Strategic Environmental Assessment - SEA5
Technical Report for Department of Trade & Industry

NORTHERN NORTH SEA SHELLFISH AND FISHERIES

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EXECUTIVE SUMMARY

The SEA5 zone covers an extensive area of the northern North Sea, and unlike previous assessments, it includes a substantial inshore area supporting valuable shellfish resources and fisheries. The SEA5 zone includes the entire east coast of Scotland and the east coasts of Orkney and Shetland. The water depth within this zone ranges from the inter-tidal down to around 200m and the variety of habitats is diverse. The species covered in this report include six species of crustacean, four species of bivalve mollusc and two species of gastropod mollusc:

Norway lobster, *Nephrops norvegicus* (L)
European lobster, *Homarus gammarus* (L.)
Edible crab, *Cancer pagurus* (L.)
Velvet swimming crab, *Necora puber* (L.)
Shore crab, *Carcinus maenus* (L.)
Pink shrimp, *Pandalus borealis* Kroyer

Giant scallop, *Pecten maximus* (L.)
Queen scallop, *Aequipecten opercularis* (L.)
Cockle, *Cerastoderma edule* (L.)
Mussel, *Mytilus edulus* (L.)

Whelk, *Buccinum undatum* (L.)
Periwinkle, *Littorina littorea* (L.)

The distributions of these species are mainly governed by two partially inter-related factors, depth and the physical nature of the seabed. Norway lobsters and pink shrimps occur on mud or sandy mud sediments in relatively deep water, whereas species such as cockles and mussels are mainly found inter-tidally on sandy beaches or rocky shores respectively. Lobsters, shore crabs and velvet crabs are mostly found in shallow reef, rock and boulder habitat. Both scallop species occur mostly on sand and shell-sand sediments over a wide depth range, while the edible crab and the whelk share similar depth distributions but may also occur on gravel, boulder and rock. Of major importance in the context of this assessment is that all the species are relatively sedentary. While local movements may occur in some species, others are either sessile or have limited mobility. This means that they are extremely vulnerable to environmental disturbance and pollution.

In this report the extent of the shellfish fisheries is given in terms of reported landings. Although fishing effort information is collected, the data are not considered reliable, particularly in recent years. Fishery landings data were available from yearly additions of Scottish Sea Fisheries Statistics and from the Aberdeen Marine Laboratory fishery statistics database. The latter information is stored with reference to ICES statistical rectangle codes. Each rectangle covers an area of seabed of approximately 30 square nautical miles.

The grid of ICES statistical rectangles does not match precisely with the boundaries of the SEA5 zone, requiring a degree of compromise in selecting the most appropriate fishery data. Account was also taken of the fact that when the SEA5 boundaries were originally established, several inshore areas were excluded from oil and gas

exploration; inner Firth of Forth, the Tay estuary, the inner Moray Firth, and the inshore waters around Orkney and Shetland. In view of the fact that the DTI remit now includes wind-farm developments, it was considered that the above inshore areas should be included in the SEA5 assessment of shellfish resources.

Relevant aspects of the biology of each species are described, including habitat preference, distribution, feeding, life-cycle, reproduction and spawning. Details are given about the fishing methods used, assessments of the state of stocks, and the management regime and legislation currently used to control each fishery.

Landings of shellfish from the SEA5 zone in 2000-2002 varied from 15,191 to 17,719 tonnes, and were valued at £26.4–32.7 million. The value of shellfish landings in 2002 (£26.4 million) represents 29% of the total value of shellfish landings from the whole of Scotland (£92.1 million). The Norway lobster is by far the most important shellfish species exploited in Scottish waters. Landings of this species taken within the SEA5 zone were estimated to be worth about £18 million, representing nearly 70% of the total value of all shellfish taken within the zone.

Norway lobsters are located in areas of soft mud or muddy sand in which they excavate and inhabit burrows. Within SEA5, stocks are found in the Moray Firth, Firth of Forth, west of Orkney (Noup) and at Fladen. Roughly half the Fladen ground occurs in SEA5. The condition of Norway lobster stocks is assessed regularly by a working group of the International Council for Exploration of the Seas (ICES). This species and pink shrimp are the only resources that are currently assessed in this way. The Norway lobster fisheries are managed by Total Allowable Catch (TAC) limits and a number of technical measures, imposed by the EU. TACs are not set for individual stocks, however, but are combined for the whole North Sea, which makes it difficult to achieve a balanced exploitation for each stock. Fishing is carried out by various types of trawl in which the mesh size varies, but must not be smaller than 70mm. This mesh size is much smaller than the mesh size imposed for demersal whitefish trawls, resulting in a considerable fish by-catch and discard problems. To help solve this problem, Norway lobster trawls must be fitted with a square mesh panel of 90mm mesh to allow small fish to escape, though there are doubts about its effectiveness. Other methods may have to be used in the future, including separator trawls and sorting grids.

In coastal waters, a baited creel fishery exploits four species, the European lobster, edible crab, velvet swimming crab and to a lesser extent, the shore crab. A new vessel licensing system is being introduced in the creel fishery in an attempt to cap fishing effort. The Inshore Fishing Order 1989 sets aside certain areas as static gear reserves for creel fishing, to avoid conflict with mobile gear. The creel fishery is also regulated by certain technical measures, including Minimum Legal Sizes (MLS) for the first three species. The fishery for the shore crab is unregulated. The SEA5 zone accounts for virtually all North Sea landings of these species into Scotland. The overall value of the creel fishery in SEA5, for lobsters and all three species of crab, was about £5.8 million in 2002. For the European lobster, several approaches are being tried to increase egg production and subsequent recruitment; release of hatchery –reared juveniles (at Orkney and Shetland); v-notch tagging of large egg-bearing female lobsters and a maximum size limit to improve the breeding stock, and construction of artificial reefs. Legislation to ban the landing of v-notched lobsters was introduced in Scotland in 1999. The first artificial reef in the UK was constructed off the Berwickshire coast using rubble from the Torness nuclear power station construction. Studies have demonstrated higher lobster catches on the reef compared to adjacent sites.

Within the SEA5 zone, pink shrimps are found only on the Fladen ground where their distribution overlaps with the Norway lobster. On the Fladen ground, pink shrimps are relatively short-lived with few of them surviving beyond the age of three. Mortality of shrimps is very high due to predation by fish. The Fladen pink shrimp stock is exploited mainly by vessels from Denmark and Scotland. The landings of pink shrimps from the SEA5 zone are derived from the NW corner of the ground and accounted for 3–36% of recent landings by UK vessels into Scotland. The Scottish landings have declined in recent years and were very small in 2002 due to lack of market demand. Stocks of pink shrimps are assessed regularly by an ICES working group, but the only control on the Fladen fishery is a trawl minimum mesh size of 35mm.

