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Principles for the Management of Inshore Scallop Fisheries around the United Kingdom

(Photo: Peter Duncan)

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Executive Summary:

Fisheries for scallops, particularly the great scallop *Pecten maximus* and to a lesser extent the queen scallop, *Aequipecten opercularis*, are of considerable economic importance to the United Kingdom (UK) fishing industry. Landings of great scallops have been growing steadily since the 1970s and now consistently place this fishery in the top five most valuable species in the UK. Queen scallop catches have been much more variable over the same time period. Great scallops are predominately taken using Newhaven scallop dredges while queen scallops are mostly captured with otter trawls. A very small percentage (< 5 %) of the great scallop catch is taken by hand by SCUBA divers.

There are no catch limits on UK scallop fisheries and licence number restrictions are widely regarded as ineffective. Instead great scallop fisheries are mostly managed through minimum sizes, restrictions on dredge number and seasonal closures in some regions. The use of towed fishing gear (dredges and trawls) is also prohibited in a few small areas, generally for conservation purposes. There are few management measures for queen scallops. UK fisheries for great scallops appear to be stable at present, but there is considerable evidence that their productivity could be improved dramatically by better management. This is because at present the fishery has a number of negative effects on juvenile scallops and provides few spawning refuges for replenishment of stocks. The use of towed fishing gear also damages much of the habitat that is crucial for the settlement and survival of young scallops.

The negative effects of towed fishing gear, particularly scallop dredges, on benthic habitats and communities are also of considerable conservation concern. In general, areas subject to high fishing pressure tend to lose structural complexity and have lower biodiversity, species richness, species abundance and rates of benthic production. Biogenic reefs / substrates are the most sensitive to disturbance, followed by sandy / gravel areas. However, sandy / gravel substrates have strong potential for recovery if protected. Shallow, sandy areas subject to high levels of natural disturbance are more resilient to fishing disturbance, but tend to support few scallops and lower diversity of benthic species in general. Scallop fisheries also have a high by-catch of mobile benthic species such as crabs, starfish and some fish species. Although the ecological significance of this bycatch is unclear it has the potential to negatively affect crab fisheries.

A new management regime for UK scallop fisheries that provided better protection to key scallop nursery and breeding areas, and maintained healthier benthic ecosystems in general would undoubtedly result in more productive and sustainable fisheries. We therefore

examined a series of well managed scallop fisheries from around the world to glean how this might be achieved.

These fisheries provide good insight into successful management practices for scallops. In Australia the Queensland scallop fishery was incorporated into the Management of the Great Barrier Reef Marine Park as a whole showing that an ecosystem level approach is feasible. In fisheries such as the US sea scallop where the stock was officially declared overfished, reduction in fishing effort resulted in a return to healthy biomass levels. This has included improvement of the size class structure, a characteristic which would be of great benefit to the UK fishery. Protection of juveniles has proven to be a key factor in several cases and in the French fishery in the Bay of Saint Brieuc it was considered a main reason for their success by increasing the number of virgin (previously undisturbed / captured) scallops and therefore the yield per recruit. Habitat mapping has proven invaluable in most examples for providing information on the location of areas that should be protected for the benefit of juvenile scallop settlement and nursery grounds for other commercial species as well as habitat types that should be protected in their own right to conserve biodiversity.

There appear to be two successful ways of implementing these changes. One way is with firm government legislation, which includes tight fishing restrictions that is backed up by a strong enforcement plan. This would include measures such as satellite tracking, patrol boats, on board observers and dockside monitoring. An alternative strategy would be to confer on the fishers a level of ownership of their resource and in some cases this has lead to an industry funded and managed recovery of the resource. This strategy ultimately requires little policing.

We suggest a UK management plan primarily based on conferring a level of ownership to fishers operating within the 6 mile zone. This may be met with some resistance in the first instance and we would envisage that a level of enforcement may be required at first. This has been found in other examples but as time passes less enforcement is necessary. This should be set within a framework of zones that should consider all users. We further suggest that all interested parties should be included in an ecosystem level management plan and that the scallop fishery should fit into that plan. Provision should be made to minimize the negative effects of one user group on another such as scallop dredges damaging crabs and tangling in crab pots. The inshore area up to 3 miles should be considered a low impact zone with the 3-6 mile area being a medium impact zone. The low impact zone would include fully protected areas, areas just for static gear fisheries (e.g. crab fishers) and scallop divers and other low impact uses such as recreation. Most of the inshore scallop fleet which uses dredges or trawls should operate within the medium impact zone. The larger vessels in the nomadic offshore fleet should operate outside 6 miles. The key to the success of this scheme for the scallop fishery would be to improve the productivity by increasing spawning stock biomass and improving the size class structure of the populations. Recommended management measures include reducing fishing effort, increasing minimum dredge belly ring size and protecting juveniles and key habitats.

If these measures were to be put in place, the UK scallop industry has the potential to provide a much more profitable and stable income for its stakeholders.

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Prelude:

There have been a number of high profile cases recently in UK waters where scallop dredging has come into conflict with nature conservation interests. These include Lyme Bay and the Fal and Helford, Firth of Lorn, Strangford Lough and Pen-Llyn-ar-Sarnau Special Areas of Conservation (SACs). These high profile cases have brought the issue of the environmental impact of scallop dredging into the media spotlight and highlighted the need for a scallop management regime which will fully address the issues of stock, environmental and socio-economic sustainability, in a way that engages all interested parties.

In the meantime, work has commenced on the development of a strategy for Scottish scallop fisheries and two meetings of a UK Scallop Dialogue Group were held in 2008.A one off Scallop Symposium is also planned for 2009. The overarching intention of these initiatives is to bring scalloping industry and interested parties together with the intention of developing a longer term approach to the fishery and reduce future conflict over environmental concerns through agreeing an acceptable footprint.

In order to contribute fully to these initiatives the Country Agencies (Natural England, Scottish Natural Heritage and the Countryside Council for Wales) offered to prepare an overview of scallop fishery / environment interaction with a view to developing a set of principles for scallop harvesting (dredging and diving) with the objective of minimising the overall environmental footprint of the fishery. This work is the subject of this report. This report will be used to help inform the Country Agencies' position on the management of scallop harvesting in UK inshore waters, whether in designated sites or the wider marine environment.

Aims:

1. Provide an objective overview of the environmental interactions arising from both the dredge and dive scallop fisheries (drawing upon existing reviews/analyses of the scientific literature currently available rather than a review from scratch).

2. A review and assessment of scallop management measures and operational best practice employed elsewhere in the world (in particular where measures have implications for, or have been specifically implemented to address, biodiversity conservation). This section should include:
    a. Gear specification
    b. Spatial management
    c. Fishing operations (i.e. best practice or measures that guide where / when / how often)

3. To develop recommendations for a set of principles and/or management measures for the sustainable exploitation of scallops by both dredge and diving. This should include identifying management measures that are beneficial for both scallop stock management and conservation of biodiversity and should include considerations of both habitat sensitivity and recoverability.

1. Inshore Scallop Fisheries around the United Kingdom and their Effect on Marine Ecosystems.

1.1. UK fisheries for the great scallop (*Pecten maximus*) and queen scallop (*Aequipecten opercularis*):

1.1.1. Biology

Two species of scallop (Pectinidae) support important commercial fisheries in the inshore (< 12 miles offshore) waters of the United Kingdom (UK); the larger and more valuable great scallop, *Pecten maximus,* and the smaller queen scallop, *Aequipecten opercularis*. The biology of the two species is quite different and this influences both the productivity of their fisheries and methods of exploitation. In UK waters great scallops become sexually mature at approximately 2-3 years old and 80 to 90 mm in shell length (SL), but may live for over 20 years and grow to over 200 mm SL in undisturbed populations (Tang 1941). In comparison, the queen scallop matures when between 1 and 2 years old and approximately 40 mm SL, and rarely lives for more than 5 or 6 years or grows to more than 90 mm SL (Vause et al. 2007). Both species spawn during spring / summer and reproductive success and consequently recruitment levels are likely to be influenced by a multitude of factors including spawning stock biomass, environmental conditions and the availability of suitable settlement habitat ((Brand 2006b, a, Orensanz et al. 2006). However, in general the more protracted life span of great scallops leads to more stable population dynamics and predictable distributions than observed for queen scallops. For example, the fishing grounds for great scallops around the Isle of Man in the Irish Sea have remained remarkably consistent throughout the history of the fishery, with some grounds producing commercially viable quantities every year for almost 80 years (Brand 2006a). In contrast, the productivity of queen scallop fisheries tends to be highly variable both temporally and spatially, with queens sometimes being absent from previously productive fishing grounds for more than a decade before appearing again in high densities (Vause et al. 2007).

Figure 1.1. The great scallop, *Pecten maximus* - left (*Photo: B. Beukers-Stewart*) and the queen scallop, *Aequipecten opercularis* - right (*Photo: Port Erin Marine Laboratory*).

1.1.2. Fisheries dynamics and distribution

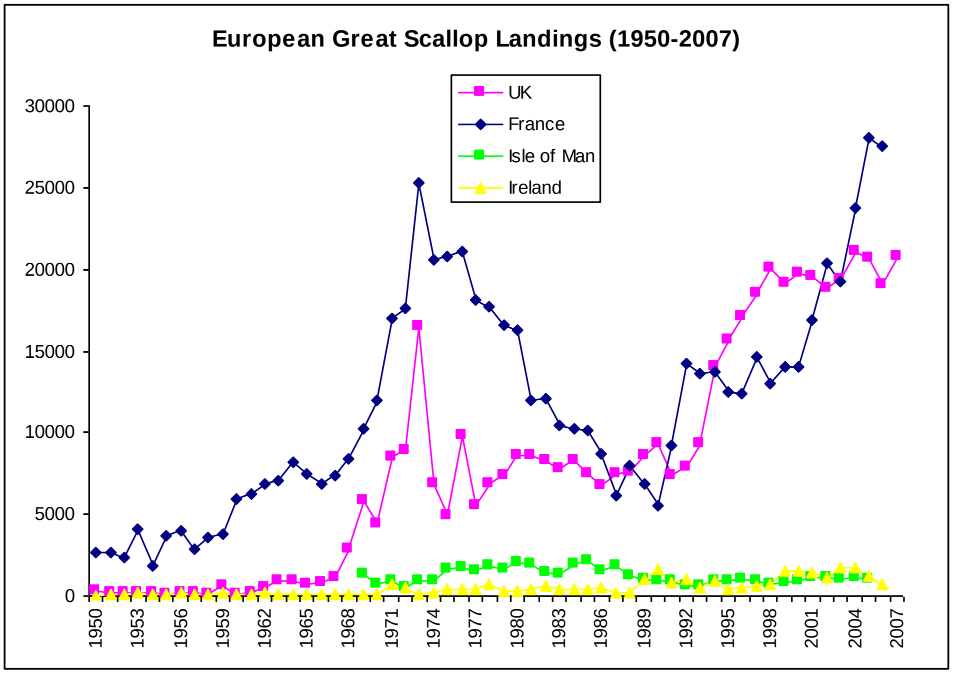
Both species of scallop have undoubtedly been exploited and consumed by humans for millennia, but commercial scallop fisheries in European waters have expanded rapidly since the 1970s (Figure 2). The main European fisheries for the great scallop, *Pecten maximus,* are around the UK and France (approximately 20000 tonnes have been landed into each country per annum in recent years), with much smaller quantities (generally between 1000 and 2000 tonnes per annum) being landed into the Isle of Man and Ireland (Figure 1.2a). The first sale value of the UK fishery for great scallops was £38.8 million in 2007, making it the fourth most valuable British fishery. Indeed great scallops have ranked in the top five most valuable UK fisheries for at least the last 5 years (Marine and Fisheries Agency, UK Marine Fishery Statistics 2007). The inherent variability of queen scallop populations is reflected in the landing statistics for their European fisheries (Figure 1.2b). In contrast to the relatively steady growth in landings of great scallops, landings of queen scallops have fluctuated between approximately 1000 and 10000 tonnes per annum over the last 30 years (a commercial fishery did not develop until 1969) for each of the main countries exploiting the stocks (UK, Faroe Islands, France and the Isle of Man). The UK has consistently landed the largest amounts of queen scallops in European waters, with an average of almost 6000 tonnes taken in each of the last five years. In 2007, the first sale value of the UK queen scallop fishery was £2.2 million (Marine and Fisheries Agency, UK Marine Fishery Statistics 2007), illustrating the much lower per unit value of this species compared to great scallops.

The landings statistics also reveal the predominantly westerly distribution of great and queen scallop fisheries around the UK. The main fisheries for great scallops are concentrated in the eastern and western English Channel, the Irish Sea, and off the west and north-east coasts of Scotland (Brand 2006a). Scottish boats generally account for approximately half of the UK great scallop catch (Howell et al. 2006).Very few great scallops are taken in the mid or southern North Sea. In comparison, queen scallop fisheries are mostly concentrated in the Irish Sea and off the west coast of Scotland, with relatively few queens taken in either the English Channel or the North Sea (Brand 2006a).

