benefit.

The refuge benefit afforded to fish by the IPA appears to be partly dependent on the size attained by each species. The plot of the slope of the relationship between the mean weight of specimen fish reported with time against L_{mat} suggests that rate of decline in mean weight was greatest for long-lived species with a large L_{mat} (Fig 5.7). However, this figure also suggests that the decline was significantly later within the IPA in comparison to the AA, in favour of fish with a larger L_{mat}. Whilst there is potential for the comparison of regressed mean reported specimen angling weight against L_{mat} for all species to be confounded by incorrect estimates of L_{mat}, fish of a large body size do tend to be more susceptible to the effects of fishing (Trippel 1995; Jennings, Reynolds & Mills 1998). This seems to have been confirmed by the data collected for this study. Roundfish, flatfish and ray species also exhibit different susceptibilities to fishing gears (Rogers & Ellis 2000), or differences in their response to exploitation (Jennings *et al.* 1998; Jennings 2000). Ray species typically exhibit slow growth, late maturity and low fecundity, and the larger species are particularly susceptible to overfishing (Walker & Hislop 1998; Dulvy *et al.* 2000; Dulvy & Reynolds 2002). In contrast, smaller flatfish species mature early, are relatively fecund, and population growth rates may have increased due to compensatory mechanisms as predators and competitors are removed through fishing (Jennings 2000). These different responses are demonstrated through the pattern of decline observed in the species compared in this study. It is apparent that the IPA has some benefit for even the largest species in the present study, although each species has at least declined in either abundance or in mean weight over time. Whilst populations of fish species are typically subject to large fluctuations over time (Horwood 2000), it appears that the IPA has not provided sufficient protection to prevent population level effects in any of the fish species studied.

An important transition for plaice, brill and turbot appears to have taken place during the 1980s, in that catches of these species declined in the IPA whilst increasing in the AA. A number of explanations are possible; firstly that there was an increase in angling effort in the AA, with a corresponding decrease in effort in the IPA area; secondly that commercial fishing pressure increased in the region of the IPA whilst decreasing in the AA; and thirdly that the environment within the IPA became less favourable during this period, and the stock 'moved' such that they became more available to anglers fishing in the AA. Without direct observation, it is not possible to attribute the switch in catch numbers to an individual cause, although it is likely that the relative angling effort between the IPA and the AA did not effect the change as no other species showed this pattern. Further, there is no evidence to suggest that the suitability of the habitats in the two areas changed such that any significant stock movement occurred. However, angling effort within the IPA is heavily concentrated around the Skerries Bank. For example, during angling competitions, as many as 80 angling boats, each with at least 2 anglers aboard, have been counted fishing over the Bank (RB, pers. obs.). This concentration of effort may have impacted the local fish stocks. Although evidence of angling-induced stock declines appears rare, the abundance and size of a number of fished species were shown to be lower in a New Zealand marine park open to angling than in commercially fished areas nearby (Denny & Babcock 2004). However, the concentration of angling effort on the Skerries Bank does not explain the corresponding rise in reported catches for plaice, brill and turbot in the AA. On further examination, much of the increase in flatfish catches in the AA was attributed to the Shambles and Portland Banks, another complex of sand and gravel banks that lie to the east of the IPA off Weymouth (Fig. 5.2). A number of inshore trawlers that regularly targeted this area reportedly retired in the early 1990s (Colin Penny and Richard English, Weymouth charter angling skippers, pers. comm.), and the reduction of commercial pressure in this area may have allowed anglers to catch an increased number of large flatfish. However, the rise in catches appears to have started prior to this date, and therefore the reason for the change in catches between the IPA and the AA remains unknown.

Commercial landings of fish species that are not specifically targeted should correspond to stock size, on the basis that greater numbers will be caught by chance as bycatch in abundant years than in poor years. Dab and spotted ray are not subject to quota restrictions in the Western Channel (ICES area VIIe), and there is no reason to suspect that commercial fishermen under-report landings of these species. It is also likely that few anglers specifically target these smaller species. Significant positive correlations were determined between the number of angling catches and commercial landings for dab and spotted ray (Fig. 5.7). It is further apparent that these relationships would be even more striking if the commercial landings were correlated against angling catches from 3 years later. This is probably because individuals from year classes entering commercial fishery statistics take a further period before reaching a specimen weight and then entering the angling data. Importantly, the relationship between angling catches and relative stock size may provide information useful for the management of fisheries of particular species in data-poor situations, where conventional stock assessments cannot be conducted but where angling records do exist. However, caution should be taken in using this approach, as anglers may be able to maintain catches of species with high site fidelity (e.g. snappers and groupers from tropical reefs; gadoids from wrecks in temperate waters) despite falling stock size due to aggregation effects, and preferential targeting by anglers.

CONCLUSIONS

Marine protected areas are proposed as important tools by which commercial fish stocks may be sustainably managed. However, their establishment can be problematic as fishers are typically unsupportive of systems that exclude them from areas of the sea because of the potential loss of earnings, present or future, that may result (Fiske 1992). For fishermen to support the introduction of such systems, it seems likely that any reduction in catch resulting from the loss of area in which to fish would need to be quickly compensated for by overspill, emigration and recruitment of fish from within the area (Jennings 2000). Globally, marine protected areas have demonstrated this ultimate goal, although there are many examples of benefits accruing to benthic communities and populations of commercially important fish within these systems (Gell & Roberts 2003). Importantly, because few large marine protected areas exist, and because the introduction of more will be politically and technically difficult, any systems that do exist should be carefully studied. Recreational angling records may provide a source of data that proves useful in this endeavour, particularly in the absence of other baseline data collected specifically to investigate the implications for targeted species.

The IPA was not established for stock maintenance or conservation reasons, and yet benefits appear to have developed for commercially fished species as a result of its function. Other systems that were not established for stock maintenance or conservation reasons, but which act as *de-facto* marine protected areas for intensive commercial exploitation, such oil fields or wind farms, may present the best opportunity to investigate the effect on fish stocks of introducing other marine protected areas in temperate waters. However, it appears from this study that even relatively large systems such as the IPA are insufficiently large to afford protection to longer-lived, late maturing, or migratory fish species.

CHAPTER 6

PAYING FOR THE BIG ONE: THE ECONOMICS OF ANGLING AND MARINE PROTECTED AREAS IN THE SOUTH-WEST OF THE UNITED KINGDOM

6: PAYING FOR THE BIG ONE: THE ECONOMICS OF ANGLING AND MARINE PROTECTED AREAS IN THE SOUTH-WEST OF THE UNITED KINGDOM

SUMMARY

A conflict of interest exists potentially between commercial fishermen and recreational anglers (anglers) because both groups often target similar species, and large 'trophy' fish typically disappear first from commercially fished stocks. Marine protected areas (MPAs) have been shown to provide benefits to fish populations as a result of reducing commercial fishing pressure on the protected population. Anglers may benefit from an increase in the availability of large fish to catch. However, the establishment and maintenance of MPAs may be costly. As one of the main groups to benefit from increases in fish stock abundance, anglers represent a potential source of income that may allow a greater number of MPAs to be established.

In this study, a contingent valuation survey was used to determine if anglers fishing off the south-west coast of the UK were willing to pay, a) to fish in MPAs where they could catch fish that were larger than average, and b) for the establishment of MPAs around the UK coastline. 314 questionnaires were collected, and analyses determined that anglers older than 51 years were willing to pay less to fish in MPAs than anglers younger than 30 years. Other socio-demographic descriptors of the sampled group made no difference to respondents' willingness to pay to fish in MPAs, and the mean bid of all respondents for catching 10% larger fish was £8.14 per day. The mean bid of all respondents to establish MPAs around the UK coastline was £14.21 per year. Annual household income and membership of conservation organisations were the only socio-demographic descriptors that significantly affected respondents' willingness to pay for MPA establishment.

Using the mean daily willingness to pay to catch 10% larger fish, and an estimate of the annual number of charter angling boats days taken by anglers in the south west of England, it is suggested that the value of MPAs in the region would be £861,780. In contrast, £2,842,000 would be raised if 10% of the sea anglers fishing annually in the UK contributed to establishing MPAs. The findings of this study suggest that

most UK sea anglers would not object to paying a sea angling license if MPAs were designed and established for the purpose of enhancing angling opportunities.

INTRODUCTION

Recreational sea angling (angling) is a popular hobby in many coastal regions. In the UK, it was estimated that two million sea anglers fished at least once in 2002, and that these anglers spent £1B in pursuit of their hobby in the same year (Anon. 2004). Logically, a primary aim for anglers is to catch fish, and it seems likely therefore that few anglers would go fishing if there was a very low probability that they would catch something. Accordingly, spending on angling would also be low. In fact, anglers often target large fish, but it is these 'trophy' fish which typically disappear first from commercially exploited stocks (Pauly *et al.* 1998; Bianchi *et al.* 2000; Myers & Worm 2003). Marine protected areas (MPAs- here defined as areas of the sea where commercial fishing is prevented, but recreational angling is allowed) may boost the angling value of fish stocks by allowing the average age and body-size of fish within the protected population to increase (Bohnsack 1992; Hutchings 1996; Russ & Alcala 1996b; Roberts *et al.* 2001).

Despite the benefits that MPAs may bring, in order to promote their use as a fishery management tool it is important to show that establishing and maintaining MPAs can be achieved with a positive benefit-cost ratio. However, it may take years for growth to be observed in fish stocks, and realisable benefits from MPAs therefore accrue slowly (Jennings 2000; Gell & Roberts 2003). In contrast, MPA management costs may accrue rapidly, and these costs may be considerable. For example, the annual median cost of managing MPAs in developed and developing countries in 2000 was £5886 and £1039 per km^2 per yr respectively, but the cost per unit area of running reserves decreased significantly as MPA size increased (Balmford *et al.* 2004).