Four species of bivalve mollusc are exploited in the SEA5 zone, of which the giant scallop is by far the most important. The main fisheries are located around Orkney and Shetland, in the Moray Firth and off the east coast of Scotland, with most of the landings taken within the zone. The estimated value of this fishery in 2002 was £2.5 million. The scallop fishery is important to the SEA5 exercise because of the heavy toothed dredges used to dig out the recessed scallops and the proximity of the offshore fishery to mature oil fields and pipelines. Recently imposed restrictions limiting the number of dredges may make fishing uneconomic for the larger vessels and lead to a reduction in exploitation on the offshore grounds. Assessments show that the North Sea scallop stocks are at a low level because of poor recruitment over several years, though recent surveys have shown some improvement. The Shetland stock is in a better condition and the fishery there is now controlled by a local management regime, based on a Regulatory Order.

The other exploited bivalve species are queen scallop, common mussel and the cockle. The fisheries for these three species are relatively small and mostly located around the Orkney and Shetland Isles. The only mussel fishery at present is in the Dornoch Firth and is well managed by the Highland Council. All mussel fishing rights in Scotland are either privately owned or belong to the Crown. The only cockle fishing at present is located at Orkney, mainly on the Otters Wick beach at Sanday. The cockles are gathered by hand raking. There are other small stocks of cockles within the SEA5 zone but, because of environmental concerns, they are not exploited at present.

For three of the above species, giant and queen scallops, and mussels, production from fishing is supplemented by culturing them. In addition, the native oyster, *Ostrea edulis*, and the introduced Pacific oyster, *Crassostrea gigas*, are also farmed in Scotland. Although expanding slowly, the shellfish farming industry in Scotland is still relatively small. Within SEA5, most shellfish farming is confined to the sheltered waters of the Orkney and Shetland Isles. In 2002, there were 72 active shellfish farms in Shetland and 12 in Orkney, producing mainly mussels. The total value of farm production from the Northern Isles in 2002 was estimated to have been £1.33 million, of which 99% was accounted for by Shetland mussel production.

Gastropod molluscs are represented by two species, the common whelk and the periwinkle. Some fishing for whelks takes place around the whole Scottish coast, though mostly in the North Sea and the Northern Isles. The main method of fishing consists of baited pots made from perforated 5 gallon plastic containers. The SEA5 zone accounts for nearly all whelk landings from the North Sea and a high proportion of total Scottish landings in most years.

Winkles are inter-tidal in distribution and are harvested by hand at low tide. The fishery largely operates in the ‘black economy’ so that landings data are grossly under reported. Both whelk and periwinkle fisheries are unregulated, except on Shetland where there is a Minimum Legal Size regulation for whelks. Several of the other fisheries within SEA5, for example, queen scallop, shore crab, velvet crab and cockle, are also poorly regulated. A possible solution to this is to follow the Shetland example more widely by using Regulatory Orders. Several Orders could also be used more widely to promote the culture and ranching of scallops.

Previous SEA reports have dealt with the impact of oil and gas extraction on fisheries so the present report concentrates on some aspects of the problem in relation to shellfish species. Most studies on the biological effects of seismic sound energy have concentrated on marine mammals and fish, groups which have highly sensitive hearing organs. Invertebrates, on the other hand, have been little studied in terms of bioacoustics. Crustaceans have a variety of hair-like sense organs that are potentially capable of responding to mechanical stimuli, including sound, but similar structures have not been identified in bivalve and gastropod molluscs. These mollusc groups are therefore unlikely to change their behaviour in response to seismic sound waves, though they could show physiological reactions and anatomical damage.

Recent studies off the coast of Newfoundland, investigated the behaviour, physiology and anatomy of snow crab, *Chionoecetes opilio*, in relation to seismic surveys. Results showed no effect from seismic transmissions on snow crab creel catch rates, crab behaviour in cages, or on blood chemistry and composition. Similarly, no pathological changes were detected in the exoskeleton, appendages, statocysts, hepatopancreas and heart. None of the snow crabs died during these tests, in some of which, the source was positioned only 2m away. Some additional experiments were carried out on fertilized eggs stripped from ovigerous female crabs. Eggs exposed to a single air-gun source at a range of 2m showed some differences from controls when examined after 12 weeks. There was a small increase in egg mortality in the seismic treatment group, and there appeared to be a reduction in the rate of egg development. It should be noted that the eggs were exposed at a range much closer to the source than would occur in the nature.

Within the SEA5 zone, the main crustacean resource likely to experience exposure to seismic sound energy is the Norway lobster. Using sound level measurements from the air-gun arrays used in the snow crab work it can be shown that seismic sound energy at 100m depth is from 4–40 times larger than the acoustic response threshold for Norway lobsters. It is possible that detection would lead to an escape response in Norway lobsters, though these responses are likely to be transient and have no lasting effect on normal behaviour rhythms and trawl catches.

The problem of alien marine species introductions has concentrated on the transport of potentially harmful phytoplankton in ships' ballast water. Another source of such introductions is the transport of sessile species attached to ships and oil platforms. An example of this occurred in 1994 when clusters of the Magellan mussel, *Aulacomya ater*, were caught in the Moray Firth. The source of the Magellan mussels was not positively identified but they were likely to have fallen from a barge, ship or oil platform anchored in the area.

The shellfish species considered in this report are generally considered to be particularly vulnerable to the uptake of environmental contaminants. All of the species are relatively sedentary, and this lack of mobility is an important factor in the accumulation of environmental contaminants by shellfish.

Bivalve molluscs, such as the common mussel and giant scallop, are filter feeders taking in particulate food with a respiratory current of sea water, and in so doing, acquiring chemical contaminants. It appears that molluscs such as the common mussel do not regulate persistent chemical compounds but accumulate them in body tissues. The mode of feeding in periwinkles, browsing on algae in the littoral zone, can result in contaminant accumulation, such that this species has been routinely monitored close to the Sullom Voe Oil Terminal at Shetland. Contamination problems can also arise in crustaceans, either indirectly through feeding or directly from the environment. Evidence from the *Braer* accident at Shetland revealed that shellfish species can be very seriously affected by an oil spill. Because of the nature of the oil and the weather conditions prevailing at the time, much of the oil was deposited on the sea bed in deep basins of fine sediment. A fishery exclusion zone was established by the Scottish Office to prohibit the taking of farmed and wild fish, and shellfish, from the contaminated area. The zone restrictions were finally removed for mussels and Norway lobsters more than seven years after the oil spillage. The persistence of oil contamination in the fine sediments found in deep basins, as happened following the *Braer* incident, is to be expected since many of the components of oil are hydrophobic and tend to adhere to particulate matter.