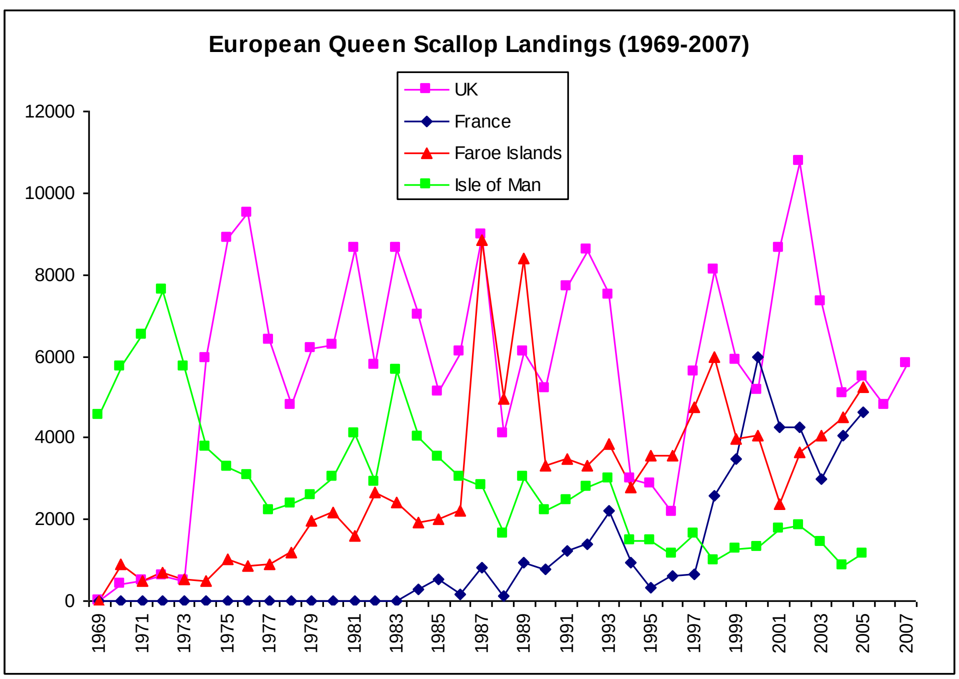
Fluctuations in scallop landings are driven by a wide variety of factors, including stock size, regulations, market demand / price and operating costs (particularly fuel and more recently the price of steel used in dredge and vessel construction) (Brand 2006a, Palmer 2006, Beukers-Stewart & Brand 2007). One of the features of the UK scallop fishery is variability in the number of participating vessels – also driven by the above factors. This is because in the UK there are no restrictions on total scallop catches and licences were only capped, at very high levels, in 1999 (Brand 2006a). Therefore, during periods of low stock abundance there is often considerable latent effort awaiting more favourable conditions for exploiting scallops. As a result there is generally a fairly tight relationship between effort and landings in these fisheries (Palmer 2006). The rapid increase in landings of great scallops into the UK over the last decade is generally attributed to increased effort resulting from vessels switching to scallop fishing because of; favourable stock levels, the demise of many traditionally exploited white fish stocks, the consistently high market value of great scallops, and their predominately inshore distribution (which offers reduced operating costs over more distant fisheries) (Brand 2006a, Palmer 2006, Beukers-Stewart & Brand 2007).

Figure 1.2. European commercial landings of great and queen scallops – note the different scales (data: Fishstat Plus, FAO and the Marine and Fisheries Agency, UK).

a) Great scallops (*Pecten maximus*)



b) Queen scallops (*Aequipecten opercularis*)



1.1.3. Methods of exploitation

Great and queen scallops are exploited using different fishing gear and methods as a result of differences in their behaviour. Although capable of swimming several metres when disturbed (Brand 2006b), great scallops naturally recess into the seabed, with their upper / flat shell valve level with the substrate. The main method of capturing great scallops involves towing spring-loaded "Newhaven" scallop dredges (Figure 1.3). Each dredge is fitted with a spring-loaded bar of 8 or 9 teeth up to 11 cm long which are designed to rake up scallops from their recessed position in the seabed. Behind this tooth bar is a mesh bag (steel underneath (the belly) and nylon on top) designed to retain the catch. The mesh size of the belly and top net on dredges used in the UK is generally 80 mm and 100 mm respectively. Capture efficiency of this gear is relatively low – between 5 and 40 % for legal sized scallops depending on seabed type and operating conditions (Dare et al. 1993, Beukers-Stewart et al. 2001, Jenkins et al. 2001, Lart 2003). UK vessels tow gangs of between 2 and 22 dredges per side depending on local regulations (see section 1.3) and vessel size. Each dredge is normally 75 cm in width and gangs of dredges are suspended from a towing bar that has rubber wheels on each end designed to roll along the seabed. Perhaps not surprisingly, the use of these dredges can also cause considerable disturbance and damage to the seabed and associated benthic communities (see section 1.2).

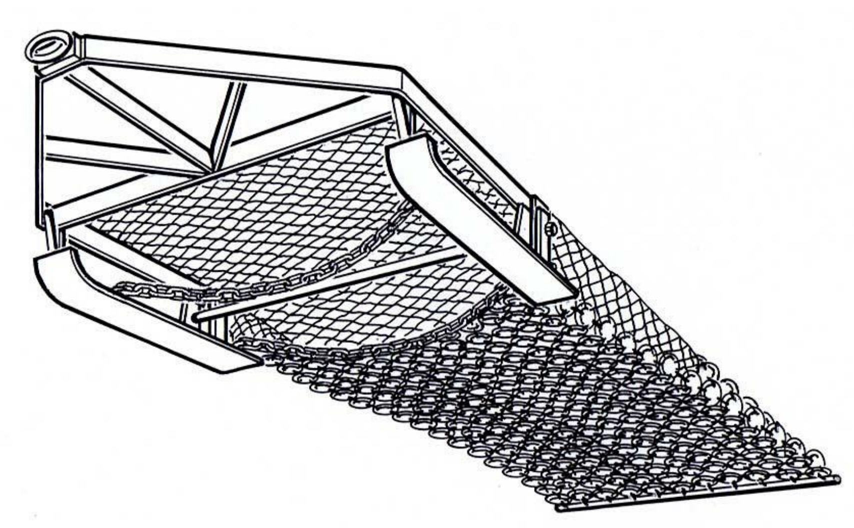
Figure 1.3. A gang of spring toothed, Newhaven scallop dredges during retrieval (*Photo: B. Beukers-Stewart*)

In contrast, queen scallops are much more active swimmers than great scallops and do not recess into the seabed (Brand 2006b). They are also predominantly targeted using towed fishing gear, but this is in the form of either skid dredges (modified Newhaven dredges) or otter trawls (Figure 1.4). Skid dredges are set up and operated in much the same way as

Newhaven dredges, but have the tooth bar replaced with a tickler chain and are fitted with skis or skids on either side designed to run along the top of the seabed. Both skid dredges and otter trawls take advantage of the natural propensity of queen scallops to swim up into the water column when disturbed, rather than relying on extraction of the scallops from the sediment as is the case for Newhaven dredges. Consequently, the general consensus is that queen scallop fishing causes less disturbance to the seabed than great scallop dredging (Collie et al. 2000, Lart 2003). The choice of skid dredges or otter trawls is largely governed by the nature of the substrate on different fishing grounds, with skid dredges being more effective in rough / coarse sediment areas and trawls in sandy / muddy areas (Vause et al. 2007).

Figure 1.4. Fishing gear used in the UK queen scallop fishery

a) A skid dredge (Lart 2003). These are also towed in gangs as for Newhaven dredges.



b) A demersal otter trawl (*Photo: Simon Park*)

Both scallop species may also be taken by hand-collection by divers. In comparison to the use of towed fishing gears, diving for scallops has a minimal impact on the wider environment. Divers are also only able to fish very small and shallow (< 30 m depth) areas of the seabed relative to boats towing dredges or trawls (< 5% per person per day). However, there are some concerns that scallop diving has the potential to negatively effect stocks, at least on a local scale (see section 1.2). Diving only accounts for a very small percentage of total scallop production in the UK at present, being most important in Scotland where it produced 4.7 % of great scallop landings in 2003 (Howell et al. 2006). Scallop diving is very rare in other parts of the UK, except off Devon and Cornwall where it has become more popular recently. Due to the limited numbers of scallops that can be collected during each dive these fisheries concentrate on the higher value great scallop species to ensure economic viability. A switch from dredge to dive fisheries for scallops is being strongly encouraged by several eNGOs (e.g. Marine Conservation Society www.fishonline.org, Greenpeace www.greenpeace.org.uk/oceans) and "Celebrity Chefs" (e.g. Hugh Fearnley Whittingstall (Fernley-Whittingstall & Fisher 2007), Gordon Ramsey www.channel4.com/food/recipes/chefs/gordon-ramsay) because of concerns over the environmental impact of scallop dredging. While such as switch may be possible to some extent, it is very unlikely that dive fisheries in the UK will ever be able to expand to match the current capacity of towed gear fisheries due to logistical constraints. Management of dive fisheries would also need to be improved to ensure the sustainability of accessible stocks.

1.1.4. Current Management

The current management of UK scallop fisheries generally consists of measures designed to directly influence the sustainability of the target species rather than the ecosystem as a whole. As mentioned previously, there are no restrictions on total catches in UK scallop fisheries and licences (for vessels > 10 m only) were only capped in 1999. Despite this restriction on licences there are concerns that it has had little effect on limiting fishing effort as far more licences were granted than there were boats participating in the fishery (Chapman 2004, Brand 2006a).

Instead, UK scallop fisheries are controlled predominantly through the use of: minimum sizes (100 mm SL for great scallops, except for the western English Channel and Irish Sea where it is 110 mm SL); various Sea Fishery Committee (SFC) (in England and Wales) or Scottish Executive restrictions on the number of dredges permitted (generally a maximum of between 6 and 8 per side within 6 nautical miles (nm) of the shore) (Howell et al. 2006, Palmer 2006); and seasonal closures. Dredges used in all areas must also adhere to certain specifications regarding internal belly ring diameter (≥ 75 mm), top net mesh size (≥ 100 mm), tooth number (< 10) and tooth spacing (≥ 75 mm). Some SFC's also limit vessel sizes within their jurisdictions to 12-15 m and scallop dredging is banned within 3 miles of the shore in the Sussex SFC district and in several inshore areas in Wales (e.g. up to 6 miles from the shore in parts of Cardigan Bay) (Palmer 2006). In English waters there are few restrictions on dredge number outside the 6 mile limit, allowing some boats to fish more than 20 per side. Instead dredge number is only limited by the size and horsepower of the fishing vessels. Regulations are somewhat more stringent in Welsh and Scottish waters. In Wales boats can only fish 4 dredges a side (towing bar no longer than 3.8 m) in the 0-3 nm zone and may only use a towing bar no longer than 7.6 m and not capable of taking more than 8 dredges a side within the 3-12 nm zone (Scallop Fishing (Wales) Order 2005). In Scotland 8 dredges per side are allowed within 6 miles (as is the case in much of England) but only 10 dredges per side are permitted between 6 and 12 miles and 14 per side outside 12 miles (Howell et al. 2006). Despite differences between countries, these differing restrictions on scallop fishing power in relation to distance from shore have effectively split the UK scallop fishing fleet into two components. Smaller vessels (8-15 m in length), fishing fewer dredges, dominate the inshore sector (within 6 miles of shore), and generally land their catch locally on a daily basis. In comparison, the offshore fleet of large vessels (> 15 m in length) fish large numbers of dredges and may operate around the clock for 4 to 5 days at a time. This fleet is often highly nomadic, with some boats fishing right around the UK coastline in response to changing stock availability and regulations (Palmer 2006). The inshore fleet is therefore likely to be more naturally inclined towards stewardship of their resources due to the obvious negative economic effects of local declines in stock abundance.

Seasonal closures of the great scallop fishery are enforced in the Irish Sea and within 6 miles of the Sussex, Devon and Welsh coastlines. The closed season normally runs from June to October, although in there are variations in Wales (the Northern Wales and NW SFC closure runs from June to December). These closures have the effect of protecting scallops during the period when they are breeding and larvae are settling on to the seabed from the plankton. In some areas of the UK, scallop fishing effort is also limited either to certain times of the day (e.g. from 5 am to 9 pm in Northern Ireland and from 7 am to 7 pm in the Devon SFC area) or through the use of weekend bans (e.g. in Northern Ireland and some parts of Scotland).

There are very few regulations on the UK fishery for queen scallops. The EU minimum size is 40 mm shell height (SH); however, it is generally uneconomic to process queens less than 55 mm SH. There are no closed seasons for queens or restrictions on fishing time or catches.

The UK dive fishery for great scallops and queens is also subject to very few regulations other than minimum sizes (as above) and the closed seasons for great scallops which apply to both dredgers and divers.

It should be acknowledged that all of above restrictions on scallop fisheries would have some benefits for conservation of the wider environment by limiting the intensity of disturbance by scallop fisheries in some areas. However, to date the UK scallop fishery has only occasionally been regulated to specifically address the negative effects of fishing disturbance on benthic habitats and communities (see section 1.2).

The few targeted conservation measures currently in place in UK waters predominately take the form of spatial restrictions on the use of towed fishing gears. Most of these restrictions are designed to protect key sites of biodiversity interest – but have only been designated or enforced in the last 5 years, generally after long-running and concerted campaigns by environmental groups and nature conservation agencies. Examples include Special Areas of Conservation (SACs – EU Habitats Directive 1994) in the Fal and Helford (England), Lyn Peninsula (Wales), the Firth of Lorn (Scotland) and Strangford Lough (Northern Ireland); Conservation Zones (Lyme Bay – England); No Take Zones (Lundy Island – England, Isle of

Arran – Scotland) and Marine Nature Reserves (Skomer Island – Wales). The exception to these designations (all eventually enforced via a top down process involving national governments or the EU) is the Devon Inshore Potting Agreement which originated in the 1970s. This was a voluntary agreement (statutory since 2002) designed to reduce conflict in a multi-species fishery where fishermen were operating dredges and trawls (towed gear) alongside pots and fixed nets (static gear) (Kaiser et al. 2000b, Blyth et al. 2002, 2004). Prior to the agreement, static gear was frequently tangled in towed fishing gear – causing loss of gear and earnings in the static sector. The region was therefore zoned to give either towed or static fisheries exclusive access to certain areas, on either a seasonal or permanent basis. An unplanned for, but welcome side effect of this agreement has been considerable benefits to marine biodiversity in the areas where towed gear has been excluded (Kaiser et al. 2000b, Blyth et al. 2002, 2004, Blyth-Skyrme et al. 2006, Kaiser et al. 2007).

1.2. Sustainability and ecosystem effects of UK scallop fisheries

Scallop fisheries are known to have considerable effects on both the target species and the wider environment. We will now consider both of these effects, but with a focus on the wider environment in line with the main objectives of this project.

1.2.1. Target species:

There are numerous examples from around the world of scallop stocks undergoing "boom and bust" cycles (or at least dramatic fluctuations in abundance) in response to inadequate fisheries management (Shumway & Parsons 2006). This is largely caused by unsustainable levels of direct removal of individuals via fishing in combination with variable recruitment to stocks (Orensanz et al. 1991). High levels of fishing can also skew scallop populations towards younger ages and smaller sizes, reducing the productivity of stocks and threatening their ability to breed at sustainable levels in the future (Beukers-Stewart et al. 2005).