The costs of MPAs may be readily calculated through determining the costs of management and enforcement and, initially at least, through lost commercial fishing revenue. Determining the total economic benefit of MPAs is difficult because a significant proportion of the value of environmental commodities may be derived from non-use values (Carson, Flores & Meade 2001). For MPAs, these non-use values may include existence value for particular species or for marine biodiversity generally, and bequest and option values for future angling opportunities. An advantage of determining these non-use values is that they may immediately balance costs, because the act of establishing a closed area may ensure that specified environmental goods are safe-guarded (Jakobsson & Dragun 2001).

Quantifying non-use values may be achieved through a contingent valuation survey. This technique determines respondents' 'willingness to pay' (WTP) for stated benefits, and has been used to determine the value of items such as clean water (Carson & Mitchell 1993), high quality beaches (Smith, Zhang & Palmquist 1997), habitats of endangered fish (Giraud, Loomis & Cooper 2001) and freshwater angling opportunities (Baker & Pierce 1997; Roth *et al.* 2001). Contingent valuation also enables estimates to be made of the total value of goods where no market currently exists (Carson *et al.* 2001). This factor is important because there is currently no license or permit system for sea angling in the UK However, as one of the principle beneficiaries of enhanced fish stocks, anglers could be important in contributing towards the cost of establishing and managing MPAs.

This study used a contingent valuation survey to determine if recreational anglers fishing in the south west of the UK were willing to pay, a) to fish in MPAs where they could catch fish that were larger than average, and b) for the establishment of MPAs around the UK coastline.

THE INSHORE POTTING AGREEMENT

The Inshore Potting Agreement (IPA) is a fishery management system located off the south-west coast of England (Fig. 6.1). The IPA was established in 1978, and the system functions as a form of MPA because the use of towed commercial fishing gear (i.e. trawls and dredges) is restricted within its boundaries (Chapter 2, this thesis). As a result of this restriction, the benthic community inside the IPA is more diverse than that in adjacent, towed-gear areas (Kaiser *et al.* 2000). The restriction on towed gears has also benefited anglers fishing within the IPA. Analyses of angling catches over the period 1973-2002 determined that the mean reported weight of 'specimens' (minimum qualifying 'specimen' weight as defined by the National Federation of Sea Anglers: www.nfsa.org.uk) of three flatfish and two ray species was greater in the area of the IPA than in adjacent areas (refer to Chapter 5 of this thesis). The IPA therefore represents a plausible scenario as to how commercial fishing in some coastal areas might be conducted to the advantage of recreational anglers.

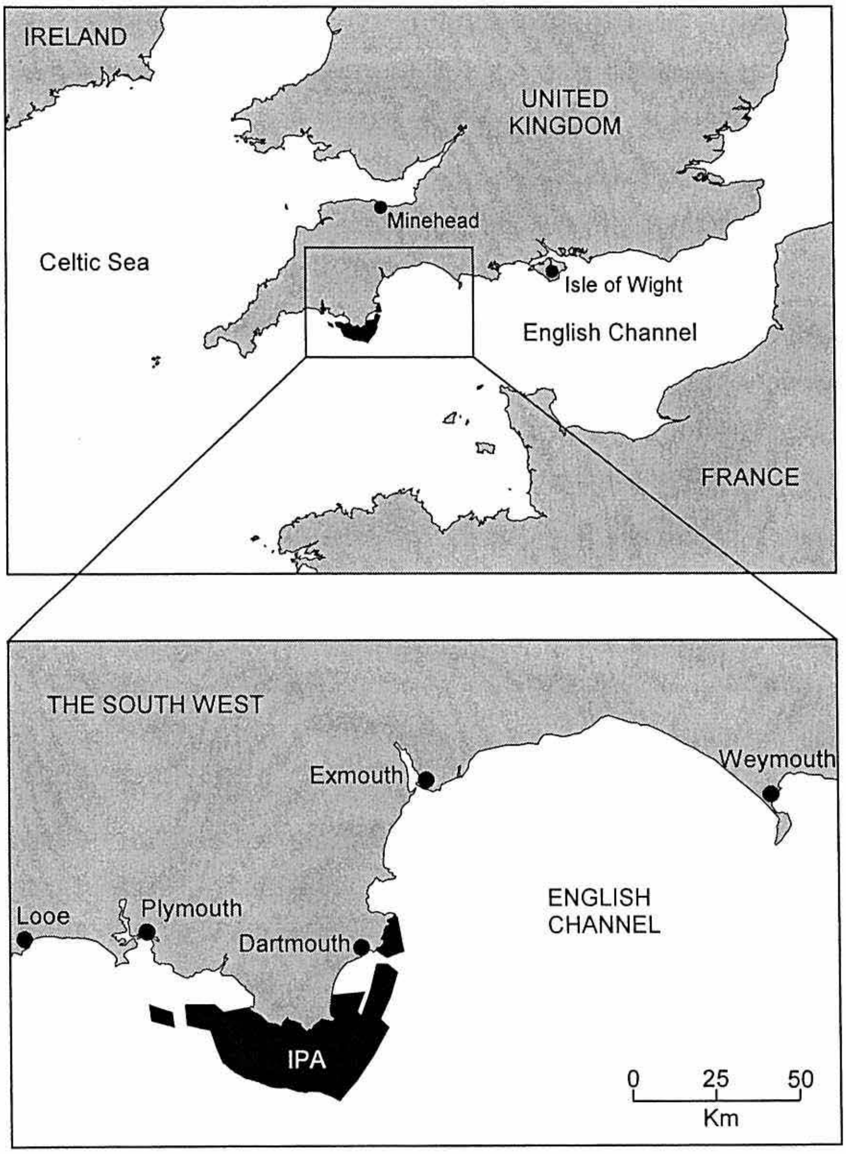

Figure 6.1: The location of the Inshore Potting Agreement (IPA) and home-ports of charter angling skippers used in the present survey.

METHODS

THE STUDY AREA AND SURVEY

The skippers of eight charter angling boats harboured between Weymouth and Looe (Fig. 6.1) were asked to distribute questionnaires amongst their customers over the 2003 summer season. These skippers agreed to promote the study aboard their vessels and provide the questionnaire to any customers who were interested in completing one during their time on the boat. This meant there would be no way of directly controlling the distribution of questionnaires, or calculating a response rate. However, it was considered that obtaining a large number of angling respondents would be impossible without adopting this technique, as anglers would be difficult to identify when not angling. Furthermore, during an early shore-based test survey it was found that anglers were not receptive to questioning while actually angling. However, on charter angling boats, there is a transit time of up to two hours between the port and fishing mark, and the same on the return trip. These journeys provided an opportunity for questionnaires to be completed, and a number of the skippers commented that the survey provided a welcome distraction to their customers. To ensure that respondents were in control of their own expenditure, only anglers greater than 18 years of age were sampled in the study. All questionnaires were retrieved from the anglers before they departed the boats at the end of each day.

QUESTIONNAIRE FORMAT

The questionnaires were constructed so that the simplest questions were asked first. It was assumed that this would encourage respondents to begin and then progress through the questionnaires. These first questions included the number of years that the respondents had been sea angling, and their favourite fish species to catch. Some questions on angler motivation followed. These questions included asking the respondent if they usually returned most of the fish they caught alive, and if they could be satisfied with an angling trip even if they caught nothing.

In the contingent valuation section, respondents were provided with a small chart and a short description of the IPA, and the following statement was highlighted, "The Inshore Potting Agreement protects seabed habitats and species, and may have enabled anglers to catch larger and more fish, in particular flatfish and rays".

Respondents were then posed the question, "If when you fished in a special area, on average you caught **10% bigger** fish than normal, how much **extra** would you be willing to pay **per day** to fish in that area". The two subsequent questions then asked for respondents' daily WTP for 30% and 50% larger fish. The survey used a payment-card format (Watts-Reaves, Kramer & Holmes 1999), such that respondents were offered WTP values of £0, £1, £2, £5, £10, £20, £30 and £50 for each benefit level offered. An option of 'other amount £......' was also provided. It would have been preferable to ask for WTP for only one benefit level in each questionnaire, but have three different versions of the questionnaire (Carson *et al.* 2001). However, the system of using skippers to distribute the questionnaires, and limited sampling effort, necessitated the use of a multiple-scenario format.

A further question asked respondents, "Should systems similar to the Inshore Potting Agreement, which limit commercial fishing effort in specific inshore areas, be established in other locations around the UK?". Respondents were offered the choice of, 'Yes definitely', 'Yes probably', 'Neutral', 'No probably', or 'No definitely'. The next question asked, "If you said 'Yes definitely' or 'Yes probably', how should this contribution be paid?". In answer to this, respondents were offered the choice of, 'small increase in tax on fishing tackle', 'donate to a special fund', 'pay a sea angling license', or 'other method......'. Respondents were subsequently asked, "If you said 'Yes definitely' or 'Yes probably', how much would you pay **per year**?". The payment options offered for this question were £1, £2, £5, £10, £20, £30, £50, £100 and 'Other amount £......'.

Finally, socio-demographic details were requested from respondents, including an estimate of household income. It was assumed that by this stage in the questionnaire, the respondents would perceive the relevance of the survey to their hobby and so would be more willing to divulge personal details. This assumption seemed to be confirmed by the results because almost all questionnaires were returned completed. Refer to Appendix 2 for a copy of the questionnaire.

Subsequent to initial questionnaire development, a pilot test was conducted at an angling club meeting in Starcross, Devon. As a result of this test, a number of questions were modified to remove ambiguity. However, the range of payments offered on the payment card were found to be consistent with anglers' WTP to establish and fish in MPAs.