A high level of certain trace metals in marine organisms is a natural phenomenon as they are required for metabolic purposes. In crustaceans, for example, metals such as zinc, copper and manganese are essential elements and there are mechanisms for their take up, metabolism and excretion. For other metals, there appears to be no metabolic need but they are nevertheless taken up, examples being cadmium, mercury and lead. These elements accumulate in body tissues as there appears to be no pathway for excreting them. Instead, decapods such as Norway and European lobsters, crabs and shrimps appear to store these metals in a detoxified form without ill effect. The main concern then, in a fisheries context, is that the metal content can exceed recommended limits for human consumption.

Some studies on mercury concentration in the abdominal musculature of Norway lobsters suggested that the metal accumulated in proportion to age. In view of the above findings regarding both hydrocarbon and trace metal contamination in Norway lobsters, it is surprising that little monitoring of this species appears to have been done on the Fladen ground in proximity to mature oil fields.

The main impact of offshore wind farms on fishing will arise from the disruption to activity during construction and after commissioning, it being assumed that turbines, sub-stations and cables will have surrounding exclusion zones, as for oil and gas production platforms. The effects on shellfish populations are likely to be site specific and are difficult to predict. Further monitoring of existing operational offshore wind farms, mainly in Scandinavian waters, is highly desirable. Although all developments involve a preliminary environmental impact assessment (EIA), there are few studies providing information on what actually happens after a wind farm is commissioned. Wind farms could be designed to have positive benefits. In some locations, there may be scope for scour protection works around the base of the turbines to serve as artificial reefs providing suitable habitat for the European lobster.

Topics identified during the review, where more research is needed include; spawning migrations and location of over-wintering areas of edible crabs; role of inter-tidal zone as nursery areas for edible, velvet and shore crab; recruitment problem in North Sea scallop stocks; contaminant monitoring of Norway lobsters on the Fladen ground, and the environmental impact of wind farms, including effects of noise underwater.

1. Introduction

The SEA5 zone covers an extensive area of the northern North Sea, and unlike previous assessments (SEA2, SEA3 & SEA4), it includes a substantial inshore area supporting valuable shellfish resources and fisheries. The SEA5 zone includes the entire east coast of Scotland, extending from the Anglo-Scottish border to Caithness and the East coasts of Orkney and Shetland (Fig.1). The water depth within this zone ranges from the inter-tidal shore zone (littoral zone) down to around 200m and the variety of habitat within the zone is diverse. The distributions of the species covered in this report are mainly governed by two partially inter-related factors, depth and the physical nature of the seabed. Norway lobsters and pink shrimps occur on mud or sandy mud sediments in relatively deep water, whereas species such as cockles and mussels are mainly found inter-tidally on sandy beaches or rocky shores respectively. Lobsters, shore crabs and velvet crabs are mostly found in shallow reef, rock and boulder habitat. Both scallop species occur on sand and shell-sand sediments over a wide depth range, while the edible crab and the whelk share similar depth distributions but may also occur on gravel, boulder and rock.

Of major importance in the context of this assessment is that all the species are relatively sedentary. While local movements may occur, most of the species have limited mobility and do not undertake extensive migrations. This means that they are extremely vulnerable to environmental disturbance and pollution (Section 4). Excluded from this report are the more mobile cephalopod molluscs, squid and octopus which are dealt with in a separate report by Aberdeen University.

2. Shellfish resources

2.1 Fishery data

Fishery landings data were available from yearly additions of Scottish Sea Fisheries Statistics, the most recent addition being for 2002 (Anon., 2002), and from the Aberdeen Marine Laboratory (MLA) fishery statistics database. The latter information is stored with reference to ICES statistical rectangle codes. Each rectangle is defined by 0.5^{o} latitude x 1.0^{o} longitude and covers an area of seabed of about 56 x 61km (approximately 30 square nautical miles). Because of the curvature of the Earth's surface, the longitudinal dimension of the rectangle increases slightly with decreasing latitude.

The grid of ICES statistical rectangles does not match precisely with the boundaries of the SEA5 zone, requiring a degree of compromise in selecting the most appropriate fishery data. Account was also taken of the fact that when the SEA5 boundaries were originally established, the following areas were excluded from oil and gas exploration; inner Firth of Forth (west of 2^{o}50'W long.), the Tay estuary (west of 2^{o}45'W long.), the inner Moray Firth (Firths of Inverness, Cromarty and Dornoch, all west of 4^{o}W long.), and the inshore waters around Orkney and Shetland. In view of the fact that the DTI remit now includes wind-farm developments, it was considered that the above inshore areas should be included in the SEA5 assessment of shellfish resources. Many of these areas provide valuable shellfish fisheries for local communities. With these considerations in mind, the grid of ICES statistics rectangles selected for shellfish data analysis extends beyond the original SEA5 zone, as shown in Fig.1. Some information on the shellfish resources in Orkney and Shetland inshore waters was provided in the SEA4 report by Gordon (2003), while information on some shellfish species occurring offshore was included in the SEA2 report by Rogers & Stocks (2001).

In this report the extent of the shellfish fisheries is given in terms of reported landings. Although fishing effort information is collected, the data are not considered reliable, particularly in recent years. Some information on the distribution of trawling effort relevant to the fisheries for Norway lobster and pink shrimp in the SEA5 zone was included in previous assessments (Rogers & Stocks, 2001; Gordon, 2003).

The relative importance of shellfish fisheries may be appreciated with reference to Table 1. This shows a comparison of fishery landings by weight and value from the SEA5 extended zone in the three categories, demersal fish, pelagic fish and shellfish (crustaceans and molluscs). Landings of shellfish in 2000-2002 from the SEA5 zone varied from 15,191 to 17,719 tonnes, amounting to about 17-20 % of the total for all species combined. Because of the higher average value per tonne of shellfish compared to fish species, the contribution of shellfish to overall landings value is relatively greater, amounting to 32-35%. The value of shellfish landings in 2002 (£26.4 million) represents 29% of the total value of shellfish landings from the whole of Scotland (£92.1 million).

Table 1: Comparison between total shellfish landings (*) from SEA5 and landings of demersal and pelagic fish in terms of weight (tonnes) and estimated value (£ million), 2000-2002. Data from Scottish Sea Fisheries Statistics (e.g. Anon., 2002) and Marine Laboratory, Aberdeen database (hereafter referred to as MLA database).