Towed gear fisheries
There is now growing evidence that scallop fishing using towed gear can also have a range of effects on juvenile scallops that have been caught and discarded, and on both juvenile and adult scallops that have encountered dredges without being captured. For example, the growth and survival of juvenile scallops in heavily fished areas is reduced compared to those in areas protected from fishing (Beukers-Stewart et al. 2005). The reproductive capacity of scallops on fishing grounds may also be reduced compared to equivalent sized individuals in protected areas (Kaiser et al. 2007). Furthermore, the ability of scallops to swim to escape predators is reduced after they have been caught and discarded or disturbed on the seabed (Jenkins & Brand 2001).

The teeth used on Newhaven scallop dredges may also cause considerable, sometimes fatal, physical damage to scallop shells (Beukers-Stewart et al. 2001, Jenkins et al. 2001, Shephard et al. 2009, Beukers-Stewart et al. in prep). Fatal damage to captured and non-captured undersize great scallops can vary from 2 % to more than 20 % on different fishing grounds, largely due to spatial differences in strength of scallop shells (Beukers-Stewart et al. in prep). The current configuration of the scallop dredges used in the UK reaches a maximum efficiency of approximately 30 % at a threshold of 90 mm SL (Beukers-Stewart et al. 2001). Undersized scallops (particularly between 90 and 100 or 110 mm SL) can therefore make up a considerable proportion of the catch - up to 70 % in some areas (Beukers-Stewart et al. 2003). In heavily fished areas these various indirect effects of fishing can reduce the survival or productivity of juvenile scallops before they have had a chance to breed or recruit to the fishery – a considerable waste of the resource that directly reduces the profitability of future fisheries (Myers et al. 2000, Beukers-Stewart et al. 2005). Strategies designed to protect juvenile scallops until they reach exploitable size, particularly when they recruit in large numbers, may therefore dramatically improve fisheries yields.

Figure 1.5. Fatal damage to an undersized great scallop caused by a scallop dredge tooth. (*Photo: B. Beukers-Stewart*)

Finally, scallop dredging may also have profound effects on scallop settlement habitat and cause aggregation of scallop predators (Veale et al. 2000a, Bradshaw et al. 2003, Jenkins et al. 2004), compounding the above negative effects on the abundance and sustainability of scallop populations (See section 1.2.2). Contrary to some suggestions, there is no scientific evidence that scallop dredging or trawling ever “improves” benthic habitats, biodiversity or the suitability of areas for maintaining populations of scallops.

However, despite the various direct and indirect effects of fishing on scallop stocks mentioned above, the continued increase in UK landings of great scallops in recent years suggests current effort levels, for this species at least, are still sustainable. Indeed, even when standardised for engine power (a measure of fishing effort), average catches of all UK vessels have increased significantly between 1994 and 2005 (Shephard et al. in review). Recent regional reviews in the Irish Sea (Beukers-Stewart et al. 2003, Brand et al. 2005), Scotland (Chapman 2004, Howell et al. 2006) and England and Wales (Palmer 2006) also indicate current catch rates are relatively stable, although there are some local exceptions (e.g. recent declines in spawning stock and recruitment in north west Scotland (Howell et al. 2006)). However, the current overall stability off UK scallop fisheries does not mean that they are being optimally managed; as there are various alternative avenues of management that could improve the productivity and profitability of these fisheries considerably (see above and sections 1.2.3 and 2). Furthermore, stable landings or catch rates in fisheries do not always mean that stock levels are stable. Instead such patterns can arise when fishermen continuously move to new fishing grounds (in a process known as serial depletion that is common in scallop fisheries) once the original areas have been fished down to uneconomic levels (Beukers-Stewart et al. 2003).

A particular issue in UK fisheries for great scallops is that due to high exploitation rates the older (> 6 years) and larger (> 130 mm SL) scallops have largely been removed from most populations (Brand 2006a). As a result most UK fisheries for great scallops rely heavily on the recruitment of young scallops each year – a risky scenario both biologically and economically (Beukers-Stewart et al. 2003, Chapman 2004, Brand et al. 2005, Brand 2006a, Howell et al. 2006, Palmer 2006). It is therefore doubtful if UK great scallop fisheries will remain truly sustainable in the future if effort levels are allowed to continue to increase and management practices are not improved.

The current sustainability of queen scallop fisheries is perhaps even more questionable. Queen scallop fisheries are also largely driven by recruitment variability as like great scallops, queens rarely avoid capture by fishing for more than a year or two after reaching marketable size (or maturity) (Vause et al. 2007). Given that environmental conditions also appear to generate large natural variability of these stocks it is possible that inappropriately high effort levels during periods of low stock abundance could drive populations below the level from which they can recover (Vause et al. 2007). Queen scallop stocks collapsed from over fishing in Spain in this way in the 1960s and have never recovered (Orensanz et al 2006).

Dive fisheries

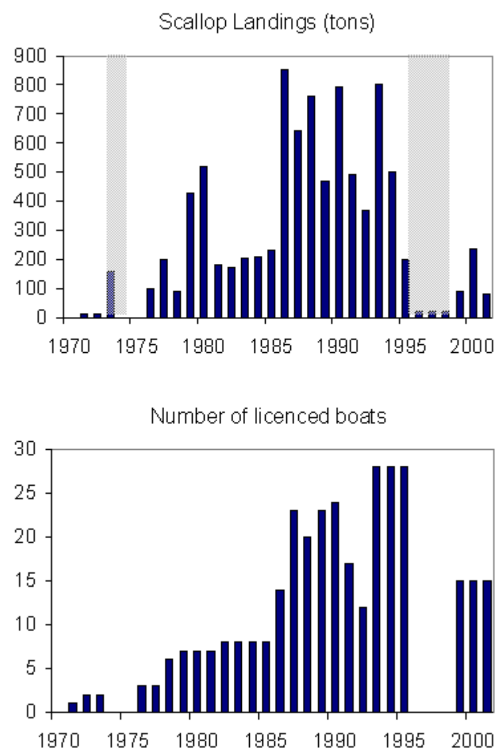
Low levels of participation in UK dive fisheries for scallops probably pose little threat to stocks at present. However, divers selectively target large individuals that are the key breeders. They are also able to access areas that have previously remained unexploited because they are too rough or dangerous to fish with towed fishing gear. Furthermore, some areas that are protected from towed fishing gear (e.g. by the Devon Inshore Potting Agreement) remain open to scallop divers (Kaiser 2007a). These previously inaccessible and therefore “protected” areas provide breeding refuges that may be crucial for ensuring stock sustainability in some areas (Beukers-Stewart et al. 2005, Brand et al. 2005, Kaiser 2007a).

Given the current lack of regulations imposed on UK dive fisheries for scallops, a rapid increase in participation could significantly increase pressure on some local stocks in inshore areas. There are a number of examples of dive fisheries for scallops (or other similar invertebrate species) being successfully managed around the world (see section 2). However, unregulated or poorly managed dive fisheries for scallops have also been known to cause population collapses or declines (e.g. the Purple scallop (*Argopecten purpuratus*) in Peru

(Wolff & Mendo 2000), and the Tehuelche scallop (*Aequipecten tehuelchus*) in Argentina (Parma et al. 2003, Ciocco et al. 2006).

In the case of the Argentinean (San Jose Gulf) inshore fishery for Tehuelche scallops, dredging was banned in the 1970s because of concerns over the effect on scallop populations and habitat suitable for settlement of scallop larvae (Parma et al. 2003, Ciocco et al. 2006). An open access dive fishery developed as an alternative; however, a strong export market for scallops resulted in size limit violations and an expansion of the fishery into deeper water in the early 1990s, fishing out the last remaining reproductive refuges. The fishery collapsed in the mid 1990s and remained closed for 3 years before resuming at more moderate and tightly regulated levels in 1999 (Parma et al. 2003, Ciocco et al. 2006) – see Figure 1.6 & section 2.

Figure 1.6. Scallop landings and numbers of licensed boats in the Argentinean (San Jose Gulf) dive fishery for Tehuelchus scallops. Shaded areas indicate when the fishery was closed (adapted from Parma et al. 2003).



Climate change

All UK scallop fisheries also face an uncertain future in the face of global climate change. Research to date indicates that ocean warming may in fact be behind the recent increase in catches in European scallop fisheries (Shephard et al. in review). This effect could potentially continue to somewhat boost scallop fisheries for the next few decades. However, greenhouse gas induced acidification of oceans in the longer term (by 2050 if not sooner) is expected to have significant negative impacts on biology of shellfish, threatening entire stocks and coastal ecosystems (Gazeau et al. 2007, Hall-Spencer et al. 2008, Kurihara 2008, Zeebe et al. 2008).

1.2.2. Non- Target Species and Habitats:

Towed gear fisheries
Numerous studies and reviews have now examined the effects of towed gear scallop fisheries on the wider environment (Eleftheriou & Robertson 1992, Currie & Parry 1996, Kaiser et al. 1996, Jennings & Kaiser 1998, Hill et al. 1999, Bradshaw et al. 2000, Collie et al. 2000, Hall-Spencer & Moore 2000, Kaiser et al. 2000a, Veale et al. 2000b, Bradshaw et al. 2001, Jenkins et al. 2001, Watling et al. 2001, Bradshaw et al. 2002, Thrush & Dayton 2002, Lart 2003, Broadhurst et al. 2006, Gray et al. 2006, Kaiser et al. 2006, Sheppard 2006, Hall et al. 2008, Leslie & Shelmerdine in prep). The particular concern arising from many of these studies is that scallop dredges are considered to be among the most damaging of all fishing gears to benthic communities and habitats (Collie et al. 2000, Broadhurst et al. 2006, Kaiser et al. 2006). Furthermore, the Newhaven dredges used in the UK fishery for great scallops are likely to be one of the most damaging types of scallop dredge due to the effect of their long teeth which are designed to penetrate the seabed (Shephard et al. 2009, Beukers-Stewart et al. in prep). UK scallop fisheries are concentrated in the inshore waters right around the coastline in all areas except the mid and southern North Sea. In Scottish inshore waters scallop dredging is perceived to be the main fishing activity threatening marine benthic habitats, as other potentially damaging fishing methods, such as beam trawling, are rare (David Donnan, Scottish Natural Heritage, *pers. comm.*). The inshore area right around the British coast is predisposed to feature the majority of the UK's sites of high marine biodiversity interest (Hiscock & Breckels 2007). This is because shallower inshore areas tend to be the most productive and offer the greatest diversity of habitats, both topographically and biologically. Given this spatial overlap with patterns scallop dredging and trawling it is therefore highly likely that scallop fisheries have already had considerable negative effects on marine biodiversity and will continue to do so unless new approaches are taken to improve the management of these fisheries. On a more positive note, the UK has the most control over its inshore waters, and therefore the greatest potential use innovative solutions for this problem.

Scallop fisheries may disturb biological communities both directly and by changing the physical attributes of the areas being fished. We will now consider each of these aspects in turn, focusing on variation in both the level of effects and the ability of different ecosystems to recover from disturbance.

1.2.2.1. Biological effects:

Mobile megafauna
Both the scallop dredges and trawls used in the UK scallop fishery capture a wide variety of non-target mobile megafauna, including some commercially important species. Examples include; fish (flatfish, dogfish, skates, rays, monkfish and dragonets), crustaceans (edible crabs, swimmer crabs, spider crabs and hermit crabs), urchins, molluscs (bivalves and gastropods), starfish, brittlestars and cephalopods (octopus and cuttlefish) (Hill et al. 1996, Veale et al. 2001, Enever et al. 2007). Commercially valuable species are retained in some cases, (particularly fish in the queen scallop trawl fishery and cuttlefish in the English

Channel dredge fishery); however, most by-catch is discarded. Scallop dredges have been classified as relatively “clean” compared to other types of mobile fishing gear such as beam trawls (Kaiser 2007b). However, this appears to vary considerably, with much higher levels of bycatch in the Irish Sea than in the English Channel and western approaches (Bill Lart, Seafish Industry Authority, *pers. com*). Catch composition also varies between the different types of gear used in UK scallop fisheries, with the skid dredges used in queen scallop fisheries catching less great scallops and stones (but similar levels of other megafauna) than Newhaven dredges used in great scallop fisheries (Lart 2003). The otter trawls used in queen scallop fisheries catch much higher numbers of fish, but lower numbers of great scallops, than either type of dredge (Lart 2003, Enever et al. 2007).

Figure 1.7. Typical by-catch from a Newhaven scallop dredge operated in the Irish Sea.
a) An unsorted catch – note the bycatch levels and the large number of stones. *(Photo: Port Erin Marine Laboratory)*

b) Benthic megafauna only – note the relative proportion of scallops to other species *(Photo: B. Beukers-Stewart).*

Many individuals of the non-target species captured by scallop fisheries are discarded dead, damaged or dying. A recent assessment of the 10 most common by-catch species in the Irish Sea scallop fishery found approximately 20 to 30 % of individuals suffered fatal damage after dredge capture (Shephard et al 2009). However, the proportion of individuals affected varies greatly between species, even within the same family (e.g. starfish) (Hill et al. 1996, Jenkins et al. 2001, Veale et al. 2001). The most sensitive species to dredge damage include the seven armed starfish, *Luidia ciliaris*, the edible sea urchin, *Echinus esculentus*, and the commercially important edible crab, *Cancer pagurus* (Hill et al. 1996, Jenkins et al. 2001, Veale et al. 2001). In contrast, the pin cushion starfish, *Porania pulvillus*, rarely appears to suffer any damage from being captured in a scallop dredge. As is the case for scallops, initial contact with the dredge teeth causes most of the fatal damage suffered by by-catch species, while non-fatal damage appears to occur in the mesh bag during the tow and landing of the catch (Shephard et al 2009). Intensity of non-fatal damage may be related to amount of stones in the catch and the fullness of dredges – suggesting shorter tow lengths could reduce this type of damage (Veale et al. 2001).

Although the amount and composition of non-target species taken as by-catch in scallop fisheries may be their most visible effect on the wider environment, diver and video surveys in recent dredge tracks show that far higher numbers of these species are damaged on the seabed after encountering the dredges without being retained (Eleftheriou & Robertson 1992, Beukers-Stewart et al. 2001, Jenkins et al. 2001). In the case of the commercially important edible crab, this pattern could give rise to considerable conflict between crab and scallop fisheries. Scallop dredging captures approximately 25 % of the edible crabs present in the path of dredges, (Beukers-Stewart et al. 2001) however, more than 40 % of the remainder may be left dead or dying on the seabed (Beukers-Stewart et al. 2001, Jenkins et al. 2001). Scallop dredging is therefore a very inefficient way to catch crabs, and wastes a resource that would be otherwise available to fishermen using pots. Furthermore, towed fishing gear can cause entanglement and loss of crab pots when operating in the same area as crab fisheries (Blyth et al 2002, pers. obs). Management plans that spatially or temporally separate scallop and crab fisheries (e.g. the Devon Inshore Potting Agreement) should therefore be encouraged and become more widespread.