DATA ANALYSES

Incomplete questionnaires were discarded from the analysis. The remaining questionnaires were then examined to determine the number of protest bids in the contingent valuation. Protest bids were identified when a respondent valued the offered benefit but refused to pay for it because they felt that they should not have to (Jorgensen *et al.* 1999). For WTP to fish in MPAs where larger than average fish could be caught, a protest bid was considered to have been made when the respondent had a WTP of £0 for all levels of increased fish size, and subsequently answered positively to 'I object to the idea of paying to fish in specific locations'. However, £0 bids were included in analyses if the respondents replied that they could not afford any extra payment, or did not think that the benefits offered were worth paying anything extra for (i.e. real £0 bids). For WTP for establishing fishery management systems similar to the IPA, a protest bid was considered to have been made if the respondent answered 'Yes definitely or 'Yes probably' to whether more MPAs should be established, but 'No probably' or 'No definitely' to whether sea anglers should contribute to their establishment.

Normal distribution could not be achieved with any dataset, which constrained all analyses to non-parametric tests. Hence, Kruskal-Wallis tests were conducted to compare the median WTP of anglers from different socio-demographic groups for each level of benefit (on average catching 10, 30 or 50% larger fish) offered for fishing in MPAs, and for establishing MPAs in other locations (Arlinghaus & Mehner 2004). The socio-demographic descriptors used in these analyses were the location of the port that the angler was fishing from relative to the IPA, and the respondent's age, sea angling experience, annual frequency of sea angling and annual household income. The proximity of the respondent's home to any coast was also considered, together with their membership of conservation organisations (e.g. the Worldwide Fund for Nature, Greenpeace, Royal Society for the Protection of Birds, etc.) and whether they had fished in freshwater in the UK in the previous year. For membership of conservation organisations and whether the respondent had fished in freshwater, the categories were 'yes' or 'no'. For other descriptors, three categories were defined (Table 6.1).

Table 6.1: Categories for demographic descriptors of angling respondents.

Demographic Group	Group i	Group ii	Group iii
Port location relative to the IPA	West	IPA	East
Age of respondents (years)	18 - 30	31 – 50	51+
Sea angling experience (years)	< 5	5 – 20	> 20
Annual angling frequency (times)	< 10	10 – 30	> 30
Membership of conservation organisations	No	Yes	
Fished in freshwater in U.K. in previous year	No	Yes	
Proximity of respondents home to the coast (km)	< 50	50 – 100	> 100
Annual household income (£)	< 20K	20K - 30K	> 30K

RESULTS

SAMPLE CHARACTERISTICS

A total of 800 questionnaires were distributed to charter boat skippers in Spring 2003, and 314 were returned completed at the end of the study in October 2003. A further 32 questionnaires were returned partially completed or were completed by persons under the age of 18, and so were discarded, whilst the remainder had not been attempted. This provided an overall response rate of completed questionnaires of 39.3%.

The average age of all respondents was 45.3 years, with 10.8% being 18-30 years of age, 56.4% being 31-50 years of age, and 32.8% being greater than 51 years of age. Only two of the respondents were female. This sex bias in the respondents was probably unavoidable, given that angling in the UK is traditionally a male-dominated hobby and because, until recently at least, relatively few charter angling boats were equipped with toilet facilities for female anglers. All anglers were residents of the UK, with a mean distance travelled of 240 km (range 0-824 km) between the respondent's home and the fishing port (estimated from the Automobile Association route-planner: www.theaa.co.uk).

After removing all protest bids, 265 questionnaires were subsequently analysed for WTP to fish in MPAs where larger than average fish could be caught, and 240 questionnaires were analysed for WTP to establish IPA-like fishery management systems in other locations (Table 6.2).

Table 6.2: Charter angling boat port locations, questionnaire numbers and number of protest bids for larger than average fish and IPA-like management systems.

Region	Port	Charter Boats	Questionnaires Completed	Protests for Bigger Fish	Protests for IPA-like Systems
West	Looe	1	55	7	12
IPA	Plymouth	2	40	7	11
IPA	Dartmouth	2	128	16	27
East	Exmouth	1	72	12	17
East	Weymouth	2	19	7	7
	Total	**8**	**314**	**49**	**74**

DAILY WTP TO FISH IN MPAS.

Following the removal of protest bids, £0 bids for 10%, 30% and 50% increases in fish size accounted for 15.1%, 10.8% and 9.6% of all bids respectively. The mean bid (including £0 bids) for 10%, 30% and 50% increase in fish size was £8.13 ± 8.07 (S.D.), £11.59 ± 9.94 (S.D.) and £16.04 ± 13.86 (S.D.) respectively. This difference in daily WTP between benefit levels offered was significant (H= 75.33, DF= 2, *P*< 0.001).

The age of the respondent was the only demographic descriptor that was found to significantly affect respondents' daily WTP for fishing in MPAs where larger than average fish could be caught (Table 6.3). The oldest age group of anglers (51+ years) were willing to pay less for fishing in MPAs than those anglers in the two younger age groups, but only for 30% and 50% larger fish. At the 10% level, no significant difference was found (Fig. 6.2). It was noticeable that annual household income did not significantly affect respondents' WTP for fishing in MPAs where larger fish could be caught.

Table 6.3: Results of Kruskal-Wallis tests for comparisons of WTP for catching 10%, 30% or 50% larger fish by anglers from different socio-demographic groups. Bold italics indicate significant comparisons.

Port location relative to the IPA

		10%					30%					50%				
	N	Median	Rank	Z			Median	Rank	Z			Median	Rank	Z		
West	48	5.00	146.2	1.32	H	3.70	10.00	141.8	0.88	H	1.11	17.50	145.4	1.24	H	1.65
IPA	145	5.00	125.3	-1.79	DF	2	10.00	129.2	-0.90	DF	2	10.00	129.8	-0.75	DF	2
East	72	5.00	139.7	0.87	*P*	0.157	10.00	134.9	0.24	*P*	0.574	10.00	131.1	-0.24	*P*	0.438

Age of respondent (years)

	n	Median	Rank	Z			Median	Rank	Z			Median	Rank	Z		
18-30	29	5.00	145.1	0.90	H	1.56	10.00	161.4	2.11	H	6.32	20.00	172.2	2.92	H	15.22
31-50	151	5.00	134.5	0.36	DF	2	10.00	134.0	0.25	DF	2	10.00	137.3	1.04	DF	2
51+	85	5.00	126.2	-0.99	*P*	0.459	10.00	121.5	-1.68	*P*	***0.042***	10.00	112.1	-3.06	*P*	***0.000***

Sea angling experience (years)

	N	Median	Rank	Z			Median	Rank	Z			Median	Rank	Z		
< 5	43	5.00	126.5	-0.60	H	4.54	10.00	123.0	-0.93	H	5.71	10.00	123.0	-0.93	H	4.05
5-20	85	5.00	121.5	-1.68	DF	2	10.00	121.1	-1.74	DF	2	10.00	123.7	-1.36	DF	2
> 20	137	5.00	142.2	2.02	*P*	0.103	10.00	143.5	2.31	*P*	0.057	10.00	141.9	1.96	*P*	0.132

Annual sea angling frequency (times)

	n	Median	Rank	Z			Median	Rank	Z			Median	Rank	Z		
< 10	140	5.00	132.6	-0.10	H	1.17	10.00	133.0	-0.01	H	2.80	10.00	133.5	0.11	H	0.86
10-30	95	5.00	129.5	-0.55	DF	2	10.00	126.8	-0.98	DF	2	10.00	129.0	-0.64	DF	2
> 30	30	10.00	146.1	1.00	*P*	0.557	10.00	152.8	1.50	*P*	0.247	15.00	143.4	0.79	*P*	0.649

Membership of conservation organisations

	n	Median	Rank	Z			Median	Rank	Z			Median	Rank	Z		
No	204	5.00	133.7	0.28	H	0.08	10.00	132.7	-0.13	H	0.02	10.00	129.7	-1.29	H	1.76
Yes	61	5.00	130.6	-0.28	DF	1	10.00	134.1	0.13	DF	1	20.00	144.1	1.29	DF	1
					P	0.774				*P*	0.892				*P*	0.185

Fished in freshwater in the UK in previous year

	N	Median	Rank	Z			Median	Rank	Z			Median	Rank	Z		
No	159	5.00	128.9	-1.07	H	1.23	10.00	128.6	-1.15	H	1.42	10.00	129.4	-0.93	H	0.91
Yes	106	5.00	139.1	1.07	DF	1	10.00	139.6	1.15	DF	1	10.00	138.3	0.93	DF	1
					P	0.268				*P*	0.233				*P*	0.341

Proximity of home to the coast (Km)

	n	Median	Rank	Z			Median	Rank	Z			Median	Rank	Z		
< 50	182	5.00	129.1	-1.24	H	1.66	10.00	129.8	-1.02	H	1.28	10.00	132.2	-0.26	H	0.09
50-100	38	5.00	142.0	0.78	DF	2	10.00	136.4	0.30	DF	2	10.00	133.5	0.05	DF	2
> 100	45	5.00	141.3	0.80	*P*	0.436	10.00	143.2	0.98	*P*	0.526	10.00	135.9	0.28	*P*	0.956

Annual household income (£)

	n	Median	Rank	Z			Median	Rank	Z			Median	Rank	Z		
< 20K	86	5.00	126.1	-1.02	H	1.17	10.00	123.5	-1.40	H	2.10	10.00	120.5	-1.84	H	3.59
20-30K	69	5.00	134.9	0.24	DF	2	10.00	137.7	0.59	DF	2	10.00	140.0	0.88	DF	2
> 30K	110	5.00	137.2	0.75	*P*	0.558	10.00	137.5	0.80	*P*	0.351	10.00	138.4	0.96	*P*	0.166