Units	Category	Year 2000	2001	2002
Weight (tonnes)	Demersal fish	54706	38863	46028
	Pelagic fish	17719	22752	26263
	Shellfish	17285	15559	15191
	Total	89710	77175	87482
	% shellfish	**19.3**	**20.2**	**17.4**
Value (£ million)	Demersal fish	53.5	44.0	49.0
	Pelagic fish	6.9	9.3	7.3
	Shellfish	32.7	27.6	26.4
	Total	93.2	80.9	82.7
	% Shellfish	**35.1**	**34.1**	**32.0**

(*) Data in this Table includes cephalopods

2.2 Crustacean species

2.2.1 Norway lobster

The Norway lobster is by far the most important shellfish species exploited in Scottish waters. In 2002, the first sale value of the landings was £56 million, making this species second only to mackerel in terms of value to Scottish fishermen.

Biology

The Norway lobster occurs over a broad depth range in Scottish waters, from 10-200m and its distribution is largely governed by the nature of the sea bed. The species is found on a range of muddy–sand sediments, varying from fine mud (100% silt/clay particles) to muddy sand (20% silt/clay particles), in which the lobsters construct and inhabit burrows extending down to about 300mm below the sediment surface (Chapman, 1980). The burrows offer some protection from predation, including the capture by mobile fishing gear. Major predators on Norway lobsters are various species of fish, principally cod, lesser spotted dogfish and thornback rays (Chapman, 1980). Trawl catches are only made when the lobsters emerge from their burrows to feed. Some details of the diet were given in previous SEA reports (Gordon, 2003; Rogers & Stocks, 2001), and in Thomas & Davidson (1962) and Bailey *et al*. (1986). The timing of emergence mainly depends on the intensity of light reaching the sea bed, varying from nocturnal in shallow water to diurnal in deep water and crepuscular at intermediate depths (Chapman and Howard, 1979). There are also seasonal cycles of emergence, particularly in mature females. Each mature female, depending on size, spawns between 1000 to 6000 eggs which are attached to swimmerets under the abdomen. In Scottish waters most females spawn once every year, though there is evidence in some stocks suggesting that the largest females may only spawn every two years (Bailey *et al*., 1986). This mode of egg brood carrying by the female is a general feature of all the crustacean species considered here.

Details of the spawning, prolonged egg development and hatching cycle were given in the earlier SEA reports cited above. The planktonic larvae hatch out in the spring and after going through three larval stages, a metamorphosis occurs to a post-larval or juvenile phase which settles on the sea bed. On most Norway lobster grounds, it seems the larvae may be retained in the vicinity of the adult beds by anti-cyclonic surface gyres (Brown *et al*., 1995). Thus, most settlement of juveniles occurs on the same beds as the adults. This, together with the fact that the adults do not migrate, suggests that adjacent mud patches may be effectively isolated from one another, implying that in the event of a decline in stock abundance, whether from disease, fishing pressure or environmental stress, recovery of the stock could take a considerable period of time.

Research in the 1990s identified a major disease in Norway lobsters caused by parasitic dinoflagellates of the genus *Hematodinium* (Field *et al*., 1992; 1998). After a few weeks, infection by the parasite normally proves fatal and the high prevalence rates in some areas, such as the Firth of Clyde, is thought to have been a major cause of Norway lobster abundance fluctuations in this stock. The prevalence of infection in North Sea stocks in the early 1990s was very low (MLA, unpublished data).

Fisheries

The main areas of mud, sandy mud and muddy sand, providing suitable habitat for Norway lobsters, occur in the following locations within SEA5; Firth of Forth, Moray Firth and the northwest corner of the Fladen ground. These grounds can be clearly identified by the chart of elevated landings given by Rogers & Stocks (2001, Fig. 4.1.6.1). In addition, there is the Noup ground northwest of Orkney (Gordon, 2003) and some small isolated grounds off Arbroath and the Shetland Islands.

The Firth of Forth ground covers an area of 915km^2 and is exploited by about 150 vessels; of these, about 80 contribute 80% of the landings (Anon., 2003a). The main landing ports are Eyemouth, Port Seton and Pittenweem. Most of the landings are made by single rigged otter trawls, using 70mm mesh. Recently, a few vessels have started fishing with twin-rig trawls. These rigs consist of two nets linked together which are usually towed by a system of three warps. These gears have a much greater spread, covering a broader swath of seabed, and consequently have a greater catching power than the standard single–rig trawl. Occasionally, more than two nets may be linked together; such gears are referred to as multi-rig (Table 3).

In the Moray Firth, the Norway lobster ground covers an area of 2,195km^2 on the south side of the Firth. This area is exploited by up to 150 vessels, the majority of which target the Norway lobster primarily, though 16% of the landings arise as a by-catch of whitefish trawlers. A high proportion of the vessels primarily fish on the Fladen ground and only fish the Moray Firth in bad weather. The main landing ports are Burghead, Fraserburgh, MacDuff, Buckie, Peterhead and Helmsdale (Anon., 2003a). 75% of the landings are made by single rig trawls of mainly 70mm mesh. The remaining, more powerful, vessels employ twin-rig trawls of 100mm mesh, or more recently 80mm mesh.

The Noup ground, northwest of Orkney, is relatively small, covering an area of 400km^2. Between 50 and 80 vessels have exploited this ground in recent years with most landings being made at Buckie, Fraserburgh, Peterhead and Scrabster (Anon., 2003a). For most of these vessels the Norway lobster is the main target species; other vessels target whitefish but land the lobster as a by-catch. Most vessels use single-rig trawls of 70 or 100mm mesh. Around 10-20% of the fleet use twin-rig trawls, mainly made with 100mm mesh.

The Fladen ground is the largest known Norway lobster ground covering an estimated area of 28,200km^2. About half of the Fladen ground, in the northwest corner, coincides with the SEA5 zone. It is estimated that up to 215 vessels fish this ground, mainly Scottish but with some vessels from Denmark. About 95% of the landings are made by Scottish based vessels, of which two-thirds use single-rig trawls and the remainder employ twin-rig gear. The trawl mesh size varies; two-thirds of vessels use 100mm mesh while the remainder use 70-80mm mesh. Although most vessels at Fladen specifically target Norway lobsters, a higher proportion than elsewhere target whitefish and land the lobster as a by-catch.