Discards and damage from scallop fisheries may provide a short term increase in food supply for some predatory and scavenging species (e.g. starfish, crabs and dogfish), causing them to aggregate in dredge or trawl tracks (Kaiser & Spencer 1994, Kaiser & Hiddink 2007). However, being lured to this “honey pot” on fishing grounds may place these species at increased risk of being caught or damaged during the next pass of the fishing gear (Bradshaw et al. 2000). Such aggregations of predators may also place additional pressure on exploited scallop populations, particularly where some individuals have already been damaged by fishing activity (Veale et al. 2000a, Jenkins et al. 2004).

Sedentary benthic species and habitats

Great and queen scallops inhabit various soft sediment areas of the seabed, including coarse and fine sand, mixed sand and mud areas, and gravel / shingle beds (Brand 2006b). Scallops may also be found in high densities on biogenic substrates (e.g. Maerl beds, Horse Mussel (*Modiolus*) reefs, Oyster beds and Tube worm (*Sabellaria*) reefs) (Hall-Spencer & Moore 2000, Hall-Spencer et al. 2003). Both soft sediment and biogenic seabeds are also inhabited by a range of upright species of fauna and flora (known as epibiota) attached to the seabed. This includes species such hydroids, bryozoans, sponges (e.g. Dead man's fingers – *Alcyonium*), seasquirts (Ascideans) seafans, kelp and seagrass. All of these species provide an element of 3-dimensional structure which in turn provides settlement substrates for juvenile scallops, further epibiota and crucial nursery and feeding areas for fish (Collie et al. 1997, Bradshaw et al. 2003). Such complex communities may also help to stabilise seabed sediments (Bradshaw et al. 2003).

One of the most marked effects of scallop dredges and trawls on the seabed is physical removal and damage to these upright species of epibiota (Watling & Norse 1998, Collie et al. 2000, Kaiser et al. 2006). The loss of these species through fishing disturbance can therefore cause a series of knock on effects that dramatically reduce marine biodiversity in an area (Watling & Norse 1998, Kaiser et al. 2000b, Bradshaw et al. 2003).

The degree of disturbance suffered by different benthic habitats and communities is dictated by; the type of fishing gear used (scallop dredges being the most damaging), the intensity of fishing effort, the type of species present, and the make up of the underlying substrate (Kaiser et al. 2006). Although scallop fisheries are known to have negative impacts in almost all habitat types, some are highly sensitive while others are more resilient to disturbance (Kaiser et al. 2006, Hall et al. 2008). In general, the more naturally stable an area of seabed is, the more sensitive it will be to disturbance (Collie et al. 2000) Within each habitat, different species or feeding guilds will also vary in their response to disturbance. Large, slow growing epibiota such as sponges and soft corals tend to be much more sensitive to damage than faster growing infauna (animals that live buried in the sediment) such as polychaete worms (Kaiser et al. 2006). The habitats and species most sensitive to initial disturbance also tend to be the types that take the longest to recover (Kaiser et al. 2006, Hiddink et al. 2007, Hall et al. 2008). Mapping the distributions of different habitat types and the spatial coverage and intensity of different fisheries could therefore be a crucial tool for reducing the impact of fishing on the wider environment (Hall et al. 2008).

Biogenic substrates and their associated benthic communities are the most sensitive to disturbance by scallop fisheries, particularly scallop dredging (Collie et al. 2000, Hall-Spencer & Moore 2000, Kaiser et al. 2006). For example, on maerl beds a single pass of a scallop dredge may cause damage that requires decades for recovery (Hall-Spencer & Moore 2000). Damage to biogenic reefs can cause a series of negative knock on effects that reduce biodiversity and the abundance of commercial species of fish and shellfish. This is because the high complexity of biogenic reefs allows them to naturally support a high diversity of other species, particularly epifauna (Hall-Spencer & Moore 2000, Hall-Spencer et al. 2003). Furthermore, these complex and diverse habitats provide especially important settlement substrates for scallops and other invertebrates (Hall-Spencer & Moore 2000, Hall-Spencer et al. 2003, Kamenos et al. 2004b, a) and nursery and feeding sites for fish (e.g. cod) (Hall-Spencer et al. 2003, Kamenos et al. 2004c). High settlement of juvenile scallops on biogenic reefs often translates to high densities of adults, causing them to act as spawning "hotspots" that provide larvae to surrounding areas, including fishing grounds (Hall-Spencer et al. 2003). Therefore, given the importance of biogenic reefs to both fisheries and biodiversity, along with their inherent vulnerability to disturbance, there is a strong argument for completely protecting biogenic reefs from all towed fishing gear, at the very least.

Gravel and mixed sand and mud habitats also tend to support diverse benthic communities of high biomass and are the main focus of commercial scallop fisheries in the UK (Bradshaw et al. 2000, Kaiser et al. 2006). These habitats are known to be relatively sensitive to disturbance by scallop fisheries, as experimental scallop dredging in these areas has been shown to have both short and long-term negative effects on biodiversity (Collie et al. 1997, Bradshaw et al. 2000, Collie et al. 2000, Bradshaw et al. 2001, Kaiser et al. 2006). However, unlike in biogenic areas, benthic communities in gravel and mixed sand and mud substrates will recover if protected from fishing, although time frames vary for different species (Bradshaw et al. 2003, Kaiser et al. 2006) – see above. For example, the summer closed season in the Irish Sea is thought to allow certain hydroid species to start to re-establish themselves on gravel seabeds each year (Bradshaw et al. 2003). Given their importance as settlement habitat, the recovery of these structurally complex benthic species may in turn provide further benefits to both scallop populations and biodiversity in general. Although recovery may only be for a few months, the timing may be crucial, as summer is also the key settlement period for many invertebrate species (Bradshaw et al. 2003).

Re-establishment of "natural" levels of benthic biomass, however, will take much longer, but be more biologically important (Kaiser et al. 2006). In recent years the settlement of juvenile great scallops in a protected area of sandy gravel seabed off the Isle of Man has been more than 4 times higher than on the adjacent fishing ground (Beukers-Stewart et al. 2005, Brand et al. 2005, Beukers-Stewart & Brand 2007). The most likely explanation for this pattern is that high amounts of upright epibiota, developed during more than 10 years of protection, (Bradshaw et al. 2001, Bradshaw et al. 2003) has increased the settlement and survival of scallop spat in the protected area. Such "habitat effects" can therefore accelerate the recovery of scallop populations and other species in areas protected from fishing. Furthermore, there is increasing evidence that build-up of high biomass and reproductive capacity of scallops (and probably other invertebrates) in such protected areas is likely to provide substantial fisheries and biodiversity benefits to surrounding areas via larval export (Murawski et al. 2000, Gell & Roberts 2003, Beukers-Stewart et al. 2004, Blyth et al. 2004, Beukers-Stewart et al. 2005, Kaiser et al. 2007, Neill & Kaiser 2008).

The benthic communities most resilient to scallop fisheries tend to be those inhabiting shallow sandy areas subject to high levels of natural disturbance (e.g. wave and tidal action) (Collie et al. 2000, Kaiser et al. 2006). Although benthic species in these areas do suffer significant negative effects from fishing disturbance, the relative impact tends to be lower and recovery quicker, than in other habitats (Kaiser et al. 2006). However, this type of habitat naturally supports lower levels of biodiversity (including scallops and epifauna) than areas of coarser sediment (Bradshaw et al. 2000, Brand 2006b), and hence is less likely to be targeted by scallop fisheries.

Figure 1.8. *(Photos: Port Erin Marine Laboratory)*

a) A healthy seabed community associated with a boulder in a sandy protected area in the Irish Sea.

b) Juvenile queen scallop spat attached to a bryozoan.

c) An illegal scallop dredge track in a “protected” area in the Irish Sea. Note the detached kelp thallus and the dead bivalves.

1.2.2.2. Physical effects

Along with direct biological effects, scallop dredging and trawling may also change the physical nature of the seabed. These physical effects may indirectly flow back to cause further negative effects on benthic communities. Overall, the general effect of towed gear scallop fisheries, particularly dredging, is to cause homogenization of sediments and seabed topography through penetration, mixing and flattening of sediments by the scallop dredges (especially the teeth) or trawl ground ropes (Collie et al. 2000, Kaiser et al. 2002). Furthermore, scallop gear is known to capture and remove significant quantities of stones or boulders from some fishing grounds (Bradshaw et al. 2002), which may be reasonably common even in areas where the underlying substrate is sand or gravel (*pers. obs,* see Figure 1.7). In such cases these boulders or stones provide prime settlement substrates for many epi-benthic species in expanses of otherwise less suitable habitat (see Figure 1.8). Where scallop dredges have been used in areas of soft mudstone or limestone (e.g. Lyme Bay) they have also been known to break up the integrity of the reefs (Lart et al. 1993, Kaiser 2007b). Again, this causes loss of substrates suitable for colonization by species such as sponges and seafans and an overall reduction in biodiversity (Kaiser 2007b). In general, however, even areas of patchy reef (where scallops may be found between areas of hard substrate) are usually avoided by fishermen using towed gear due to the potential for damage or loss of fishing gear or entanglement that could threaten the safety of fishing vessels (*pers. obs*).

In areas of soft sediment, disturbance by fishing gear may cause removal and / or re-suspension of surface layers (Black & Parry 1999). High levels of suspended sediment can cause smothering of surrounding sessile marine life, and have negative effects on the growth and reproduction of filter feeding invertebrates, including scallops (Brand 2006b). In addition, removal or disturbance of surface sediment layers can change patterns of nutrient cycling or carbon flux, for example by exposing underlying anaerobic sediments (Watling et al. 2001, Kaiser et al. 2002). Furthermore, burrowing species of infauna often play a key role in controlling the scale and direction of nitrogen flux in benthic communities (Leslie & Shelmerdine in prep), but fishing disturbance tends to favour small but abundant burrowing species over less common larger ones (changing the rate of flux) and destroy the structure of existing burrows (Kaiser et al. 2002, Leslie & Shelmerdine in prep).

All of the above physical and chemical effects of scallop fisheries can further reduce or change the productivity of benthic communities. However, it should be noted that effects will vary greatly between different sediment types. For example, issues regarding suspended sediment are likely to be much reduced in areas of gravel or cobbles when compared to finer sediments. It is also important to put fishing disturbance within the context of natural disturbance. As was the case with direct biological effects, the physical effects of scallop fishing in shallow areas subject to high amounts of wave or tide action are likely to be less significant than those occurring in deeper areas that more naturally stable (Collie et al. 2000, Kaiser et al. 2002, Leslie & Shelmerdine in prep).

1.2.3. Ecological Significance of the Effects of Scallop Fisheries.

It is possible to make a number of generalizations regarding the large-scale and long term effect of scallop dredging and trawling on benthic communities and habitats - see (Hill et al. 1999, Kaiser et al. 2000a, Kaiser et al. 2000b, Veale et al. 2000b, Bradshaw et al. 2001, Bradshaw et al. 2002, Hermsen et al. 2003, Blyth et al. 2004). Areas subject to high fishing disturbance tend to undergo a change in species composition and structural complexity and become dominated by small, fast growing, opportunistic and encrusting species that offer much less 3-dimensional structure than in undisturbed areas. Overall, disturbed areas also tend to have lower biodiversity, species richness, species abundance and rates of benthic production. Along with directly removing scallops, these negative effects of scallop fisheries on benthic communities and habitats are also highly likely to reduce the productivity of these areas for future scallop populations. This is because towed gear often damages or removes crucial settlement and nursery areas for juvenile scallops and reduces the suitability of habitats for remaining adults (Bradshaw et al. 2001, Blyth et al. 2004, Beukers-Stewart et al. 2005).

The overall significance of the effects of scallop fisheries on mobile megafauna is less well understood (Hill et al. 1996, Bradshaw et al. 2000). This is because the at least some of the species taken as by-catch in scallop fisheries are also targeted by other commercial fisheries (e.g. flatfish, skates and rays, monkfish). This makes it difficult to interpret trends in abundance of these species on scallop fishing grounds. Population dynamics and distributions of other by-catch species, particularly starfish, are also strongly influenced by environmental variation (Freeman et al. 2001, Gallagher et al. 2008), and this to may also mask the effect of scallop fisheries on their populations. Furthermore, aggregation of predators and scavengers on fishing grounds may actually make them appear more abundant in disturbed areas than in protected areas (Bradshaw et al. 2003). Work is currently underway at the University of York, using long-term datasets on scallop fishery by-catch and environmental conditions, to untangle the effects of fishing and environmental change on this component of the benthic community.

1.2.4. Management Needs:

The above review has identified a number of priorities for improving the management of UK scallop fisheries. The overall goal should be to improve productivity (yield per unit effort) in both great and queen scallop fisheries, while minimising environmental impact, to ensure long-term sustainability and profitability.

The main priorities for achieving this goal can be briefly summarised as follows:

- Enable scallop and queen populations to recover towards more natural age and size structures to increase spawning stock biomass and improve resilience to environmental change
- Reduce the indirect effects of fishing on scallop populations, particularly juveniles
- Develop an appropriate management framework to ensure that UK dive fisheries for scallops are sustainable.

- Reduce by-catch of mobile benthic megafauna in scallop fisheries, particularly when this threatens vulnerable species or causes conflicts with other commercial fisheries
- Reduce the effect of scallop fisheries on benthic species and habitats, particularly in the most sensitive areas that provide crucial nursery and feeding grounds.

Although recent measures to increase protection of marine biodiversity in the UK are welcome (see 1.1.4), considerably more progress will be required if the UK is to meet it's international commitments to halt biodiversity loss by 2010 (Convention on Biological Diversity), move towards an "Ecosystem-based" approach to fisheries management, and create networks of Marine Protected Areas (Marine Bill – 2012, OSPAR 2010, World Summit on Sustainable Development 2012). The management of scallop fisheries will need particular attention in this context, given the above evidence for their negative effect on biodiversity, especially in some areas.