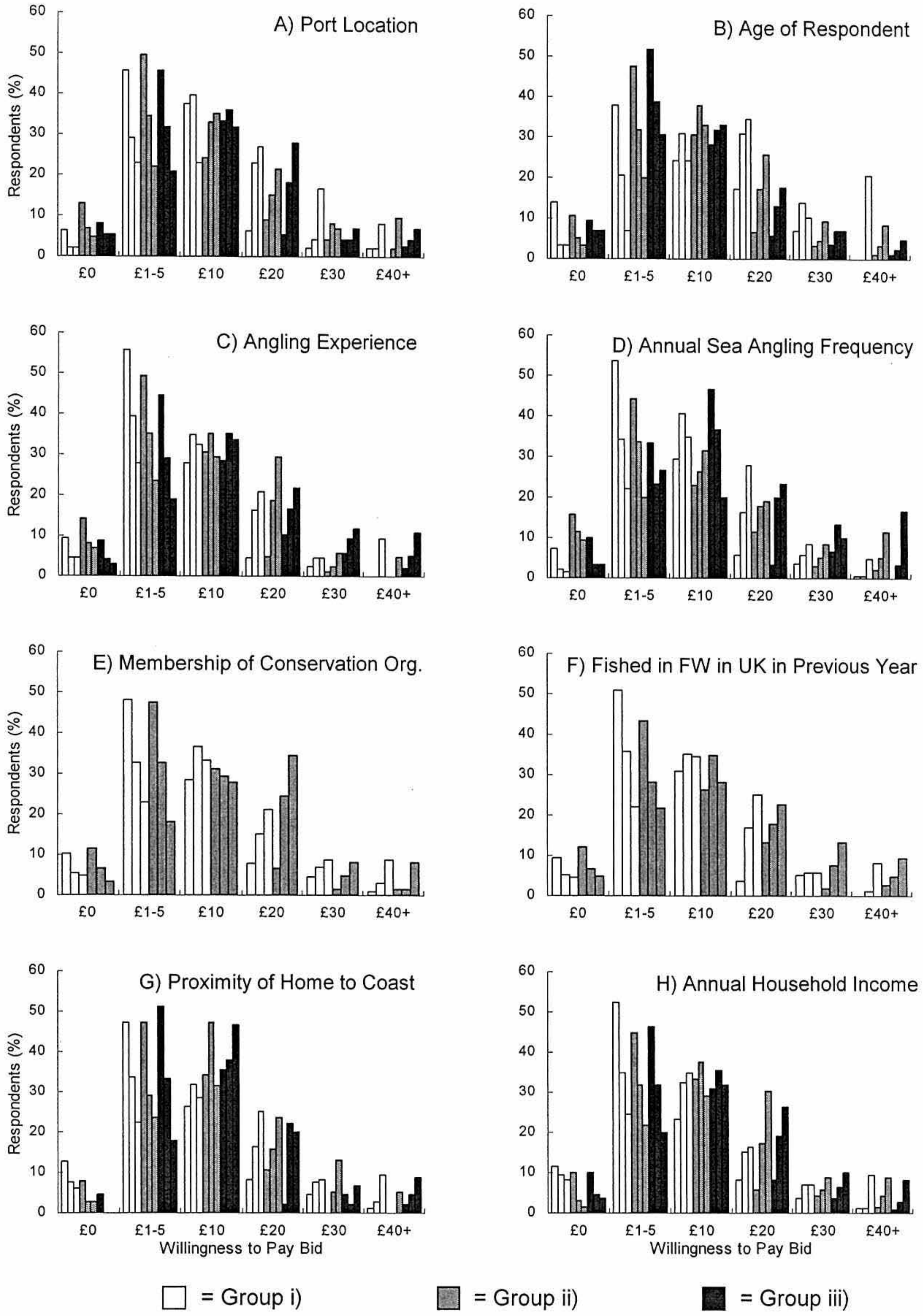

Figure 6.2: Willingness to pay to fish in MPAs to catch 10%, 30% or 50% larger than average fish by the percentage of anglers from different demographic groups. Within each angler group and bid level the data show values for 10%, 30% and 50% increased fish size respectively. Groups compared for A] were i) to the West of the IPA, ii) adjacent to the IPA or iii) to the East of the IPA; for B] were i) 18-30, ii) 31-50 or iii) 51+ years; for C] were i) 0-4, ii) 5-20 or iii) 20+ years; for D] were i) 0-9, ii) 10-29 or iii) 30+ times; for E] were i) No or ii) Yes; for F] were i) No or ii) Yes; for G] were i) 0-50, ii) 51-100 or iii) 101+ km; and for H] were i) <£20, ii) £20-30 or iii) £30K+.

ANNUAL WTP TO ESTABLISH MPAS.

The mean annual WTP for establishing MPAs was £14.21 ±17.70 (S.D.), although even after removal of protest bids, 40.0% of respondents bid £0. Of those respondents that were prepared to pay a sum, 62.7% of respondents listed a sea angling license as being their preferred payment option, whilst 20.4% preferred to donate to a voluntary fund and 16.9% preferred a small increase in tax on fishing tackle purchases.

Membership of conservation organisations and annual household income were the only demographic descriptors that were found to significantly affect respondents' WTP for establishing IPA-like management systems (Table 6.4). Respondents who were members of conservation organisations had a higher annual WTP, as did those with a higher annual income (Fig. 6.3).

VALUE OF MPAS IN THE SOUTH-WEST OF THE UK

At least 106 registered commercially-operated charter angling boats operate in the south-west of the UK, between the Isle of Wight and Minehead (Professional Boatman's Association: www.pba.org.uk/boats.html) (Fig. 6.1). These vessels are typically licensed to carry 10 anglers, and it may be estimated conservatively that each vessel is chartered for 100 days per year. If all of the anglers using these vessels were taken to fish in MPAs where 10% larger than average fish could be caught, and if each angler was charged an extra £8.13 (the mean WTP for 10% larger fish) for the opportunity, the annual value of MPAs to the economy of the south west of the U.K would be £861,780. If the mean bids for 30% and 50% larger fish (£11.59 and £16.04) were used in the calculation in the same way, the value would be £1,228,540 and £1,700,240 respectively.

In regard of establishing MPAs, if only 10% of the 2M sea anglers who fished in the UK in 2002 paid £14.21 for a sea angling license, then £2,842,000 would be raised.

Table 6.4: Results of Kruskal-Wallis tests for comparisons of WTP for establishing closed areas by anglers from different socio-demographic groups. Bold italics indicate significant comparisons.

Port location relative to the IPA

	n	Median	Rank	Z		
West	67	10.00	124.3	0.53	H	1.30
IPA	130	10.00	116.1	-1.06	DF	2
East	43	10.00	127.8	0.76	*P*	0.522

Age of respondent (years)

	n	Median	Rank	Z		
18-30	26	10.00	125.8	0.41	H	2.55
30-50	141	10.00	124.9	1.17	DF	2
51+	73	10.00	110.1	-1.53	*P*	0.279

Sea angling experience (years)

	n	Median	Rank	Z		
< 5	37	5.00	101.1	-1.85	H	3.80
5-20	78	10.00	122.3	0.28	DF	2
> 20	125	10.00	125.1	1.08	*P*	0.149

Annual angling frequency (times)

	n	Median	Rank	Z		
< 10	126	10.00	115.0	-1.28	H	1.79
10-30	84	10.00	126.8	1.03	DF	2
> 30	30	10.00	125.8	0.44	*P*	0.409

Membership of conservation organisations

	n	Median	Rank	Z		
No	187	10.00	114.4	-2.55	H	7.06
Yes	53	20.00	142.0	2.55	DF	1
					P	***0.008***

Fished in freshwater in the UK in previous year

	n	Median	Rank	Z		
No	141	10.00	117.4	-0.83	H	0.75
Yes	99	10.00	124.9	0.83	DF	1
					P	0.388

Proximity of home to the coast (Km)

	n	Median	Rank	Z		
< 50	161	10.00	117.0	-1.11	H	3.41
50-100	39	20.00	138.5	1.77	DF	2
> 100	40	10.00	116.9	-0.36	*P*	0.181

Annual household income (£)

	n	Median	Rank	Z		
< 20	78	2.50	105.2	-2.37	H	11.30
20-30	65	10.00	113.3	-0.97	DF	2
> 30	97	20.00	137.6	3.15	*P*	***0.004***