<u>Landings</u>

Landings from the SEA5 enlarged zone (as defined in Section 2.1) during the most recent 10 year period (for which data are available) are shown in Table 2. The total landings of Norway lobsters from the SEA5 zone range from 5,849 to 7,978 tonnes. Landings for the Firth of Forth, Moray Firth and Noup grounds are shown separately in Table 2 for comparison. These three inshore grounds have accounted for at least half of SEA5 landings in most years and it may be assumed that the remainder of the total derive mainly from the northwest corner of the Fladen ground. From 1994 onwards, around 46-64% of Fladen ground landings have been taken within the extended SEA5 zone. In 2002, the value of the Norway lobster landings taken within the zone was estimated to be about £18 million, representing nearly 70% of the total value of all shellfish from the zone (Table 1).

Table 2: Landings (tonnes) by UK vessels of Norway lobsters from different grounds within the extended SEA5 zone and from the whole Fladen ground, 1993-2002. Data from Anon. (2003a) and MLA database.

Year	SEA5					
	F. Forth	Moray F.	Noup	NW Fladen*	Total	Fladen
1993	2369	1808	376	1427	5980	3532
1994	1850	1523	495	2668	6536	4686
1995	1763	1297	280	3336	6676	6624
1996	1688	1451	344	3171	6654	5368
1997	2194	1446	316	4022	7978	6266
1998	2145	1032	254	2418	5849	5230
1999	2205	1008	279	3968	7460	6696
2000	1785	1541	275	3187	6788	5650
2001	1528	1405	177	3090	6200	5645
2002	1327	1118	401	4416	7262	7345

*these figures were derived from the total by subtraction of the landings from the other three main grounds and will include small landings from some isolated populations elsewhere

As we have seen from the above consideration of the individual stocks, Norway lobsters are mainly caught by different forms of demersal trawl. To some extent, the gear classification is artificial in that it may depend on the ratio of Norway lobster:fish species in the landings. It is assumed that Norway lobsters are the main target species when their proportion in individual landings is 30% or more by weight. The gear would then be classed as a Norway lobster (*Nephrops*) single, twin or multi-rig net depending on the specific design. Where Norway lobsters contribute less than 30% by weight to landings, the vessel gear would be classed as demersal trawl (single or twin/multi rig) or light trawl. These latter gears are combined as ‘other trawl’ in Table 3 which shows a breakdown of landings from the SEA5 zone by different gears in recent years.

Table 3: Landings (tonnes) of Norway lobsters from SEA5 by UK vessels in 2000-2002, classified by gear type. Data from MLA database.

Year	Nephrops trawl-single	Nephrops trawl-twin/multi	Other trawl	Creel	Total
2000	4126	822	1835	5	6788
2001	3707	939	1552	3	6200
2002	3778	1269	2207	7	7262
Mean	3871	1010	1865	5	6750
%	57.3	15.0	27.6	<0.1	

It can be seen from Table 3 that 72% of the Norway lobster landings are made by vessels specifically targeting this species using single, twin or multi-rig gear. There is relatively little exploitation in the North Sea using baited traps or creels. This method is of much greater significance on the west coast of Scotland.

The highest landings of Norway lobsters are made in the late summer–early autumn, from July–November (Fig. 2). The lower landings at other times of the year reflect the reduced catchability of berried females that tend to remain in burrows while their eggs develop.

Stock assessments

The state of Norway lobster stocks is reviewed by an assessment Working Group (WG) of the International Council for the Exploration of the Sea (ICES). Since most stocks have remained reasonably stable, the WG usually only meets every two years. Methods employed to assess the condition of Scottish stocks vary, but generally include the following; examination of trends in landings, catch or landings per unit effort (CPUE, LPUE) and mean size of Norway lobsters; Virtual Population Analysis (VPA), and surveys by underwater television camera (Anon., 2003a). In recent years, the TV survey method has been refined, providing valuable estimates of burrow density, stock abundance and biomass, which are independent of fishery data (fishery data has become less and less reliable in recent years due to false reporting as a result of the quota management regime – see below). Table 4 shows the results of the most recent TV surveys of Norway lobster grounds in SEA5.

Table 4: Recent estimates of Norway lobster burrow density, abundance and biomass for stocks within the extended SEA5 zone and on the whole Fladen ground. Data from Marine Laboratory, Aberdeen TV surveys in 2002 (1999 for the Noup). From Anon., 2003a).

Stock	Mean density burrows/m^2	Abundance millions	95% conf. int. millions	Biomass '000 tonnes
F. Forth	0.66	600	140	7.8-12.6
Moray F.	0.29	630	146	9.2-14.8
Noup	0.30	120	42	1.9-3.8
Fladen (total)	0.29	8217	1022	168-217
NW. Fladen*	0.29	4108	-	84-108
SEA5	0.29-0.66	5458	-	103-139

* An approximation based on half the Fladen ground (ratio of ICES rectangles within SEA5 to the total number of rectangles making up the Fladen ground = ½). It is assumed that the same mean density applies throughout.

It can be seen from Table 4 that the mean density of Norway lobsters is similar on three of the grounds within the SEA5 zone, at around 0.3/m^2, but a higher density was estimated for the Firth of Forth (0.66/m^2). Combining the estimates for the different grounds, and assuming that half of the Fladen ground lies within the SEA5 zone, suggests that the current biomass of Norway lobsters within the zone is in the range 103-139 thousand tonnes. The recent (2002) landings from the zone were 7,262 tonnes (Table 2), representing about 5-7% of the total biomass. This represents a low level of exploitation for the zone as a whole, though it must be stressed that fishing effort is not uniformly applied over the whole zone. The fishing intensity (fishing effort applied per unit area) is much higher on the inshore grounds, particularly the Firth of Forth, than on the offshore Fladen ground. Current landings from the Firth of

Forth represent 10-7% of total stock biomass (Tables 2 & 4). The scientific advice from ICES is that fishing effort should not be allowed to increase on the inshore Firth of Forth, Moray Firth and Noup grounds but there is scope for increasing fishing effort on the Fladen ground. Achievement of a balanced exploitation of the various North Sea stocks is difficult, however, when they are all included by the EU within a single TAC (see below).

Management controls and legislation

All vessels have to be licensed to fish for Norway lobsters. There are no limits on vessel size, except in the Firth of Forth, where there is an upper limit of 55ft. The minimum mesh size in trawls is 70mm, though as mentioned earlier, many vessels use larger meshed trawls up to 100mm. Using the larger mesh avoids a restriction on the amount of fish by-catch that can be landed by vessels fishing Norway lobsters, and also means that twin-rig gear can be used. The by-catch limit for vessels using a 70mm mesh is such that Norway lobsters must account for 30-35% of the total weight of the landings. The fish by-catch limit only applies to certain fish species, namely those for which there are EU MLS and TAC limits. There is a MLS regulation applying to Norway lobsters, which in the North Sea is set at 25mm carapace length (CL), and 85mm total length. There is also an equivalent size regulation applying to the landing of Norway lobster 'tails' (i.e. the abdomen after removal of the cephalothorax), set at 46mm tail length.