To achieve the twin objectives of conserving biodiversity while maintaining a profitable scallop fishing industry is a major challenge that will require innovative approaches to fisheries management. Therefore we will now examine a series of case studies of scallop fisheries from around the world which have gone some way to achieving these twin goals. The lessons drawn from these examples will then be used to develop a series of principles designed to help guide the UK scallop fishery towards an ecologically sustainable and profitable future.

2. Case Studies of Successful Management of Scallop Fisheries operating with Towed Fishing Gears from around the World.

2.1 North East American Sea Scallop (*Placopecten magellanicus*)

Value:	US$ 160 million (approx.)
Governing bodies:	The New England Fishery Management Council
	The Mid Atlantic Fishery Management Council.

2.1.1 Summary

The Atlantic Sea Scallop Fisheries Management Plan was first implemented in 1982. The sea scallop was officially declared to be an overfished stock by congress in 1997 and a number of measures were implemented to rebuild stocks including effort reductions and gear restrictions. Large scale closed areas had been established in 1994 to reduce fishing mortality. In 5 years there were significant increases in scallop densities. Increased landings in 2000 were made possible by this improvement in scallop biomass and favourable recruitment. By 2001 stock levels were considered to be sustainable and have continued to rise steeply since then. There has now been a ten-fold increase in total scallop biomass since its low point in 1993.

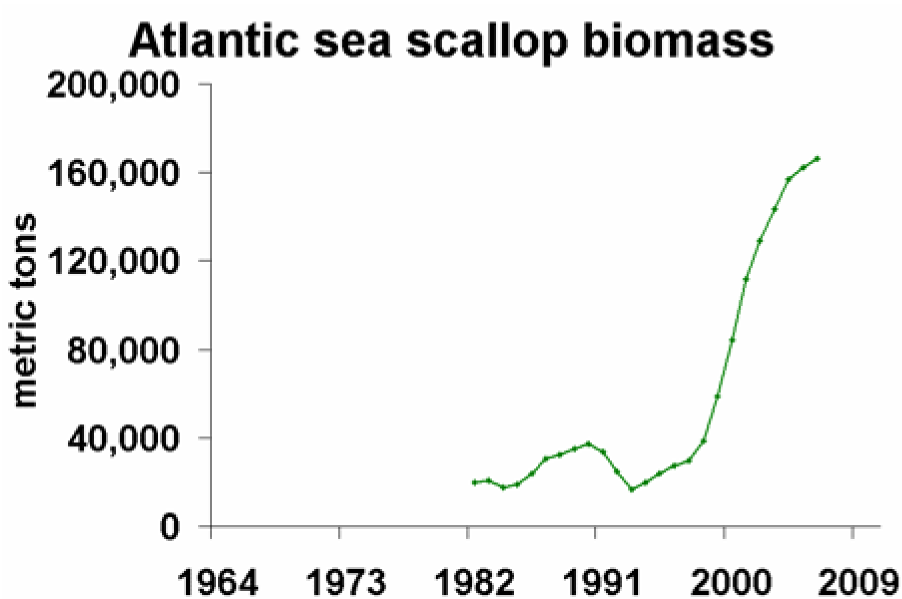


Figure 2.1 Changes in biomass of the Atlantic sea scallop, in metric tonnes, between 1982 and 2009. (Source: National Marine Fisheries Service, US Dept of Commerce. Data source: 45th North-east Regional Stock Assessment Workshop – Assessment of Atlantic Sea Scallops 2007).

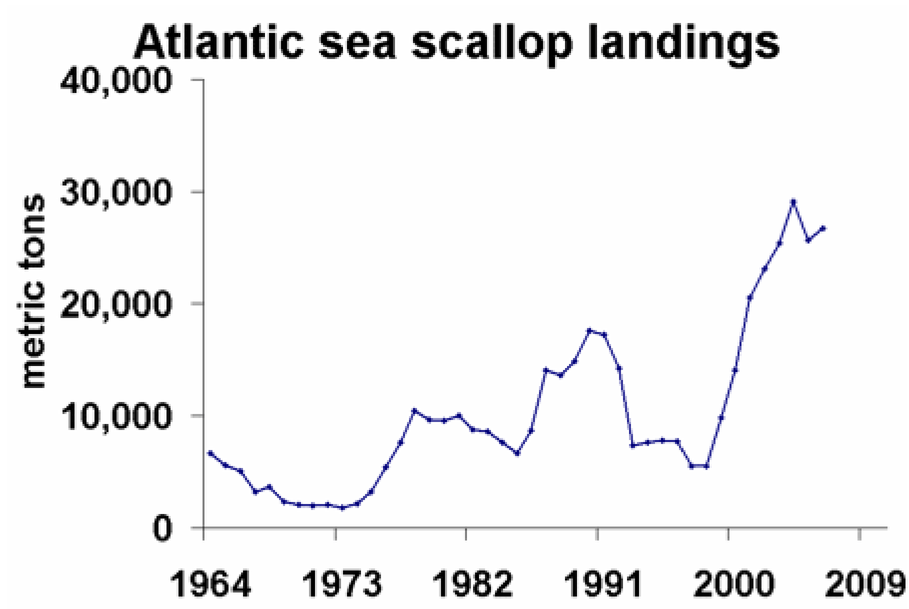


Figure 2.2 Landings of the Atlantic Sea Scallop, in metric tonnes, between 1964 and 2008. **(**Source: National Marine Fisheries Service, US Dept of Commerce. Data source: 45th North-east Regional Stock Assessment Workshop – Assessment of Atlantic Sea Scallops 2007)

2.1.2 Gear Specification

New Bedford Dredges and trawls are used in this fishery. Two main changes to gear have been implemented recently. Firstly in 2004 dredge ring size was increased to 4" in order to protect young scallops and also minimum mesh size for the mesh on top of the dredge was increased to 10" to reduce flounder by-catch. Then in 2006 chain mats were required in sea scallop dredges between May and November to reduce turtle by-catch.

2.1.3 Spatial Management

In response to severe fishery depletion of several species, three large areas, totaling 17,000km^2, were closed to fishing in 1994. The areas were selected on the basis of their importance as seasonal spawning grounds for haddock and the distribution of yellowtail flounder . It proved to be an effective tool for conserving numerous resource and non-resource species (Hermsen et al. 2003, Lindholm et al. 2004, Stone et al. 2004). It lead to large increases in the biomass of both sized and undersized scallops and in July 1998 harvestable scallop biomasses were 14 times denser in closed than in adjacent open areas (Murawski et al. 2000) . In 1998 there were further closures in the Mid Atlantic Bight region. Some areas were opened to controlled fishing in 2001 following increases in stock biomass which allowed the effects of closed areas and mobile fishing gear to be investigated (Stokesbury & Harris 2006) . These results and others (Myers et al. 2000) form the basis of amendment 10 which was implemented in 2004. The strategy employed rotates harvest areas to maximize yield while protecting young scallop beds. This means rotating open and closed areas to maximize scallop yield. At the same time limited areas of Georges Bank were re-opened to limited controlled fishing.

Wider ecosystem effects have also been considered and detailed habitat maps, scallop densities and information on other megafauna proved to be very useful (Hart 2001, Stokesbury 2002, Stokesbury et al. 2004). Competition effects have been observed between

sea scallops, seastars and crabs and the sand star *Astropecten americanus* may exclude new recruits of both *Placopecten magellanicus* and *Asterias spp* from some areas (Hart 2006). Community structure has also been found to vary with disturbance with the soft bodied tube building polychaetes dominating undisturbed sites while *Asterias spp*. and *Placopecten magellanicus* dominated disturbed sites (Hermsen et al. 2003) Some areas selected for closure were expected to afford protection to sponges, coral, seagrass and other aquatic life on which many fish such as young cod may depend.
One of the only recorded mass mortality events in scallops in a protected area was observed in this fishery (Stokesbury et al. 2007). It occurred in the Nantucket Lightship Closed Area during the 2004-2005 fishing season and in the largest and oldest scallops only. These scallops were probably greater than ten years old. Although it may be disappointing that these scallops could not have been marketed and a direct profit achieved from their sale, they will probably have played a major role in the fishery until their death. It is these older individuals who would have accounted for the vast majority of the spawn that recruited into the local fishery and thus contributed to sustainability and profits both past and future. It should also be noted that this area represents only a very small proportion of the whole fishery and other areas continued to thrive during this same period.

2.1.4 Fishing Practices

Fishing effort has been limited since the 1960's by setting a figure on the number of days a vessel is allowed to fish for scallops each year and also by restricting crew size. As the fishery recovered the number of vessels applying for scallop permits rose from 1,992 in 1994 to 2,950 in 2005. This lead to concerns that total fishing effort was increasing unsustainably. Hence February 2008 saw the introduction of limited access permits and individual fishing quotas (IFQ's). Other improvements since the plan began in 1982 include the way that commercial fishing data is collected.

2.1.5 Enforcement/ Monitoring Measures

From May 1998 all scallop vessels operating on the Georges Bank have been required to carry vessel monitoring systems consisting of a satellite-based receiver and transmitter. By 2005 vessel monitoring systems were required on open access general category vessels. Effective enforcement of the protected areas is widely considered to be key to the recovery of the scallop populations (Murawski 2000). There is also an industry funded observer program for monitoring by-catch of finfish and interactions with endangered and threatened species.

2.2 Canadian Sea Scallop (*Placopecten magellanicus*).

Value:	US$ 121,510,883 (worldwide export market) in 2005/6
Governing Bodies:	Department of Fisheries and Oceans (DFO)
	Offshore advisory Committee (OSAC)
	Minister for Fisheries and Oceans
Certifications:	Undergoing MSC assessment pending June 2009
	http://www.msc.org/track-a-fishery/in-assessment/north-west-atlantic/Eastern-Canada-offshore-scallop

2.2.1 Summary
DFO has set out an integrated management plan. A consultative management approach is provided through the OSAC who provide advice on total allowable catch (TAC), quotas, fishing seasons, size limitations and gear restrictions. On average TAC's have been set at about 20% of the spawning stock biomass over the last fourteen years. The success of this fishery has been attributed to its use of Enterprise Allocations (EA's), which the OSAC administrate. This is a management tool which confers a level of ownership on the fishers themselves and thereby provides them with an incentive to protect and nurture their resource (Orensanz et al. 2006). In this case it was given to companies or enterprises. Habitat mapping has also played a vital role in managing this fishery. There are management zones in place with voluntary and mandatory closed areas.
Since the plan was implemented in 1986 catch rates have tripled while fishing effort has been drastically reduced from 125,000 hours to just 25,000 hours. The plan is widely considered to be a success.
The industry's role in the management has become increasingly important over the years the programme has been running. Industry is responsible for funding stock assessments. This has allowed obtaining information on dynamics of the stock and seabed mapping. Industry has improved its fishing methods. The introduction of a voluntary programme to avoid areas with small scallops has been important in increasing yields and harvest efficiencies. Industry has also modernized its fleet. These functions have helped the conservation of the resource and the sustainability of the fishery (Stevens et al. 2008).

2.2.2 Gear specification
The New Bedford Scallop Rake or Dredge is used by vessels which must be able to deploy gear at 100m depth. There is currently research being carried out to look at gear modification to reduce by-catch.

2.2.3 Spatial management
This is a year round fishery located predominantly off Georges Bank, Browns and German Bank which are all within FAO area 21 Atlantic Northwest. Sensitive bottom habitats of deep sea corals in the fishery have been identified and closed coral protection areas have been implemented since 2002. There are also annual groundfish spawning area closures put in place by DFO to protect cod and yellowtail flounder stocks. Strategies have been implemented to map the bottom habitats of the fishery so that captains can accurately target scallop habitats while leaving surrounding habitats undisturbed.

2.2.4 Fishing operations
Georges Bank offshore is currently managed by individual quotas in the form of Enterprise Allocations or EA's which started in 1986. Each of the interested companies or enterprises are given a percentage of the TAC as set by DFO. These companies may use one or more vessels to catch their quota allocation. The behaviour of a fleet managed in this way has been found to be very different to those using more traditional input controls. In the EA program each enterprise manages its quota and has a major interest in the longer-term management of bumper year classes and of the fishery in general (Orensanz et al. 2006). There were 3 main objectives when EA's were introduced in 1986: to ensure protection of the resource, to

stabilize annual landings, and to provide increased economic benefits. In 1984 scallop catches were the lowest on record at 25,000t. Average catches between 2000 and 2002 were about 73,000t. Other benefits of this strategy have been a wider range of year classes within the populations and the size at which scallops are removed has increased. This means that millions fewer animals are harvested annually to achieve the same TAC. In addition effort has fallen from 125,000 hours in 1979 to only about 25,00 hours in 2002. An internal review of the EA program concluded that even unionized crewmembers agreed the objectives had been achieved (Stevens et al. 2008).
Minimum meat counts are used to protect juvenile scallops. There are practices in place to minimise by-catch. By-catch protocols are followed where-by a vessel moves out of an area when by-catch exceeds defined levels.

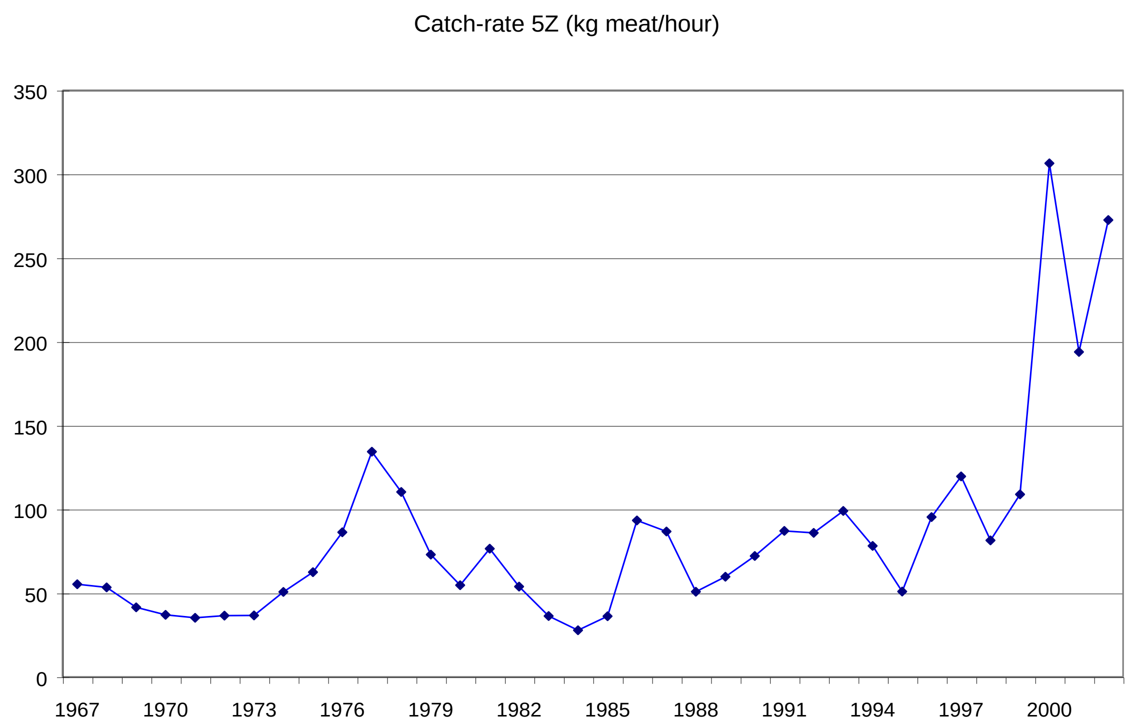


Figure 2.3 Annual Scallop Catch Rates (Kg meat/hour) for Georges Bank between 1967 and 2003. Source: (Stevens et al. 2008).