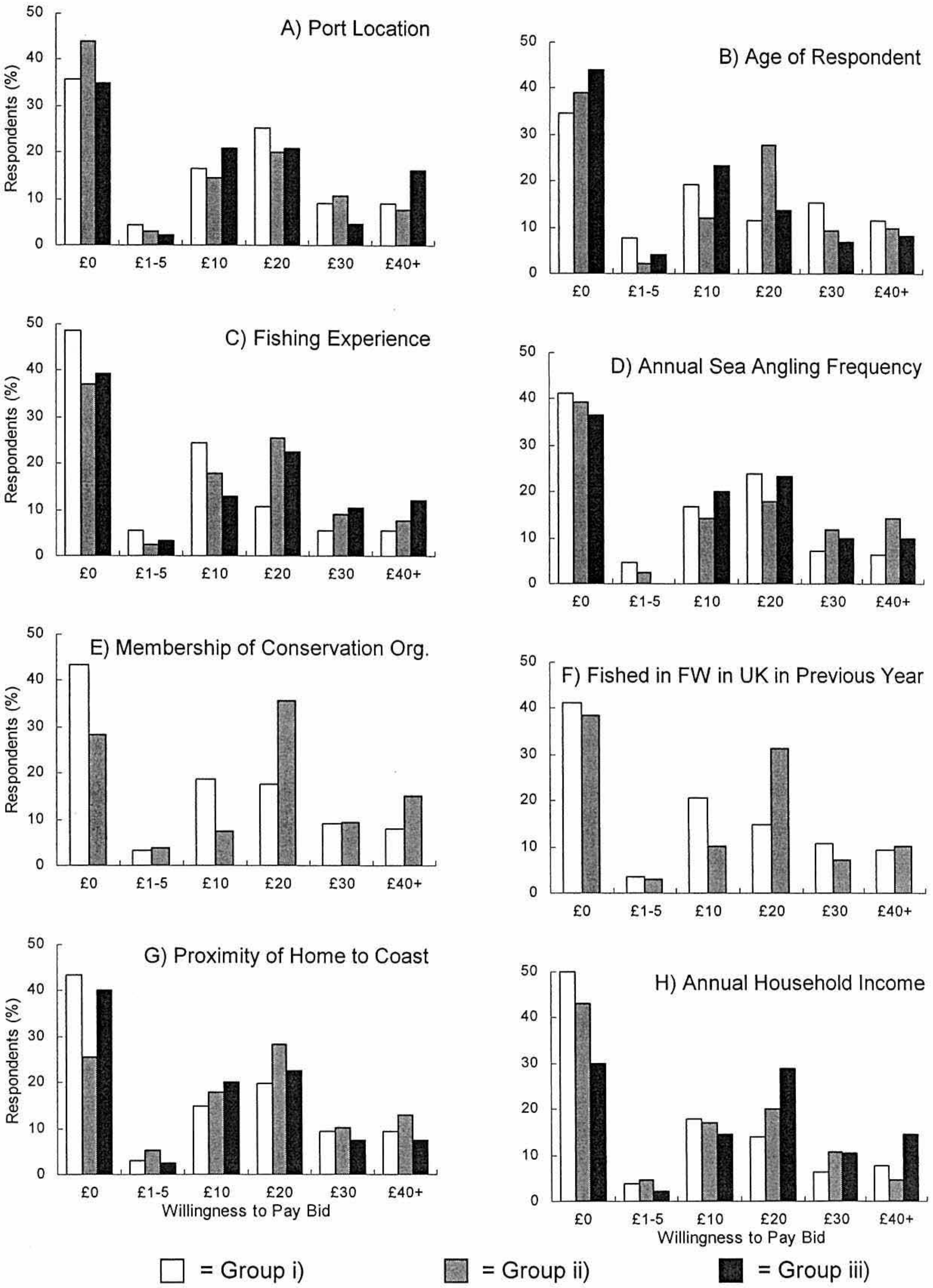

Figure 6.3: Willingness to pay for establishing MPAs by the percentage of anglers from different demographic groups. Groups compared for A] were i) to the West of the IPA, ii) adjacent to the IPA or iii) to the East of the IPA; for B] were i) 18-30, ii) 31-50 or iii) 51+ years; for C] were i) 0-4, ii) 5-20 or iii) 20+ years; for D] were i) 0-9, ii) 10-29 or iii) 30+ times; for E] were i) No or ii) Yes; for F] were i) No or ii) Yes; for G] were i) 0-50, ii) 51-100 or iii) 101+ km; and for H] were i) <£20, ii) £20-30 or iii) £30K+.

DISCUSSION

The economic value of sea angling has been of interest for some time (Glover 1980). To some extent, this is because fishery resources are scarce and there is a potential conflict of interest between recreational and commercial fisheries- effectively, a fish that is caught commercially cannot be caught recreationally. In this regard, it may be argued that some fish stocks should be managed for anglers rather than for commercial fishermen because the economic value of fish may be far greater if they were caught by anglers.

An example of the economic argument is that ten anglers may pay a total of £300 to hire a charter angling boat for a day in order to catch plaice from the south west of the UK. These anglers may also pay for accommodation and food in the local community, together with travel costs to reach the port and tackle with which to go fishing. It would conceivably make the trip worthwhile if each of the anglers caught one 1.82 kg plaice during the day (fish that would just qualify for National Federation of Sea Anglers' 'specimen' awards). The value of those fish would be £16.48 per kg (if only the charter boat hire is considered), but the true value would be much higher if all costs were included. In addition, 'catch and release' angling is now commonplace, such that the fish may be returned to be recaptured at a later date. In contrast, the average price of commercially-caught plaice on a south west UK fish market from June to August 2003 was £2.55 per kg (n= 13, range= £2.00-£3.00) (Anon. 2003), and those fish can be caught once only. However, if cod or pollack *Pollachius pollachius* are used as example species, the argument is less clearly in favour of angling because these fish grow to a larger size. Using the same principles (i.e. 10 anglers hiring a charter boat for £300 and catching one 'specimen' sized fish each), the angling value of those cod and pollack would be £3.30 and £4.13 per kg respectively, against commercial values of £2.78 (n=13, range £2.20-£3.70) and £2.00 (n=13, range £1.30-£2.70) per kg (Anon. 2003).

Importantly, some of the anglers in the notional examples above may not have caught any fish, and thus the value of any fish that were caught would be greater. However, it is critical to the argument that there must have been the possibility that fish would be caught as, in the ultimate example, extinction of a fish species would reduce the recreational angling value of that species to zero. Unfortunately, the valuation of opportunities for anglers to catch unusually large fish in wild fisheries is troubled by a single major issue; this is that there can be no guarantee that large fish will be available to be caught. Essentially, the opportunity to catch large fish may be somewhat guaranteed in freshwater fisheries where restocking can take place. In contrast, stocks of marine fish are subject to large natural fluctuations, and thus angling opportunities for marine species may be constrained. If the opportunity for sea anglers to catch large fish cannot be guaranteed, then anglers may be unwilling to pay anything extra.

In the UK, a clear precedent has been set for paying for angling opportunities. In England and Wales, an annual freshwater coarse angling license (i.e. for percids, cyprinids and non-migratory trout) cost £23.25 for the 2004 season. The argument that this charge helps to cover the restocking costs of these freshwaters and that no restocking is undertaken in the marine environment (therefore there should be no charge) is nullified because an annual migratory salmonid license (i.e. for salmon *Salmo salar* and sea-trout *Salmo trutta*) cost £62.25 in 2004. Only limited restocking of these migratory species is undertaken in the UK. Furthermore, UK freshwater licenses only provide the individual with the right to fish in publicly owned waters, and additional license or ticket costs may be charged for private waters. These costs can be considerable (mean £6.81 per day, range £2.50-£23.50, for 62 coarse waters in the southern England; mean £23.17 per day, range £8.00-£60.00, for 78 non-migratory trout waters in the southern England (www.go-fish.co.uk)), but the opportunities for catching large individual fish are often implicit within those costs.

In this study, no significant difference was found between the WTP to fish in MPAs between those anglers who had fished in freshwater in the UK in the previous year and those anglers who had not. This may have been because the non-freshwater anglers also comprised those who had fished in freshwater at some point in the past, and so were conscious of the legal need to pay for a freshwater angling license, or because the respondents did not associate paying to fish in freshwater with paying to fish in the sea. It is also possible that the anglers regarded paying to fish on charter boats as akin to paying to fish in areas where they had a better chance of catching larger than average fish. In fact, when fuel, parking, bait, fishing tackle, food and boat fees were considered, the stated average daily cost of charter boat angling to respondents in this study was £95.77 (n= 314, range £35-£310); for those visiting anglers who stayed overnight in the fishing ports, the average price of accommodation was a further £23.38 (n= 139, range £10-£50) per night.

It was noticeable that annual household income was not found to significantly affect the respondents' WTP to fish in MPAs, despite the apparent high daily cost of charter angling. However, it is not necessarily true that income and WTP must be positively correlated. Carson *et al.* (2001) described how the income elasticity of WTP is likely to be less than the income elasticity of demand for environmental goods. In the case of environmental goods that are considered 'luxuries', WTP for the good is likely to be positively correlated with income. An example of this type of good might be conserving a species endemic to a country that a respondent may never travel to. In contrast, catching big fish may have been regarded as a 'necessity' by the anglers surveyed in this study. In this case, annual income could have had little effect on anglers' WTP for bigger fish because the income elasticity of demand for bigger fish was greater than the income elasticity of WTP. Effectively, it seemed that those anglers with lower household incomes did not offer significantly lower bids for bigger fish than those anglers with higher incomes because they all regarded bigger fish as being something fundamentally worth paying for.

The respondent's age was the only demographic descriptor that was found to significantly affected their WTP for fishing in MPAs; the oldest anglers were willing to pay less to catch 30% and 50% larger fish. This may have been due to a perceived ability by older anglers to catch larger fish if patience, skill and time were utilised. However, it should be noted that whilst angling experience was not found to significantly affect respondents WTP for fishing in MPAs, the respondents' age and angling experience were positively correlated (n= 265, r= 0.197, *P*= 0.001). This contradiction may have been because whilst 137 respondents were categorised as having the most angling experience (>20 years), only 85 respondents were placed in the oldest age category (>51 years). In addition, anglers in this survey as young as 24 years old stated that they had >20 years angling experience, and so it is possible that younger respondents affected the analysis of WTP within angling experience in comparison to age.