Another condition applying to 70mm mesh trawls is that a panel of square mesh netting has to be fitted on the upper surface of the trawl no more than 18m in front of the codend. The mesh size of the panel is set at 90mm and the minimum area of the panel must be 2 or 3m^2, depending on vessel engine power. These meshes should remain open and are inserted in the trawl to allow fish to escape before reaching the codend. Now that many North Sea fish stocks are under threat from over-fishing, there is strong pressure to reduce the fish by-catch taken by Norway lobster fishing vessels using small mesh trawls. Much research is currently underway to make Norway lobster trawls more selective in order to reduce the by-catch. Various forms of 'separator' trawl have been or are being tested (e.g. Main & Sangster, 1985).

The EU attempts to control effort indirectly through the setting of TACs for different species. These are then apportioned between member states as national quotas. For Norway lobsters, a combined TAC is set for the whole North Sea (including the Farn Deeps and Botney Gut, in addition to the stocks covered by this report), and this has varied from 15,200 to 17,200 tonnes in the period 1998-2002. The UK quota has varied from 83.5-97.8% of the TAC, though the full quota has never been officially taken (Anon., 2002). The aggregation of a TAC to cover several different North Sea stocks is not ideal and makes it difficult to achieve a balanced exploitation between stocks requiring very different management strategies.

2.2.2 European lobster

Biology

The preferred habitat of the European, or common, lobster is rocky shores, reefs, cobble and boulder fields (Bannister & Addison, 1998), ranging in depth from low water of spring tides (LWST) to 60m. Lobsters are common in inshore waters with suitable habitat all around the coasts of mainland Scotland and the Northern Isles.

The species inhabits existing rock crevices or constructs a shelter under rocks and stones. There is good evidence to show that the topography of lobster habitat has a strong influence on the size composition of lobster populations (Howard, 1980a; 1980b; Howard & Nunny, 1983). The presence of suitably sized rocks and stones to provide shelters and protection from fast-flowing water currents appears to influence the upper size limit of lobsters that can survive in a given area. It is likely that tidal flow has a stronger influence on the emergence activity rhythms of lobsters than light (Howard, 1980a). The diet of lobsters, based on research in Swedish inshore waters, consists mainly of epifaunal species of other crustaceans and gastropod molluscs (Höllback & Warén, 1972).

The size at which lobsters reach sexual maturity varies with location. Lizarraga-Cubedo *et al*. (2003) found that, on average, lobsters in the Firth of Forth reached maturity at 79-80mm CL in both sexes, compared to 98mm for males and 110mm for females from the Outer Hebrides. This variability probably stems from a spatial difference in growth rates. Each female lobster spawns between 2,000–30,000 eggs per brood, depending on female size and geographical location (Lizarraga-Cubedo, 2003). There is some uncertainty about the frequency of spawning but it is generally thought to be biennial in Scottish waters. Spawning occurs in late summer-early autumn and the eggs are carried by the females for about nine months until they are ready to hatch in the spring. As in Norway lobsters, there are three larval stages before metamorphosis to the first post-larval stage. Few studies have been undertaken on the ecology of European lobster larvae. All four stages are planktonic and occur in the upper surface waters, from 0-15m depth, mainly in the same locations as the adults (Nichols & Thompson, 1988). Eventually, the post-larval or juvenile stage settles on the sea bed and seeks shelter in the same habitat as the adults. It is thought that the juveniles remain concealed within the substratum for at least two years before starting to emerge. Little is known about this fossorial phase in the life-cycle (Howard & Bennett, 1979). Extensive tagging experiments on juveniles and adults indicate that European lobsters do not undertake extensive migrations (Jensen *et al*., 1994; Bannister & Addison, 1998).

Fisheries

Fishing for European lobsters takes place all around the east coast of Scotland and in the Orkney and Shetland Islands, wherever suitable rocky and stone habitat is found. Most landings from the North Sea are made at Pittenweem, Wick and the Orkney Islands. The vessels employed in lobster fishing are generally <10m in length. The lobsters are caught in baited creels (pots, traps) that are usually fished in fleets consisting of 20 or more creels linked by a back-rope. The creels are usually baited with fresh whitefish and may also catch the edible crab and the velvet swimming crab (Sections 2.2.3 & 2.2.4) which overlap with the habitat of lobsters. The traps vary in design locally but basically are of two main types, standard and parlour creels. Standard creels are semi-circular in cross-section and consist of stout wire frames covered in netting, with two entrances into a single chamber (approx. dimensions 0.65 x 0.46 x 0.38m). Parlour creels have an extra internal chamber, are longer (1.00 m) and are designed to reduce the chance of lobsters escaping. Since 2003, the mesh size of parlour creels must be at least 60mm. Fleets are usually recovered after 1-3 days fishing, supplied with new bait and redeployed. Most European lobsters are sent live to continental markets, particularly Spain, France and to a lesser extent Norway.

Landings

Landings of European lobsters in the last 10 years from the extended SEA5 zone are shown in Table 5. Landings of lobsters from SEA5 have varied from 162 to 319t. over the time series, representing 50% or higher of total landings into Scotland since 1998. The SEA5 zone accounts for virtually all landings of lobsters into Scotland from the North Sea. The European lobster fishery is one of low volume but high value, worth over £10 thousand per tonne in 2002. The value of the fishery from the SEA5 zone was estimated to be £1.9 million in 2002.

The highest landings are made in August-October (Fig. 3), and there is a minor peak in December arising from the fact that lobsters are stored for long periods prior to the Christmas holiday, either in ponds on shore or in moored keep cages at sea, and only landed when prices are high.

Stock assessments

There is no international forum for carrying out assessments on lobster stocks at present. An ICES Working Group met three times in the 1970s (Anon., 1977b; 1979) but since all lobster stocks occur within national inshore waters it is now left to EU member states to address the problem of assessment and fisheries management in their own waters. For Scottish stocks, the Marine Laboratory, Aberdeen has carried out assessments on an irregular basis. For this purpose, the coast was divided up into several management areas, which in the SEA5 zone are; South East coast, extending from the Anglo-Scottish border to north of the Firth of Tay; East coast, extending from the Tay to Noss Head; and the Orkney Islands. It must be stressed that these areas are convenient for the aggregation of fisheries data but each area may well contain several discrete lobster populations.