2.2.5 Enforcement practices:
All vessels are monitored by electronic devices which provide real time data. Industry sponsors 100% dockside monitoring and an at sea observer coverage programme to give information to DFO on catches of both target species and by-catch species. Daily catch reporting is required. At sea inspections and aerial surveillance also take place.

2.3 Western Australian Saucer Scallop (*Amusium balloti*)

Value:	AUS$ 2 – 59 million, it is highly variable.
Governing bodies:	Department of Fisheries Western Australia (DPFWA)

2.3.1 Summary

This stock is managed by the Department of Fisheries, Western Australia (DPFWA) who have been carrying out research into the biological and environmental aspects of the WA scallop and their commercial exploitation since the 1960's. Research has centred on maximising economic returns from the resource while managing its use and harvesting at ecologically sustainable levels. This fishery is managed under the Fish Resources Management Act 1994 and operates within a World Heritage Area. In 1992 it was the second largest single-species fishery in Australia on a live weight basis. DPFWA take an adaptive management approach based on pre-season surveys that measure recruitment strength each year. Real-time stock management is in operation whereby commercial capture data is relayed via satellite to researchers on a daily basis. This has enabled short-term area closures to be implemented by industry agreement. Breeding stock levels are considered to be adequate and impacts on other species and habitats are low. In recent years there has been a problem with low recruitment levels to the fishery either due to environmental factors or perhaps because juvenile scallops recruit directly onto the fishing grounds and are vulnerable to gear impacts from the time they settle. Managers are currently considering using an adaptive management approach with research closures to assess the relative survival of the scallops settling in the closed areas compared to the areas open to trawling. Also being considered is a study looking at modelling larval transport mechanisms to facilitate placement of closed areas to best effect (Fisheries Management Paper 222, Harris et al. 1999). There has also been discussion of implementing a quota system of some description.

2.3.2 Gear specification

Saucer scallops are active swimmers and are captured using demersal otter trawls and the size of gear is designed to target those scallops at a size and age when the meat is in premium condition for the market. Gear restrictions include a minimum mesh size of 100mm, limited number of nets, set length of trawl net head rope, size of trawl net head boards and the size of ground chains. By-catch is reduced in this fishery by mandatory grids which are fitted to the trawls and secondary fish escape devices are also required by law.

2.3.3 Spatial management

Five commercial fisheries target the saucer scallop the primary ones being Shark Bay and around the Abrolhos Islands. There are seasonal closures in place in both locations. For example in Shark Bay closures were originally in place between November and April. Recently this has been modified to opening in February or March in order to take advantage of the optimum meat size earlier in the season and closing the fishery when a threshold catch level has been reached. Permanent area closures are also in place.

2.3.4 Fishing practices

Boats are either licensed to take only scallops, type A license, or a type B license entitles the bearer to also catch two species of prawns, Western king prawns, *Penaeus latisulacatus* and brown tiger prawns, *Penaeus esculentus.* A class license holders account for about 70% total catch. There is a limit on the number of vessels and on the number of crew. The class B licensed boats are also restricted to fishing between the hours of 1700 and 0800 to match constraints imposed on the prawn fishery. Management zones have been created and there are regulations which restrict entry to specific areas within each fishery.

2.3.5 Enforcement measures
All boats must have VMS installed which is a satellite tracking system recording both location and speed. The Western Australians have put significant resources into policing their fishery using both at-sea and aerial patrols to ensure that closed seasons, closed areas and gear restrictions are followed.

2.4 Queensland, Australia, Saucer Scallop (*Amusium balloti*) and Mud Scallop (*Amusium pleuronectes*)

Value:	AUS$ 18 million (approx.)
Governing bodies:	Queensland Department of Primary Industry and Fisheries (DPIF)

2.4.1 Summary
This fishery occurs within the Great Barrier Reef Marine Park (GBRMP) and is managed by the Queensland Department of Primary Industry and Fisheries (DPI&F). It falls under the East Coast Trawl Fishery Management Plan, the Fisheries Act and the Environment Protection and Biodiversity Conservation Act. This is largely an annual fishery as saucer scallops grow very rapidly, reaching commercial size in only 6 to 12 months. Effort levels in the fishery were very high from the 1960s until the mid 1990s, resulting in very low densities at the end of each scallop season. Catch rates were the lowest on record (half the long term average) in 1996 resulting in rapid management intervention in 1997 (Dredge 2001). This was in the form of three large closed areas that covered approximately 5 % of the fishing grounds and allowed for recovery of stock in the protected areas. These protected areas were opened and closed on a rotational basis from 2002. Since these closures total catches in the fishery have stabilized back at the long-term average and catch rates have increased dramatically (Dredge 2001). The other interesting point about this fishery is that it occurs within a world heritage area (GBRMP) that employs a zoned management regime such that the needs of all interested parties are addressed.

2.4.2 Gear Specification
Otter trawl

2.4.3 Spatial management
Seasonal fishing closure and a series of rotationally fished area closures. Although the link between these closures and recent improvements in the fishery can not be proven, there is strong circumstantial evidence that their introduction in the 1990s saved the fishery from collapse (Dredge 2001).

2.4.4 Fishing Practices
Input controls include seasonally varying minimum legal sizes. Entry to the fishery is now limited and fishing effort unit are allocated which restricts individual annual effort.

2.4.5 Enforcement Measures
Queensland fisheries in the GBRMP are rigorously enforced by a range of measures including at sea and aerial surveillance.

2.5 New Zealand Enhanced Scallop fishery (*Pecten novaezelandiae*)

Value:	£7.2 million approx.
Governing Bodies:	Ministry of Fisheries
	The Challenger Scallop Enhancement Company

2.5.1 Summary
Fishing for scallops in New Zealand peaked in the mid 1970's and then crashed. In 1981 and 1982 the fishery was closed completely due to the depletion of the resource. In 1986 Individual transferrable quota's (ITQ's) were first introduced to some fisheries in New Zealand. They became law for scallops in 1992 initially with a fixed quota per license and then moved to proportional quotas later. This move had a huge effect on fishers' behaviour because it gave them the opportunity to improve their allowable catch by adopting fishing methods and practices which improved scallop abundance. These quota owners formed their own unlisted limited liability public company to manage their fishery which they named "The Challenger Scallop Enhancement Company". The government brought a flexible approach to management. This combined with the strong leadership from within the fishing industry helped to develop the capacity and structures for the government to devolve management to the company. Industry took an active role in defining this new approach to management and accepted responsibility for implementation (Mincher 2008). Enhancement costs around £600 thousand per year, and has resulted in a much more stable fishery (see Figure 4) with an estimated 50% of the catch coming from the enhancement programme. *Pecten novaezelandiae* lives for between three and five years in soft bottom habitats such as mud and sand. A key component of the management strategy is the use of rotational closures and openings. This fishery is widely regarded as a success both environmentally and economically.

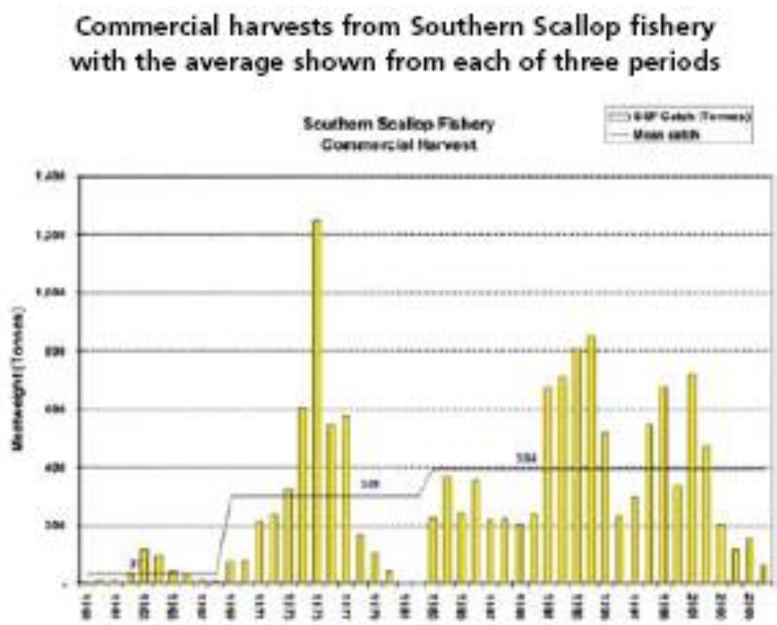


Figure 2.4 Scallop meat production in tonnes from the Southern fishery for *Pecten novaezelandiae* between 1959 and 2007 (Source: Mincher 2008).

2.5.2 Gear Specification

Commercial fishers use ringbag dredges which minimize damage to the seabed.

2.5.3 Spatial Management

Nine fishing areas were defined with rotational closures and openings. Each year management decisions were made as to which areas to open to commercial fishing. This was to allow naturally settled and seeded juvenile scallops to reach a good size so that they maximize yield. There were also some areas which were permanently closed to protect the breeding stock and sensitive habitats. After these measures were introduced the catch rates became much more stable. The stock recovered to the extent that the company had given areas to recreational divers to fish. Then in 2002 and 2003 harvests showed a decline and there was evidence of shellfish starvation. Both enhanced and unassisted spat that settled in the fishery failed to thrive. The problem was most pronounced in Tasman Bay and so the company responded by altering the rotational scheme and reducing fishing effort. Surveys in Golden Bay in 2005 and 2006 show signs of recovery with 2007 and 2008 figures expected to show significant improvement (Mincher 2008). This shows that although there appears to have been a problem with new recruit survival in parts of this fishery, flexible management has resulted in a fishery that is robust to these effects and the boom bust scenarios that have been common in other parts of the world were avoided here.

2.54 Fishing Practices

Stock enhancement measures have been in place since 1985 and have been gradually improving with experience. Synthetic material is suspended in the water column during the main spawning season to increase habitat for settlement of young scallop larvae. This material also seems to provide a refuge from predation by starfish and hermit crabs. When the scallops reach 15 to 30mm diameter they are harvested and used to seed the main scallop grounds. Stock enhancement is now thought to account for 50% of the catch in this fishery. There are size limits of 90mm and daily bag limits are used to cap catch rates on a daily basis. Other restrictions were put in place when the fishery appeared to be affected by disease as mentioned in the previous section and these measures have resulted in improved spat survival and should have secured the future of the fishery.

2.55 Enforcement
The New Zealand Southern Scallop fishery provides a good working example of fisheries self-governance.

2.6 European scallop fisheries

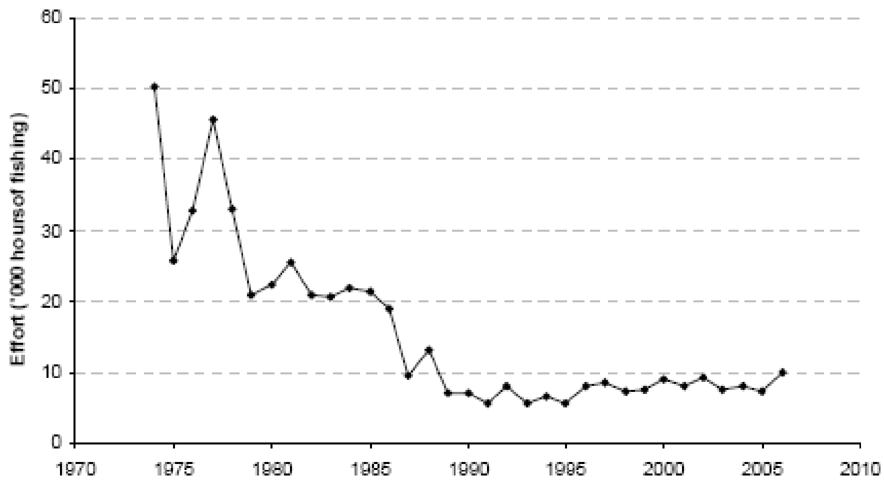
The great scallop, *Pecten maximus*, is commercially exploited in waters stretching from Northern Norway, through British waters and down as far as the Iberian Peninsular. Management strategies vary with location and the relevant country involved. Here we looked at a few specific cases.

2.6.1 Bay of Saint Brieuc, France, Great Scallop, (*Pecten maximus*)

Value:	Worth 15,400,000 Euros in 2006
Governing bodies:	Ministere del'agriculture et de la peche (The Ministry of Agriculture and Fisheries).
Stakeholders:	Comite local des peches maritimes et des elevages marins (local committee for fisheries) Comite regional des peches maritimes et des elevages marins (regional committee for fisheries).