The implications of MPAs are not just that commercially or recreationally targeted fish species are provided an opportunity to grow larger. MPAs may provide a valuable management tool to ensure that marine habitats, and benthic communities generally, are protected from impacts associated with the use of towed commercial fishing gears. These impacts may include a reduction in the biomass, complexity and productivity of benthic communities (Dayton *et al.* 1995; Jennings & Kaiser 1998;

Auster & Langton 1999; Schratzberger *et al.* 2002). In contrast to paying for fishing in MPAs, it was interesting that annual household income was found to significantly affect the respondents' WTP for establishing MPAs. In this case, the environmental good offered may have been considered a luxury, as benefits accrue to the environment generally rather than to the respondents specifically. Hence, the income elasticity of demand may have been less than the income elasticity of WTP, such that those respondents with a lower income were not willing to pay as much as those respondents with a higher income. The only other demographic descriptor that significantly affected the respondents' WTP for establishing MPAs was membership of conservation organisations. As this status did not make a significant difference to those respondents' WTP to fish in MPAs, it seems likely that the higher bid for establishing the systems was on the basis of their collateral conservation benefits.

In the UK, the *Magna Carta* may be cited by anglers when the issue of paying for the right to go sea angling is raised. A number of respondents in this study also mentioned the *Magna Carta* when they offered protest bids for fishing in MPAs. This is because Article 33 of the document promised the common man the right to fish for free on the seashore (specifically, Article 33 refers only to fish traps). However, the *Magna Carta* was written in 1215; at that time, the global human population was relatively small and fishing effort and power was limited. Therefore, marine fish stocks could truly be considered 'inexhaustible'. This is not the case now, and overfishing and numerous stock collapses have been well documented. If anglers are to attain equal status with commercial fishermen in management fora, there is a strong argument that recreational anglers should contribute towards fishery management. This payment could help to maximise opportunities for anglers by enabling proper representation, and by ensuring fishery enforcement rules within MPAs are applied rigorously.

CONCLUSIONS

MPAs have been shown to provide benefits to both marine communities (Dayton *et al.* 1995; Auster & Shackell 2000; Jennings 2000; Kaiser *et al.* 2000; Gell & Roberts 2003) and anglers (Bennett & Attwood 1991; Roberts *et al.* 2001), and calculating the potential economic value of the MPAs is therefore not without relevance. However, if the figure of £861,780 was made available for managing MPAs around the UK coastline, and if it was assumed that management costs would be £5886 per km per yr (Balmford *et al.* 2004), then an area of only 146 km^2 could be protected. This figure does not compare well with the IPA, which covered 504 km^2 in 2003. However, the area of protection that would be possible is likely to be underestimated because the figure of £861,780 was established only from the WTP of charter anglers. As such, it does not include the value associated with private angling boats, shore angling, or the potential for greater angling expenditure to be generated in the south west of the UK because of improved angling opportunities overall.

Relatively few anglers offered protest bids when presented with the options of fishing in or establishing MPAs, when potential benefits were offered. Hence, the findings from this study suggest that most anglers would not be averse to paying a sea angling license if closed area fishery management systems were designed and established for the purpose of enhancing angling opportunities.

CHAPTER 7

DISCUSSION

7: DISCUSSION

BIOLOGICAL IMPLICATIONS OF THE INSHORE POTTING AGREEMENT

The results presented throughout this thesis provide compelling evidence to support the assertion that MPAs may help to ensure that fisheries, and the marine environment generally, are exploited sustainably. In this regard, the Inshore Potting Agreement (IPA) has conferred benefits to the inshore marine environment of south Devon, UK, even though it does not provide protection from all forms of fishing. In areas of the IPA that had not been fished with towed demersal gear, the benthic community was found to be more diverse, and had a greater biomass per unit area, than the communities in surrounding areas where towed gears were used regularly (Chapter 3). This study also determined that an alternating six-month on-off fishing regime between towed and static gears within the IPA would leave the benthic community in much the same condition as if towed gears were permitted year-round. Furthermore, even an 18-month recovery period was not found to be sufficiently long to allow the community to recover fully at impacted sites within the IPA.

In general, the results of this study may help to guide fishery managers in the event that proposals were made to allow benthic communities to recover by rotating fishing effort between areas. Essentially, greater damage may be caused to benthic communities by rotating fishing effort than if fishers were allowed simply to return regularly to favoured sites (Dinmore *et al.* 2003). However, findings from other studies suggest that if a sufficient recovery period was permitted between exploitation, then significant increases in fishery production may be generated (Murawski *et al.* 2000).

The results presented on the benefits to scallops of limiting fishing disturbance provide additional evidence of the value that may accrue for benthic communities if fishing with towed gears is prevented (Chapter 4). However, it is beyond the scope of this thesis to determine the extent to which the IPA scallop stock has benefited the external scallop fishery, either from overspill of adults or through increased larval production. Further work in this regard would require histological confirmation of the spawning status of scallops found in the IPA and surrounding areas. Nevertheless, scallops are a sessile, broadcast spawning species. Because of these characteristics, it would seem likely that the high density aggregations of scallops with large gonads that were found within the IPA would contribute significantly to larval production in the south-west UK region (Malakoff 1997; Gascoigne & Lipcius 2004).

It may be argued that the most interesting result from this thesis is that the IPA appears to have conferred benefits to large, mobile fish species (Chapter 5). These benefits may be considered particularly surprising because of the recreational angling and targeted tangle netting that is undertaken within the IPA (Chapter 2). Angling in a marine reserve in New Zealand was found to have a significant detrimental effect on fish populations in comparison to open-access areas nearby (Denny & Babcock 2004). However, whilst the fishing activities undertaken within the IPA may have impacted all of the fish species studied to some extent, and the flatfish species in particular, the results presented here support claims that even relatively small protected area systems may benefit fish populations (Gell & Roberts 2003).

SOCIO-ECONOMIC IMPLICATIONS OF THE IPA

Fundamentally, the most significant features of the IPA are that it functioned voluntarily for 24 years, and that it has allowed fishers to work profitably and maintain traditional practices on inshore grounds (Chapter 2). Furthermore, the legislation that was created to protect the IPA in 2002 was progressive, and allows fishers from all sectors to request that modifications are made to the system (Chapter 2). In this regard, it has been recognised that the success of management regimes may depend heavily on achieving public compliance with regulations (Tegner *et al.* 1996). In turn, it has been accepted that compliance with fishery regulations may be achieved by ensuring that fishers are included in the processes of making and implementing regulations (Jentoft & McCay 1995; Edwards, Jones & Nowell 1997; Jentoft *et al.* 1998). Hence, maintaining the IPA fishers' direct involvement with the management process is likely to have allowed the fishery to persist successfully over time (Chapter 2).

Specific characteristic of the IPA fishery may also have contributed significantly to its success over time. The IPA has a loose system of property rights, with gear set in 'territories' (Hart 1998). It may be no coincidence that most IPA fishers fish only with pots, because the establishment of property rights has been suggested as a means by which the incentives for fishers to fish unsustainably may be overcome

(Cunningham, Dunn & Whitmarsh 1985). Interestingly, a study of sustainable, self-regulating fishery management systems in developing countries showed that nearly all of these fisheries were confined to fixed gears in inshore or coastal waters (Scott 1998). Co-operation between the fishers was facilitated by difficult working conditions, long hours or low fishery yields. These features led to very low levels of new entry to the fisheries, and so, in time, the fishers regarded themselves as being members of a club with a set of established rules. However, the rules were not ambitious, with restrictions made on the size and sex of fish landed, the allocation of fishing areas, or the closure of the fishery during the off season (Scott 1998). With the notable differences of the IPA fishery being in the developed world, and the that fact that IPA fishers may make substantial catches at certain times of the year, the described features of these sustainable, self-regulating fisheries in developing countries characterise the IPA crab fishery.

This thesis does not provide irrefutable evidence that the IPA has benefited the economy of south Devon. However, circumstantial evidence supports the suggestion that the IPA has allowed more people to be employed in the commercial fisheries sector generally than if the IPA was not in existence. Approximately 25 static-gear boats work full-time within the IPA, each with a skipper and 1-2 crew. Whilst it is likely that some of these boats would be able to operate even in the event of the IPA collapsing, it is also unlikely that each static gear boat could be replaced on a 1:1 basis with a trawler or dredger because towed-gear boats cover more ground during fishing operations. Furthermore, inshore trawlers and dredgers may be operated single-handedly (pers. obs.), and so direct employment levels in the fishery would almost inevitably fall. Finally, employment in associated processing industries ashore may also fall in the event of towed-gear boats replacing static-gear boats. Crabs are particularly labour-intensive to process, and one of the most successful boats in the IPA static-gear fleet directly employed 7 individuals in a dedicated processing factory (pers. obs.). Whilst employment levels in the towed-gear sector may be boosted through the associated auction and marketing sectors, which appeared to be mainly by-passed in the IPA crab fishery, it is unlikely that any inshore towed-gear boats could support such high levels of associated employment. However, the question of employment levels must clearly be addressed in order to gain a better understanding of the implications of the IPA for the south Devon economy.

This study has shown that the IPA has allowed economic value to accrue to the south Devon economy through providing greater opportunities for recreational anglers, and indirectly through the existence value of the coastal environment (Chapter 6). Additionally, it was previously estimated that the oceans contribute approximately 60% of the economic value of the global biosphere, and that approximately 60% of that figure may be derived from coastal and shelf systems (Costanza 1999). In 1999, this figure converted to approximately £5 trillion per year, and was derived from tangible services such as food or oil and gas production, but also from essential ecosystem services such as climate regulation, and water and nutrient recycling (Costanza *et al.* 1997). Because the natural environment of the IPA remains less disturbed than in other areas fished with towed-gears nearby, it seems likely that greater ecosystem services, and hence value, may be derived from the south west UK region. However, the value of the ecosystem services derived from the south-west UK region has not been estimated here.