Table 5: Landings (tonnes) by UK vessels of European lobsters from the extended SEA5 zone, compared to the total for Scotland, 1993-2002. Data from Anon. (1997; 2002) and MLA database.

Year	Landings (tonnes)		SEA5 zone as % of total
	SEA5 Zone	Scotland total	
1993	174	463	37.6
1994	219	493	44.4
1995	260	567	45.8
1996	221	605	36.5
1997	306	652	46.9
1998	319	638	50.0
1999	316	527	60.0
2000	260	408	63.7
2001	162	301	53.8
2002	183	328	55.8

The most recent assessments used Length Cohort Analysis (Jones, 1974) which uses average size distributions and growth information to estimate mortalities and stock sizes. The outputs from the model were then used to predict possible long-term changes in yield and stock biomass following changes in fishing effort and/or increases in MLS. Male and female lobsters were analysed separately because of the sex difference in population size composition and growth parameters. This analysis indicated that all three stocks were being over-exploited to some extent and would benefit from a reduction in fishing effort and/or an increase in MLS to 90mm CL (Anon., 1994a). The current MLS is 87mm CL in Scotland, apart from Shetland where it is 90mm. In Shetland, the management of most species of shellfish has been delegated to the Shetland Shellfish Management Organisation (SSMO) through the granting of a Regulatory Order (see Section 3).

A detailed population study on the European lobster has just been completed by a PhD student, Lizarraga-Cubedo (2004). This includes studies on the South East stock within SEA5. The thesis should eventually be available for consultation.

<u>Management controls and legislation</u>

Fishing in some areas, for different species using static gear (lines, fixed nets, creels), is protected from interference and disturbance caused by mobile or active gear (e.g. trawls, dredges) under the terms of the Inshore Fishing (Prohibition of Fishing and Fishing Methods) (Scotland) Order 1989 (Statutory Instrument 1989 No. 2307 (S.150)) and a series of six amendments (1994 No. 326; 1996 No. 1475; 1999 No. 751; 2001 No. 174; 2003 No. 404; 2003 No. 514). This legislation defines areas around the Scottish coast closed to mobile gear, either all year round or on a seasonal basis, and a brief list of those areas occurring within the SEA5 zone is provided in Appendix A. Some of the closed areas are protected as nursery grounds for juvenile fish, while others serve mainly as static gear reserves for lobster and crab creel fishing. There are exemptions in some of the areas to allow dredging for mussels and cockles (Sections 2.3.3, 2.3.4).

Although all vessels of length 10m and under have required fishing licences since 1993, a new licence specific to creel fishing will shortly be introduced for this size of vessel. This licence will apply to vessels with a proven track record in creel fishing for European lobsters, crawfish (spiny lobsters) and several species of crab. Part-time fishermen can continue to fish but will be restricted in the amount of gear they can use or in the amount of catch. At least initially, there will be no controls on the number of creels that can be fished, though this may follow in the future. The only legislation applying to lobster creels is that the mesh size of netting used in the construction of parlour creels must be at least 60mm.

In the last few years, there have been two initiatives designed to boost the recruitment of juvenile lobsters to the stocks, firstly, the release of hatchery–reared juveniles and secondly, the v-notching of female lobsters (Bannister & Edwards, 1995; Bannister & Addison, 1998; Tully, 2001). A programme of releasing lobster juveniles is undertaken each year in the Orkney Islands and on a small scale at Shetland. V-notching is a tagging method, involving the clipping of a v-shaped notch in part of the lobster's tail-fan which is generally applied to large egg-bearing females. The aim is to produce a pool of large, mature, highly fecund, females in order to improve breeding success, egg production and subsequent recruitment. Legislation to ban the landing of v-notched lobsters was introduced in Scotland in 1999. In addition, legislation has been introduced recently in Scotland to ban the landing of female lobsters larger than 155mm CL. This maximum legal size limit represents another approach towards increasing egg production and recruitment. It is too early to say whether any of these measures will have the desired effect of enhancing lobster populations.

Another initiative which should be mentioned is the idea of constructing artificial reefs to increase the available shelter for lobsters. The first such reef in the UK was that constructed off the Berwickshire coast in 1984 using 210,000 tonnes of bedrock rubble from the Torness nuclear power station construction site. A three year study of the reef (1988-1990) by St Andrews University demonstrated higher lobster catches on the reef compared to other sites close by (Todd & Bentley, 1991). This topic will be mentioned again in Section 5.

2.2.3 Edible crab

Biology

The edible crab shares the same type of habitat as the European lobster, but may also occur on less coarse sediments, such as gravel, sand and even mud. The species is therefore widely distributed throughout the extended SEA5 zone, extending in depth from the littoral zone down to 100m (Fig. 4, see also Rogers & Stocks, 2001, Fig. 3.2.16.1). Edible crabs inhabit similar crevices and shelters as European lobsters and populations are similarly affected by the availability of suitably sized stones. Howard (1980a) found there was a relationship between crab size and the area of 'roof' stone beneath which the crab sheltered. In the absence of suitable stones, on other types of sediment, crabs will inhabit depressions in the sediment or simply submerge into the sediment (Kinnear & Chapman, 1976).

The feeding behaviour and diet of edible crabs appears to differ markedly from that of European lobsters. Observations of feeding behaviour in several areas in Scotland showed that edible crabs derived much of their food by digging deep down into the sediment and that lamellibranch molluscs formed a major part of the diet (Shelton *et al*., 1979). The most striking observation was the dominance of deep burrowing razor clams, *Ensis* sp., in the diet of crabs in some areas. Such pit-digging behaviour to prey on *Ensis* and other species can alter the sea bed topography dramatically and is a major cause of habitat disturbance (Hall *et al*., 1991).

Sexual maturation has been studied recently in edible crabs at Shetland (Tallack, 2002). Males matured at a smaller size, 116mm carapace width (CW), than females, 128mm CW. A similar sex difference in maturation was also noted by Edwards (1979) for crabs off NE England. There is evidence that the breeding cycle involves the females undertaking extensive migrations to breeding areas. While tagging experiments show that males do not migrate significantly, females can move considerable distances of 100 miles or more (Edwards, 1979). It is suggested that mature females migrate offshore into deep water to spawn and incubate their egg brood. Feeding ceases at this time so that very few berried crabs are caught in baited traps (Tallack, 2002). Earlier diving studies by Howard (1982) located aggregations of berried females and showed that these crabs could not be caught in creels, highlighting the difficulty of sampling this stage in the life-cycle. Howard also suggested that, by aggregating and becoming inactive in this way, berried females could be very vulnerable to dredging and dumping operations. They could be similarly vulnerable to other fishing activities, particularly the use of mobile gear, such as trawls and dredges (Bennett, 1995).