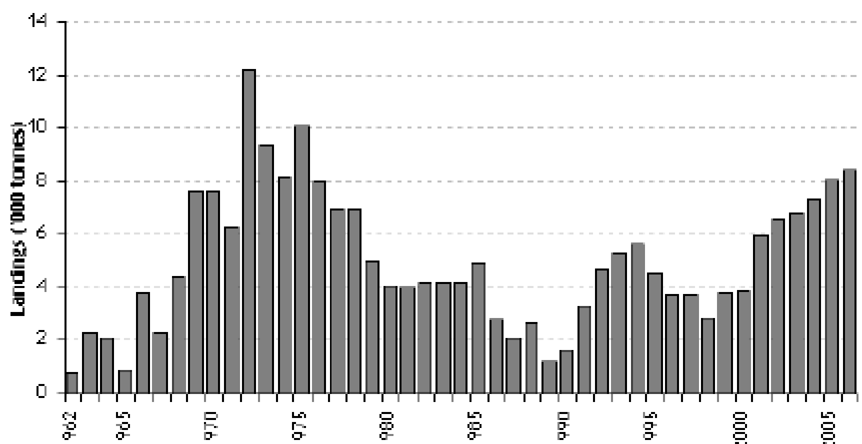
2.6.1.1 Summary
The Bay of Saint Brieuc is located in the Western English Channel and is one of the two main harvesting locations of the French fishery. Only French vessels fish the Bay and so there are no other European countries involved in its management. In 2005, the Bay of St. Brieuc produced a third of the French total scallops by volume and generally accounts for between 20 and 50% (Lesueur et al. 2008).

The fleet is multi-species and multi-gear with scallops accounting for 34% in quantity and 28% in value of all catch in the Bay of Saint Brieuc in 2006. Other target species include cephalopods, clams and various fish. Licences have been restricted in the scallop fishery since it began in 1963 to avoid overfishing. Increasing restrictions in the number of licences, time at sea per day and number of days fishing per year, have seen scallop catch rates increase dramatically. Profits have also increased due to improvement in the quality of the product.



Source: S. Fifas,,Ccom. Pers.

Figure 2.5 Total fishing effort for scallops in the Bay of Saint Brieuc between 1976 and 2007



Source: CAD22,2007

Figure 2.6 Scallop production in the Bay of Saint Brieuc between 1962 and 2007

2.6.1.2 Gear Specification

Various types of dredge are used including; the French dredge, the heavy Breton dredge and Newhaven dredges. Minimum size is restricted to 100mm. Minimum belly ring size has been set at 72mm by the European Union (EU) for all European waters however local authorities can put more stringent measures in place. The French now set minimum ring size at 92mm and have found that this means that less small scallops are captured and has also improved the quality of the adult individuals captured due to greater water circulation (Foucher 2006). Other gear restrictions vary with location and include the number, weight, width and tooth spacing of these dredges. Boat size is limited to 13m and 185kW engine size in the Bay of Saint Brieuc. The aim of these measures is to ensure regular landings from year to year rather than to maximize yield per recruit (Brand 2006a).

2.6.1.3 Spatial Management

There would appear to be no use of spatial closures within the Bay of Saint Brieuc but different quotas are set for inshore and offshore grounds.

2.6.1.4 Fishing Practices

The fishing season here is limited from November to April, the maximum number of fishing days allowed is 2 per week and the fishing day is limited to only allow between 45 minutes and 1 hour. The number of licenses issued is also limited to 225 in 2007. Total allowable catch rates (TAC's) are set based on an independent, scientific stock assessment and also take into account the quantities that need to be made available to industry (Read 2009). Decisions are made in consultation with the authorities and stakeholder groups.

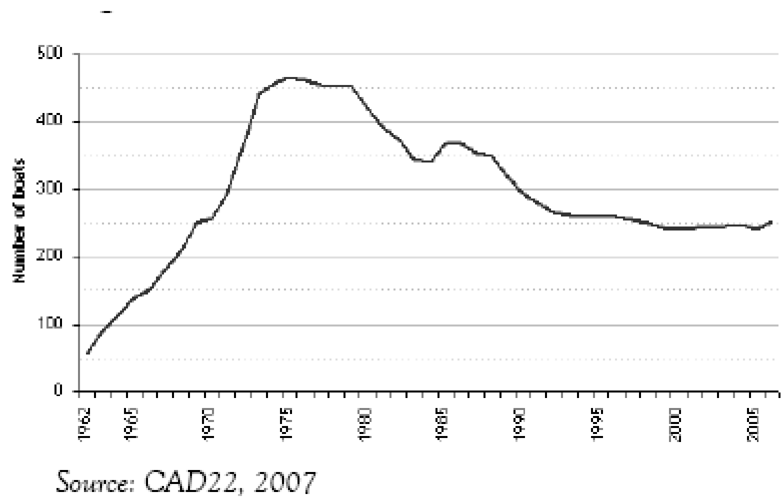


Figure 2.7 Evolution of the size of the fishing fleet (number of boats) in Bay of Saint Brieuc from 1962 until 2007.

2.6.1.5 Enforcement Measures

The fishery is policed by several government agencies, the French Navy and veterinary services, and the fishers themselves, with high penalties. Days at sea are forfeited, the number depending on the offence. The loss in revenue for a fisher has been calculated at approximately 873euros/fishing day, plus the price of the license which must be re-purchased after the ban at a cost of between 235 and 687 Euros.

	1 day withdrawal	2 days withdrawal	4 days withdrawal
Price of the licence = 235 euros	1 108 €	1 981 €	3 727 €
Price of the licence = 687	1 560 €	2 433 €	4 179 €

[3] We assume that these costs are net costs under the following assumptions : 1) vessels would go fishing anyway using other gears or targeting other species than the ones covered by the license, and 2) the gains from the 45 minutes alternative fishing are negligible compared to the revenue coming from scallop fishing.

Table 2.1 Loss in revenue (Euros) according to the number of day withdrawal. Source: Lesueur (2008).

As a guide for the general costs of enforcement in 2001 enforcement measures cost 31,797 Euros. Fishers themselves also provide air surveillance which involves the cost of an aircraft plus wages for the pilot and this was valued at 23,267 Euros in the 2006-7 fishing season.

2.6.3 Isle of Man, Great Scallop (*Pecten maximus*) and Queen Scallop (*Aequipecten opercularis*)

Value	Great scallop £1.75 million (2005) Queen scallop £450 k (2004)
Governing bodies	Isle of Man Government, Department of Agriculture, Fisheries and Forestry (DAFF)
Certifications	Queen scallop fishery currently undergoing MSC assessment

2.6.3.1 Summary

There has been a fishery for great and queen scallops around the Isle of Man since 1937 and 1969 respectively (Brand 2006a). Management of the fisheries (< 12 miles offshore) is the responsibility of the Isle of Man Government, Department of Agriculture, Fisheries and Forestry (DAFF). Between 3 and 12 miles offshore management measures must be agreed with the UK. Both fisheries have been the subject of extensive scientific research since their inception, largely aimed at the target species but also on the environmental impact of scallop fisheries (Brand 2006a). Together the great and queen scallop fisheries make up 85 % of the value of all seafood landed on the island (Brand et al. 2005). Management of Manx scallop fisheries has generally stayed ahead of the UK. The great scallop fishery has been subject to a closed season and minimum sizes since the 1940s. Additional management measures for the great scallop fishery have been continuously introduced since the early 1990s when stocks appeared to be in decline. Catch rates are now at a 20 year high on many grounds, although the local fleet is now half the size it was in the early 1980s (Beukers-Stewart et al. 2003, Brand et al. 2005). The queen scallop fishery was largely regulated by market demand until recently. Total queen catches have been highly variable from year to year since the fishery began. Although landings of queens into the Isle of Man are much lower today than they were in the 1970s and 80s, long term trends for the Irish Sea in general are relatively stable (Brand et al. 2005, Vause et al. 2007).

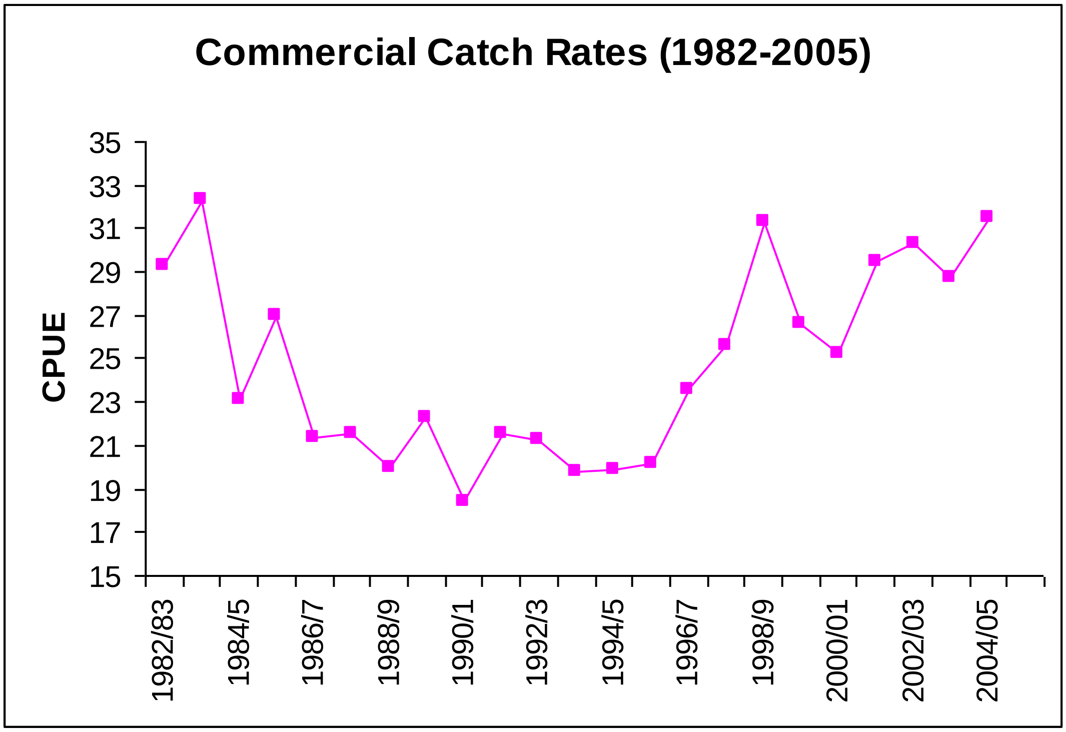


Figure 2.8 Commercial catch rates (scallops per metre of dredge per hour) for great scallops (*Pecten maximus*) taken by Isle of Man vessels (data from a subset of boats using voluntary logbooks, Beukers-Stewart & Brand (2007)).

2.6.3.2 Gear Specification

Newhaven scallop dredges are used for great scallop while either skid dredges or otter trawls may be used for queens. Aggregate dredge width (effectively dredge number) is restricted to 25 ft (10 standard dredges) within 3 miles and 40 ft (16 standard dredges) between 3 and 12 miles. Queen scallops are fished for with either skid dredges (on the rougher southern and western grounds) or trawls on the eastern and northern grounds. Vessel size in both fisheries is restricted to less than 50 ft (15 m) within 3 miles of the coast.

2.6.3.3 Spatial management

A small experimental area off the SW of the island was closed to scallop fishing in 1989. This area was expanded in 2003 and another area off the east coast was closed in 2008. The later two closures have been accompanied by juvenile scallop re-seeding exercises. Great scallop biomass and biodiversity has now increased dramatically in the original closed area (Bradshaw et al. 2001, Bradshaw et al. 2003, Beukers-Stewart et al. 2005, Beukers-Stewart et al. 2006, Beukers-Stewart & Brand 2007). There is also now growing evidence that export of larval scallops from high rates of breeding in the closed area has boosted surrounding populations (Beukers-Stewart et al. 2004, Beukers-Stewart et al. 2005, Beukers-Stewart & Brand 2007, Neill & Kaiser 2008). The local fishing industry is now strongly supportive of these spatial management measures and is actively involved in research and stock enhancement exercises (Beukers-Stewart & Brand 2007).

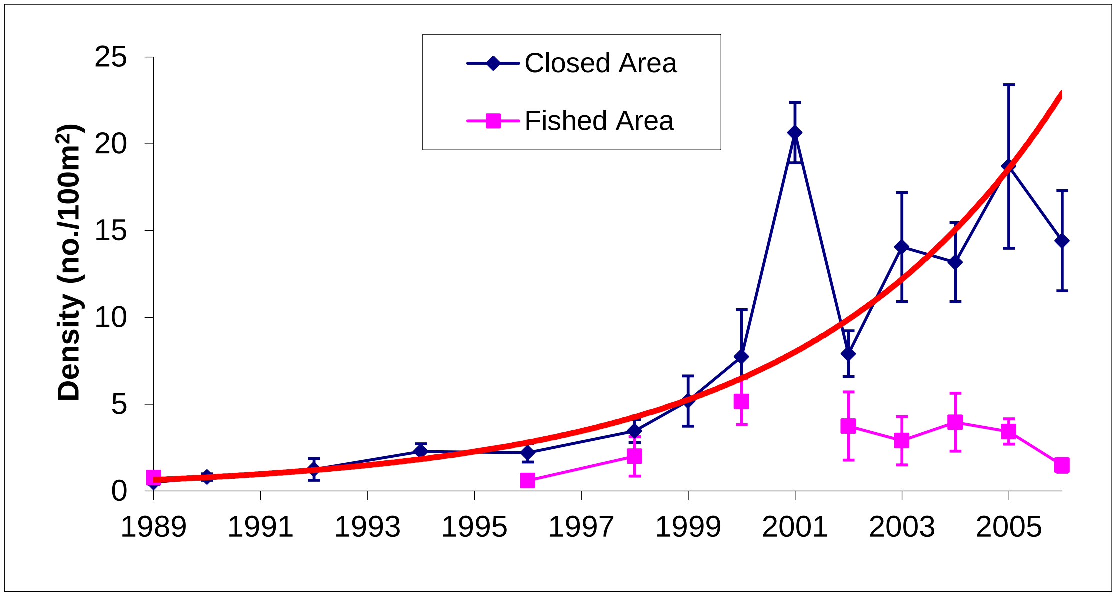


Figure 2.9 Great scallop (*Pecten maximus*) density in the original closed area and on the adjacent Bradda Inshore fishing ground (data from SCUBA surveys, Beukers-Stewart & Brand (2007)).

2.6.3.4 Fishing Practices

The fishing season for great scallops runs from November to May. Although queens can be exploited all year round the fishery predominately operates during the summer closed season for great scallops. Fishing for both great scallops and queens is restricted to between 6 am and 6 pm within 3 miles of shore and for scallops between 5 am and 9 pm from 3 to 12 miles. Most boats fishing within the 3 mile zone are registered in the Isle of Man, but further offshore both fisheries are also prosecuted by a large (approximately 70 in 2008) number of vessels from neighbouring countries (England, Wales, Scotland, Ireland and Northern Ireland).