This thesis has not sought to estimate the overall economic value of the IPA, but the potential for different management scenarios to affect the output value may be summarised graphically (Fig. 7.1). Essentially, the potential for different activities and services to be impacted by static-gear, dredge and trawl fisheries may result in changes to the net economic value that may be derived from the area currently defined by the IPA. Both trawling and dredging may impact upon the static-gear fishery, and potentially reduce the ecosystem services, the existence and bequest values of biodiversity, and the opportunities for recreational users of the system. Downstream service industries for static-gear fishers and recreational users will also be impacted. In contrast, the static gear fishery prevents the towed-gear fisheries from occurring, but it is suggested here that static-gear fishing has relatively little impact upon the other activities or services that occur within or derive from the IPA. Of course, trawling and dredging would provide economic benefits to the local community in the absence of the IPA, but their magnitude in comparison to the present system or alternative uses is unknown at present.

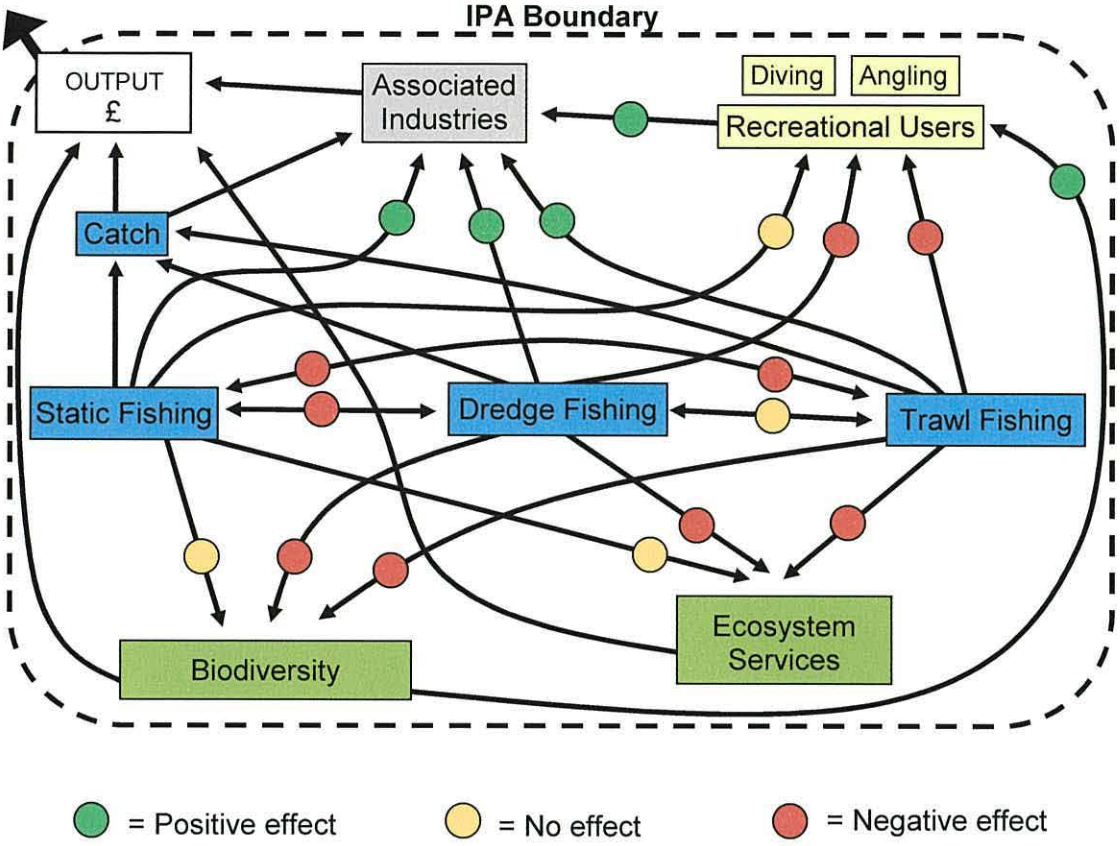

Figure 7.1: Flow diagram of economic activities and variables that may interact within the area covered by the Inshore Potting Agreement, showing the relative potential for positive and negative impacts to be caused by the static-gear, dredge and trawl fisheries on other variables and activities.

THE POTENTIAL FOR ECO-LABELLING IPA FISHERY PRODUCTS

Conservation groups have taken a keen interest in the effects of fishing on particular species. Well publicised campaigns have previously focussed successfully on 'charismatic megafauna' including turtles, albatrosses or dolphins, such that US shrimp trawlers are now required to use turtle escape panels (Lewison 2003), the Commission for the Conservation of Southern Bluefin Tuna requires members to take steps to prevent seabird bycatch (www.ccsbt.org), and tuna imported to the US must now be caught in a dolphin-friendly manner (Constance & Bonnano 1999). The impact of fishing on large and charismatic species has aroused public interest and sympathy, and can have a potent effect on fishing policies (Jones 2000).

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The conservation spotlight has now begun to focus on marine ecosystems in general. For example, Greenpeace has stated that it's current global biodiversity concerns include 'over-fishing' (www.greenpeace.co.uk), and the Worldwide Fund for Nature has also stated that it's global marine environmental targets include 'halting over-fishing' (www.panda.org). Further, the American Oceans Campaign has claimed that the world's seabed is being scraped 150 times faster than the world's forests are being clear-cut (Anon. 2000). In this regard, public interest in sustainable fisheries with minimal collateral environmental damage has clearly been raised, which may lead to increased commercial possibilities for those fisheries that satisfy these criteria.

Sustainable fisheries have been promoted by groups such as the Marine Stewardship Council (www.msc.org) and Friend of the Sea (www.friendofthesea.com). After a successful accreditation process, where it must be proved that the fishery is sustainably managed and that the fishing methods utilised have low environmental impact, fishery products are 'eco-labelled' with a recognisable logo. Eco-labelling may help to increase the value of fishery products as consumers may be willing to pay more for products which they perceive to be produced in an environmentally sustainable manner (Sutton 1998).

Well managed pot fisheries may be able to use the raised public awareness of the effects of fishing on non-target species as an opportunity to increase their value through the eco-labelling process. Hence, the Australian spiny lobster fishery and the Loch Torridon *Nephrops* fishery have already sought Marine Stewardship Council accreditation. Although the IPA crab fishery has yet to be shown to be truly sustainable, other features of the fishery appear to make it suitable for the eco-labelling process- the fishing methods employed in the IPA are highly selective and any bycatch of crustacean species can be returned alive, the bait used in pots is typically fish waste, fish by-caught in trawl fisheries that are too small for human consumption, or fast growing pelagic species, the impacts on benthic communities of static gears appear very limited in comparison to towed demersal gears, and large numbers of fishers are employed in a relatively low-technology fishery. For different biological, social or economic reasons, these are all desirable features of a sustainable fishery and, as such, the IPA crab fishery would seem to be a suitable candidate for an eco-labelling programme.

CONCLUSIONS

It has been proposed that fishery managers should bridge the gap between traditional fisheries science and socio-economic disciplines (Knudson & MacDonald 2000). One of the fundamental aspects of this process is the identification and promotion of win-win scenarios for the economy and the environment.

The Inshore Potting Agreement is an example of a management system that can provide win-win solutions to many of the problems of natural resource utilisation facing fishery managers globally. These solutions include limiting environmental degradation caused by fishing, ensuring equitable access to fishery resources, and maximising opportunities for those who extract or passively use resources from the marine environment.

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APPENDICES

Appendix 1: Chapter 3: Life mode classification for taxa collected at all sites sampled within and adjacent to the Inshore Potting Agreement.

Taxon	Mode
Actiniidae	Attached
Alcyonidium diaphanum	Attached
Alcyonium digitatum	Attached
Ascidiella spp.	Attached
Ascidia spp.	Attached
Botryllus schlosseri	Attached
Celleria fistulosa	Attached
Chaetopterus variopedatus	Attached
Eunicella verrucosa	Attached
Flustra foliacea	Attached
Hydroids, unidentified	Attached
Metridium senile	Attached
Nemertesia spp.	Attached
Pentapora fascialis	Attached
Sponge, unidentified	Attached
Suberites spp.	Attached
Tunicata	Attached
Adamsia carciniopados	Free
Aequipecten opercularis	Free
Anseropoda placenta	Free
Antedon bifida	Free
Aphrodite aculeate	Free
Asterias rubens	Free
Astropecten irregularis	Free
Atelecyclus rotundatus	Free
Buccinum undatum	Free
Calliactis parasitica	Free
Calliostoma spp.	Free
Cancer pagurus	Free
Corystes cassivelaunus	Free
Crepidula fornicate	Free
Crinoidea	Free
Crossaster papposus	Free
Cucumaria frondosa	Free
Dendronotus frondosus	Free
Ebalia tuberosa	Free
Echinus esculentus	Free
Eurynome aspersa	Free
Eurynome spinosa	Free
Galathea spp.	Free
Glycymeris glycymeris	Free
Hyas spp.	Free
Inachus dorsitensis	Free
Laevicardium crassum	Free
Liocarcinus depurator	Free
Liocarcinus pusillus	Free
Luidia ciliaris	Free
Luidia sarsi	Free
Macropodia spp.	Free
Maia squinado	Free
Marthasterias glacialis	Free
Necora puber	Free
Ophiocomina nigra	Free
Ophiothrix fragilis	Free
Ophiura albida	Free
Ophiura ophiura	Free
Pagurus bernhardus	Free
Pagurus prideauxi	Free
Pecten maximus	Free
Pilumnus hirtellus	Free
Pisa armata	Free
Pisidia longicornis	Free
Porcellana platycheles	Free
Psammechinus miliaris	Free
Sepiola atlantica	Free
Spatangus purpureus	Free
Thalassema thalassemum	Free
Tritonia hombergi	Free

Appendix 2: Chapter 6: Questionnaire used for survey of recreational charter anglers.

ANGLING SURVEY

• PRIFYSGOL CYMRU •
UNIVERSITY OF WALES
BANGOR
1884

The purpose of this survey is to examine some of the factors that make angling an important contributor to the economy of coastal towns, and to determine the value that anglers place on the marine environment and any fish that are caught. The survey is being conducted as part of research towards a PhD. For further details please contact Robert Blyth, University of Wales-Bangor, on Tel: 01248 383755.

- Your assistance in completing this form is greatly appreciated.
- Your answers will be dealt with in the strictest confidence.
- Completed surveys will be included in a draw to win a year's subscription to Sea Angler magazine. If you would like to be entered into the draw, please write your details below.

Your Name: **Contact Tel:**

Section 1: Angling

Qu.1a) **Today's Date:** Qu.1b) **Boat Name:**

Qu.2) **How many years have you been a** sea **angler?** (Please circle one)

20+ years	**10-19 years**	**5-9 years**	**1-4 years**	**less than 1 year**

Qu.4) **How often did you go** shore **angling last year?**

50+ times	**30-49 times**	**10-29 times**	**1-9 times**	**O times**

Qu.4) **How often did you go** boat **angling last year?**

50+ times	**30-49 times**	**10-29 times**	**1-9 times**	**O times**

Qu.5) **Did you go** freshwater (coarse or game) **angling in the UK last year? Yes No**

Qu.6) **Do you own a boat? (Please circle one) Yes No**

If you said 'Yes' to Qu.6, a) **Do you use your boat primarily for angling? Yes No**

b) **What is the approximate total current value of your boat £......**

Qu.7) **When sea angling in Britain, which fish species would you most like to catch? (Please name three in order of desirability)**

1st)................................ 2nd)................................ 3rd)................................

Qu.8) **In general, do you feel your chance of catching your most desirable species (Qu 7, 1st) has changed over time? (Please circle one)**

Increased a lot	**Increased a little**	**Not changed**	**Decreased a little**	**Decreased a lot**

If you said your chances of catching your most desirable species has changed in some way over time (Qu. 8), what do you think has caused this change?

..

Qu.9) **Are you a member of an angling club?** **Yes** **No**

Qu.10) **Are you a member of any angling organisations?** (Please circle all that apply to you)

NFSA **SWFSA** **BCC** **BASS** **NMC** **Others (Please specify)...............**

Qu.11) **Please indicate the extent to which you agree or disagree with the following statements.**

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
a) The more fish I catch, the happier I am..............................	1	2	3	4	5
b) I usually take home the fish I catch...................................	1	2	3	4	5
c) Even if I catch nothing, an angling trip can be successful...	1	2	3	4	5
d) I would rather catch 10 small fish than 1 or 2 big ones........	1	2	3	4	5
e) The bigger the fish I catch, the better the angling trip.........	1	2	3	4	5
f) If I thought I wouldn't catch anything, I wouldn't go angling.	1	2	3	4	5
g) I return most of the fish I catch alive................................	1	2	3	4	5
h) I am not satisfied with a trip unless I catch something........	1	2	3	4	5
i) Recreational anglers can significantly impact some fish sto	1	2	3	4	5

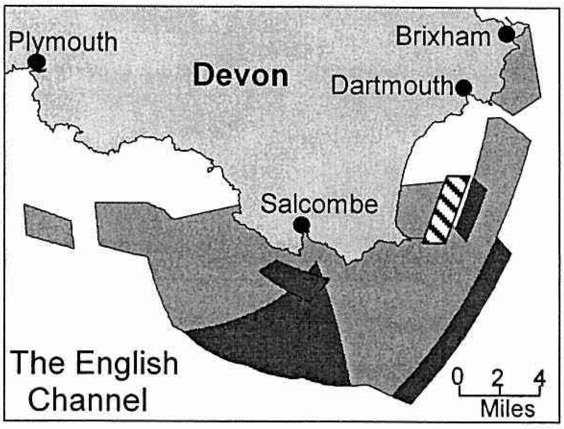
Section 2: Fishery Management

It has frequently been suggested that UK fisheries management should take account of the needs of anglers, though to date there are few examples of this occurring. However, some existing commercial fishery management systems may provide incidental benefits for anglers.

As an example, please consider the area of sea that lies off the coast of south Devon, between the ports of Brixham and Plymouth. A commercial fishery management system operates in this area, known as the Inshore Potting Agreement (Diagram 1). The system may benefit anglers because trawling and dredging is prohibited in 135 square miles of this area.

Recent scientific studies found a wider range of seabed species and habitats inside the system than in other nearby areas outside the system. It was also found that over the last 30 years, anglers have caught larger dab, brill, spotted ray and small-eyed ray inside the system than along the coast to either side.

Diagram 1: The Inshore Potting Agreement (IPA)



☐ = Any Fishing Gears

▨ = No Towed Fishing Gears

■ = Towed Fishing Gears Seasonally

▧ = The Skerries Bank

The Inshore Potting Agreement protects seabed species and habitats, and may have enabled anglers to catch larger and more fish, in particular flatfish and rays.

Qu.12) **If when you fished in a special area, on average you caught** 10% bigger **fish than normal, how much** extra **would you be willing to pay** per day **to fish in that area?** (Circle one)

£0 £1 £2 £5 £10 £20 £30 £50 Other amount £......
(please specify)

Qu.13) **If when you fished in a special area, on average you caught** 30% bigger **fish than normal, how much** extra **would you be willing to pay** per day **to fish in that area?** (Circle one)

£0 £1 £2 £5 £10 £20 £30 £50 Other amount £......
(please specify)

Qu.14) **If when you fished in a special area, on average you caught** 50% bigger **fish than normal, how much** extra **would you be willing to pay** per day **to fish in that area?** (Circle one)

£0 £1 £2 £5 £10 £20 £30 £50 Other amount £......
(please specify)

If in Questions 12, 13 or 14 **you said that you would not pay anything extra to catch bigger fish (£0), why was this?** (Please tick one)

You think that fish of the size specified are not worth paying anything extra for.... ☐
You do not like the idea of paying money to fish in a specific location................. ☐
You cannot afford to pay anything extra.. ☐
Other (please specify)...

Qu.15) **Should systems similar to the Inshore Potting Agreement, which limit commercial fishing effort in specific inshore areas, be established in other locations around the UK?**

Yes Definitely Yes Probably Neutral No Probably No Definitely

Qu.16) **If systems similar to the Inshore Potting Agreement were proposed for different locations around the UK coast, should sea anglers contribute financially to their establishment?**

Yes Definitely Yes Probably Neutral No Probably No Definitely

If you said 'definitely yes' **or** 'probably yes' **to Qu.16, how should this contribution be paid? (Please tick one)**

Small increase in tax on fishing tackle...... ☐
Donate to a special fund.......................... ☐
Pay a sea angling license.......................... ☐
Other method (please specify) ....

If you said 'definitely yes' **or** 'probably yes' **to Qu.16, how much would you pay** per year?

£1 £2 £5 £10 £20 £30 £50 £100 Other amount £........
(please specify)

Qu.17) **Do you think that conservation of the marine environment is important?**

Yes Definitely Yes Probably Neutral No Probably No Definitely

Qu.18) **Specifically, do you think that conservation of the seabed is important?**

Yes Definitely Yes Probably Neutral No Probably No Definitely

Qu.19) **Generally, do you think that UK fisheries are being well managed?**

Yes Definitely	**Yes Probably**	**Neutral**	**No Probably**	**No Definitely**

Section 3: General

Qu.20) **Have you ever been a member of a conservation organisation such as RSPB, Worldwide Fund for Nature, Friends of the Earth, etc?** **Yes** **No**

Qu.21) **Where is your home town? ....**

Qu.22) **What is the primary purpose of your being in Dartmouth? (Please circle one)**

You live locally	**A day trip only**	**Weekend break**	**Family holiday**	**Angling holiday**	**Other............** (please specify)

Qu.23) **If you do not live in Dartmouth but are staying here for 1 night or more**:

a) **How many nights are you staying locally? ....nights**

b) **Approximately how much are you paying** per night **for your accommodation? £............**

c) **How many days do you anticipate going** boat **angling in this period? ....days**

d) **How many days do you anticipate going** shore **angling in this period? ....days**

Qu.24) **Approximately how much will** you personally **spend on the following items** today?

a) **Bait £...............**

b) **Fishing tackle £...............**

c) **Your own place on the boat £...............**

d) **Food and drink (including this evening) £...............**

e) **Fuel for car/minibus £...............**

f) **Parking £...............**

Qu.25) **Where in the UK did you most frequently** boat or shore **fish last year?** (Please list the top three places or ports, **and the number of trips you made there last year)**

1) **........................ trips ......** 2) **........................ trips ......** 3) **........................ trips ....**

Qu.26) **Your age? ....years**

Qu.27) **Your sex?** **Male** **Female**

Qu.28) **Your occupation (and if retired)? ....**

Qu.29) **What is your highest level of education? (Please circle one)**

GCSE or O'Level	**A' Level**	**HND**	**Degree**	**Postgrad Degree**	**Other................** (please specify)

Qu.30) **In order that your answers to these questions may be fully analysed, please could you indicate your estimated household income this year? (Please circle one)**

Less than £10,000	**£10,000 to £14,999**	**£15,000 to £19,999**	**£20,000 to £29,999**	**£30,000 to £40,000**	**£40,000+**

Thank you very much for your time and interest. Please write any comments in the margin.