2.6.3.5 Enforcement Measures

DAFF has its own fisheries enforcement vessel and has a history of prosecuting offenders. Vessel Monitoring Systems (VMS) were initially made mandatory on vessels > 18 m dredging for scallops in 2004. This was followed by compulsory VMS on vessels > 15 m in 2005 and on all vessels within 3 miles of shore in 2007.

2.7 Conclusions

Although the details of the management regimes of each of these successful fisheries do vary there are many underlying principles that remain the same and should be used in the formation of management strategies for the UK:

1) Stock biomass should be built up.
2) The age structure of the population should be improved so that scallops remain in the water longer to mature and reproduce. This provides population resistance to disturbances such as fishing pressure, disease and environmental changes.

3) New recruits and juveniles must be afforded protection, they represent the fisheries future. Virgin scallops, that is those that have not been previously caught, also have a much greater value at market and hence this approach increases the yield per recruit and makes great economic sense (e.g. the French fishery)
4) Either management regimes need to be rigorously enforced (e.g. the North East American fishery) or fishers need to be involved in the management of their fishery and preferably be afforded a level of ownership of the resource on which their livelihoods depend (e.g. the Canadian and New Zealand fisheries).
5) Mapping complex benthic habitats has been used in many of these examples to allow best spatial management of resources.
6) In most cases by-catch reduction measures were in place.

3. Case Studies of Successful Management of other Benthic Invertebrate Fisheries and Scallop Dive Fisheries around the World.

3.1 South American benthic invertebrate fisheries; loco snails (*Concholepas concholepas*) in Chile, sea urchins (*Erizo blanco*) from Southern Chile and Argentine Scallops (*Aequipecten tehuelchus*).

3.1.1 Summary
All of these fisheries underwent severe crisis in the 1990's which has led to co-management initiatives to improve these resources ((Orensanz et al. 2005), & see section 1.2.1).
In Chile in 1991 it led to the Fishery and Aquaculture Law which covered both artisanal and industrial fisheries and was aimed at driving the fishery towards self-governance in a part of the world where policing is unrealistic for a number of reasons. This policy has been generally proclaimed a success (Gelcich et al. 2008a, Gelcich et al. 2008b).

3.1.2 Spatial Management
In Chile artisanal fishers (diving, finfishery) were given exclusive access rights to fish within a zone that extends to 5 nautical miles from the coast and individuals are restricted to working along the coast adjacent to where they reside (Castilla & Gelcich 2008). They also created Management and Exploitation Areas for Benthic Resources (MEABRs) in well defined coastal areas which gave exclusive harvesting rights for benthic resources to artisanal small scale fishing associations. These are known as Territorial User Rights for Fisheries (TURFs). Benthic resources have increased within these areas compared to open access areas. There also appear to be important knock on effects for non target species with species diversity and abundance significantly higher in these designated areas. These MEABRs could represent a complementary network that back up the biodiversity objectives of fully protected areas.

3.2 Canadian Dive fishery for the Green Sea Urchin, (*Strongylocentrotus droebachiensis)*

Value	$895,000 approx.
Governing bodies	Fisheries and Oceans Canada – Pacific Region.

3.2.1 Summary
In 1995 due to conservation concerns for a rapidly growing fishery utilising a largely unknown stock, a raft of management measures was implemented. Catch rates have been stable since then. A surplus production model was used to calculate the maximum sustainable yield (MSY) from catch data. The total allowable catch (TAC) per area is then set at 25-50% of the MSY. A TURF system was also implemented with some economic success. The green sea urchin relies heavily on a species of kelp for its survival and individual condition is thought to vary with the quality of this habitat. The condition of the sea urchins is crucial for ensuring a good price at market.

3.2.2 Gear specification
SCUBA

3.2.3 Spatial Management
Since 1995 fishing has been restricted to two principal fishing locations: Queen Charlotte Strait and the Gulf Islands – Victoria. A formal individual quota system was implemented in the same year and a TAC is set for the fishery each year.

3.2.4 Fishing practices
Minimum test size set at 55mm was established in 1988 to allow individuals to spawn at least once and because larger animals are more valuable. The number of licenses to dive for urchins was capped in 1991 and now stands at 49. A voluntary logbook scheme is used to collect information on diver hours, detailed fishing location, and percent roe yield. A requirement of the license was that the fisher must enhance the stock in their zone. Various methods were attempted including removal of the poorer quality sea urchins and increasing quantity of kelp. Only a few fishers were successful in boosting their stock. Another requirement was that they mapped the sea urchin and seaweed distributions in their zone. Nearly all harvesters admitted to finding new beds and maps were well drawn (Miller 2008).

3.2.5 Enforcement
Catch is validated at designated landing ports.

3.3 Tasmanian Dive Fishery, Australia, for sea urchins (*Heliocidaris* or *Centrostephanus)* and periwinkles (*Turbo*)

Value	Sea urchins AUS$ 67,000 Periwinkles AUS$ 56,000
Governing bodies	Tasmanian Department of Environment and Heritage

3.3.1 Summary
This fishery has been comprehensively reviewed in a report by the Department of Environment and Heritage (Anon. 2005). This stock is currently considered to be sustainable and having minimal or no effect on other species or habitats. Performance indicators used to assess the viability of the stocks are catch per unit effort (CPUE) and relative abundance of cohorts in samples of commercial catches. These indicators must remain at or higher than levels previously recorded for the fishery between 2000 and 2004. Trigger points have been set and when reached the Tasmanian Minister would review the management strategy.

3.3.2 Gear specification
Fishing is by SCUBA using limited non-mechanical methods such as tongs, a single long hook or gloved hand. Rakes are prohibited because they are too destructive.

3.3.3 Spatial Management
Three zones with separate TACs for sea urchins, zones with TAC for periwinkles,

3.3.4 Fishing Practices

Seasonal closure sometime between January and May for the 3-4 months following spawning. Fishing activity is highest around December prior to spawning when roe quality and quantity is at its best. Number of commercial dive license holders limited to 55. Size limits for both sea urchins (60mm) and periwinkles (30mm) and compulsory logbooks. By-catch is considered to be minimal due to the highly selective fishing method.

3.3.5 Enforcement

Indications from police prosecutions are that illegal fishing is minimal and the number of license holders has fallen naturally over the last few years.

3.4 Conclusions

Although dive fisheries do not have direct impacts on benthic habitats or other species they do have the potential to locally deplete the resource. Therefore good management practices would be of great benefit to similar fisheries around the UK as in these examples they have been shown to improve yields and sustainability.

4. Principles for the Management of Inshore Scallop Fisheries around the United Kingdom

There is growing evidence from around the world that healthy marine ecosystems are significantly more productive and therefore support more sustainable and profitable fishing industries. It is vital that there is sufficient suitable habitat for settlement of young scallops and protection so that young scallops are not damaged by fishing gear. This type of damage can reduce scallop survival and growth which in turn will decrease future yields and profit. It is also essential to protect key breeding areas to maximize replenishment of the exploitable stock. A key factor in any new approach would need to be the removal of the "race for fish" behaviour as shown by scallop fishing practices in the UK presently and which the current management strategy essentially encourages. Fishers need to be given a level of ownership of their resource which would provide them with an incentive not to overharvest (Baskaran & Anderson 2005, Hilborn et al. 2005). When these measures are employed scallop stocks have the potential to provide much more reliable and lucrative returns and remove the high levels of uncertainty that characterise the UK scallop fishery at present.

We have identified several management requirements in order to improve productivity (yield per unit effort) in both the great and queen scallop fisheries to ensure their long term sustainability. We will now deal with each issue in turn:

4.1 One of the fundamental problems with the fishery at the moment is that there is no ownership of the resource by the fishermen and they therefore compete to catch the most fish. As pointed out by numerous authors fishermen act in their own best interest to maximize their profits (Hilborn et al. 2005, Orensanz et al. 2006). Any management strategy must consider the effects on fishers' behaviour. Although there is no one prescription for sustainability, a range of management tools have been used worldwide to eliminate the race for fish by increasing the incentives for long term investment and efficiency. Good working examples include the Enterprise Allocations used in the Canadian fishery, the TURFS in the South American dive fishery and the proportional quotas in the New Zealand fishery.

4.2 Great scallop and queen scallop populations need to recover towards more natural age and size structures in order to increase spawning stock biomass and the yield per scallop. This will also improve the resilience of the population to environmental change and thus the stability of the whole fishery would improve. This could be achieved in several ways including quota systems, increasing minimum sizes, gear modifications and closed areas. Although there are some industry concerns that long term protected populations may succumb to disease or predation there is no scientific support for this idea on any significant scale. Detailed histological study of king and queen scallops around the UK found them to be remarkably disease free (Brand & Beukers-Stewart 2000). Indeed one of the longest running scallop protected areas in the world (the Isle of Man closed area) has continued to thrive after 20 years with scallop biomass levels at more than sixty times those shown prior to protection (Beukers-Stewart & Brand 2007). There is strong evidence that this has lead to greater returns from the surrounding fishing grounds (Beukers-Stewart et al. 2005, Kaiser 2007a).

4.3 There also needs to be a minimization of the effects of fishing on juvenile scallops for two main reasons. Firstly they are the fisheries future profit and secondly virgin (previously undisturbed / captured) scallops are worth significantly more as the French have found. Maximizing profit should be a key factor in any management plan. Minimizing these effects could be achieved either by rotational or seasonal closures, gear modifications such as ring size increases or fishing practice modifications where fishers cease fishing activity in an area when numbers of undersized exceed a trigger point (e.g. real time closures in the Scottish cod conservation scheme).

4.4 By-catch should also be reduced and this has been achieved very successfully in other fisheries using gear modifications, time of year closures, zonation, and fishing practice modifications such as ceasing fishing when by-catch rates reach a trigger value. This is important for healthy ecosystems and it is important that as a nation we utilise all our resources effectively so that one fishery does not negatively impact on another and this could be achieved by a co-management strategy for our seas.

4.5 There should be a reduction in the effect of scallop fisheries on benthic species and habitats using area closures for the most sensitive habitats. In order to achieve this we need improved and wide-scale mapping of seabed habitats and fishing activity (e.g. Welsh inshore waters (Hall et al. 2008), Clare Eno, CCW pers. comm.). There have been improvements in technology (e.g. ground discrimination software and multi-beam sonar) such that it is now possible to target between different types of seabed. In this way fisheries can concentrate on high density patches of scallops while avoiding sensitive habitats. Overall, if there is less fishing effort for greater returns (e.g. the French and Canadian scallop fisheries) this will reduce the intensity of disturbance on the areas that are open to fishing. This may be particularly significant for biodiversity in habitats that are able to withstand moderate levels of disturbance.

4.6 The issue of cost for these changes has been muted and in other fisheries this varies. In several fisheries the industry have taken sole responsibility for the costs of improvements and then reaped the rewards. In the New Zealand case this included costs of enhancement of approximately £600 thousand per annum, which was less than 10 % of the dockside value of the fishery. A similar cooperative was successfully formed in Alaska for the weathervane scallop and this was entirely financed by Alaskan fishers (Jim Stone, Alaskan Scallop Association, pers. comm.) who self manage their fishery. In other cases compensation has been offered. In the Alaskan Bering Sea Crab Fishery there was a buy back loan scheme put in place by the US Government. This was a 30 year low interest loan that bought out about 25 boats and their associated permits. In the Australian dive fishery there was a natural attrition of licence holders with the number in 2005 half that in 1993 (Anon. 2005). It would be of some benefit to consider in greater depth the various options regarding the economics of any changes introduced.

If these improvements in the management of scallops were implemented then this would increase the chances of eco-label certification (e.g. Marine Stewardship Council) which in turn could further increase the profitability of fishery. Any strategy for scallop management must be part of an overall plan in order to effectively manage the seas off our shores for all stakeholder groups. This sort of ecosystem approach has been implemented in other parts of the world and requires government to be all encompassing rather than sector based. It needs to focus on the cumulative impacts of all activities and should deal in trade-offs between these activities (Crowder et al. 2006). The goal should be to keep the ecosystem in a resilient condition. This may all seem very well in theory, but it is also practically viable and has worked successfully for marine environments in the US and Australia and in terrestrial ecosystems too. The easiest way to do so is under a place-based regime or by area / region. It requires that all stakeholders be brought together (e.g. Finding Sanctuary) and the overall process may be best managed by social scientists (Larry Crowder, Duke University, pers. comm.).

5. Proposed Best Management Strategy

The UK inshore area which extends up to 6 miles offshore is a highly diverse and much utilized resource. Careful zonation of this area should result in a reduction in conflict between different user groups, improved fisheries productivity and protection of biodiversity. Zones should range from completely protected to single use to multi-use according to area. User groups include recreational pursuits, energy production and fisheries among others.

A reasonable fisheries management regime that could be implemented under Marine Spatial Planning and the Marine Bill (or its equivalent in the devolved countries) would seem to be:

Up to 3 miles	Limit dredging (and trawling) as much as possible, to create a zone with low impact users only. The zonation scheme should include some completely protected areas alongside areas for scallop divers and static gear fisheries.
3-6 miles inshore	Medium impact zone to include ownership system (spatial or catch based) for scallop dredgers, trawl fisheries, crab potters, other static gear types and completely protected areas.
Outside 6 miles	Quota system (ITQ) for the nomadic scallop fleet and some fully protected areas. Most other finfish fisheries are managed under the Common Fisheries Policy in this area.

There should also be mandatory increases in minimum belly ring size on great scallop dredges in all areas to reduce current high catches of undersized scallops. Problems with changing dredge selectivity due to wear and tear could be significantly reduced by using case-hardened steel to construct belly rings. The French fishery has found 92mm (much greater than 75 mm common in the UK) to be appropriate for their inshore fishery. Identification of suitable sizes for use in different regions of the UK would require further study.

6. Future Work:

Priorities for future research include the following:

- Map currents and larval dispersal of scallops to identify "source and sink" locations and assist with planning networks of effective protected areas
- Map seabed habitats according to sensitivity and overlay these with maps of fishing activity to identify key areas for management action.
- Measure by-catch in all fisheries to assess ecological significance and to reduce conflicts between different fisheries.
- Conduct research into suitable increases in minimum scallop dredge belly ring size. As growth rates vary for scallops around the UK with growth being much slower in Scottish waters it is essential that minimum ring size is set according to location, at least for the inshore fleet.

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