The fecundity of edible crabs is high; depending on female size, the number of eggs per brood ranged from 64,000 to 2,540,000 (mean 1,335,000) in Shetland females (Tallack, 2002). A similar range was also found in earlier studies of females from Scotland and NE England (Edwards, 1979). Edwards (1979) also reported that 80% of females had ripe gonads just prior to spawning, suggesting the possibility that most females spawned every year. This is not certain, however, particularly in large edible crabs (J Kinnear, pers. comm.). In the North Sea, the eggs are spawned in the late autumn-early winter and will be ready to hatch in the following summer. It is likely that the females remain in their over-wintering areas until the eggs hatch. Studies of the distribution of larvae have revealed areas of larval production offshore in the southern North Sea and in the English Channel (Thompson *et al*., 1995), whereas further north over-wintering crabs are reported both inshore and offshore around NE Scotland and the Northern Isles (Rogers & Stocks, 2001, Fig. 3.2.16.1). The planktonic larval phase of edible crabs lasts about 40 days and comprises six stages before metamorphosis to the first post-larval stage (1^{st} crab stage) which settles on the sea bed (Edwards, 1979). During this phase, the larvae are dispersed by water currents. A substantial number of them drift inshore and there is evidence of dense settlement in the littoral zone. From May-June onwards, large numbers of juvenile crabs can be found in the littoral zone on all types of substrate, sheltering under rocks and stones and also burying in sandy beaches. It is not known whether the littoral zone represents a genuine nursery area for this species (and indeed other crab species – Sections 2.2.4, 2.2.5) or whether it merely represents the boundary of a broader distribution of juveniles extending into deeper water. During the littoral phase, there is a high level of predation by sea birds on all three crab species considered in this report. Tallack (2002) found evidence of bird predation on edible crabs in the size range 30-80mm CW, which were probably 1-2 years old. After this inshore phase, the crabs move into deeper water.

<u>Fisheries</u>
The edible crab is fished all round the coast of Scotland, mostly on inshore grounds over-lapping with the European lobster but occasionally in deeper water away from the coast (Fig. 4). The main landing ports in the North Sea are Aberdeen, Fraserburgh, Wick and in the Orkney and Shetland Islands. The main method of fishing is by fleets of baited creels, as in lobster fishing. In addition, vessels using bottom set gillnets to catch angler fish (*Lophius piscatorius*) have landed large quantities of crab claws as a by-catch. The full extent of this fishery is unknown since these landings are not recorded separately from whole crab. A review of the crab claw fishery in Shetland was given by Tallack (2002), who estimated that in 2000, admittedly an atypical year, about half the crabs marketed in Shetland were landed as claws only. Since the weight of claws is a fraction of the total weight of the crab, varying from 12 to 46%, depending on sex and size, this fishery represented a substantial loss in crab yield. Fortunately the claw fishery is now much reduced following recent EU legislation (see below). Edible crabs are landed alive and a high proportion are transported to local factories for processing. Edible crabs do not travel well but roughly 50% are nevertheless shipped live to continental markets, particularly Spain.

Landings

Fig. 4 shows the spatial distribution of landings of edible crabs from within the extended SEA5 zone. Most of the landings are made in inshore waters. Landings from the SEA5 zone have varied from 1,223 to 3,498 tonnes in recent years (Table 6). As a proportion of the total landings into Scotland, the SEA5 zone accounts for around 30-40%. The edible crab fishery within the zone was estimated to be valued at £2.4 million in 2002.

Table 6: Landings (tonnes) of edible crabs by UK vessels from the SEA5 zone, compared to the total for Scotland, 1993-2002. Data from Anon. (1997; 2002) and MLA database.

Year	Landings (tonnes)		SEA5 zone as a % of total
	SEA5 Zone	Scotland total	
1993	1291	5202	24.8
1994	1223	6200	19.7
1995	2051	6568	31.2
1996	2185	7243	30.2
1997	2780	7675	36.2
1998	3242	8014	40.4
1999	3156	7458	42.3
2000	3498	9615	36.4
2001	2865	8558	33.5
2002	2379	7693	30.9

The seasonal pattern of landings is shown in Fig. 5. A high level of landings are made throughout the year with above average landings in the summer months, June–September.

Stock assessments

As with European lobsters, assessments on edible crab stocks are the responsibility of EU member states, though since the populations can extend beyond national territorial waters, the EU imposes certain technical conservation measures (see below). For Scottish stocks, the Marine Laboratory, Aberdeen has carried out assessments periodically, based on the following management areas within SEA5; South East coast (as defined for lobsters in Section 2.2.2); Orkney; Shetland. The reservations expressed for lobster stock definitions are even more pertinent here because of the greater mobility of edible crabs. The assessment method used was the same as for lobsters, namely LCA (Jones, 1974) and the main objective was to make predictions about the effects on yield and stock biomass of changing the level of fishing effort and the MLS. At the time of the analyses (Anon., 1994a), the MLS was 125mm CW and the results suggested that the stocks would derive long-term benefit from increasing the MLS to 135 or 140mm CW. Most of the gains in yield and stock biomass would accrue from the catches of male crabs. In 2000, the MLS was raised from 125 to 140mm CW for all Scottish edible crab stocks. The beneficial effect of increasing the MLS to 140mm CW was confirmed retrospectively in a recent analysis of the Shetland edible crab fishery by Tallack (2002).

Management controls and legislation

The new licensing arrangements for under 10m vessels referred to earlier for European lobsters (Section, 2.2.2) will also apply to edible crabs. There are also special licensing arrangements for creel fishing vessels larger than 10m. There are no controls at present on the number of creels that can be fished. In addition to the MLS of 140mm CW, there are prohibitions on the landing of egg-bearing (ovigerous) females and soft crabs that have recently moulted. To address the problem of crab claw landings, the EU has implemented a restriction which limits the quantity of claws to 1% of the total crab catch for creel fishing vessels and to 75kg per trip for vessels using other fishing methods. It is hoped that this measure will prevent deliberate targeting of crab by attaching bait to gillnets, though it is likely to result in many damaged crabs being discarded without being recorded.

2.2.4 Velvet swimming crab

Biology

The habitat of the velvet swimming crab overlaps that of the European lobster, the adults being found on rock and stone substrates in the inshore zone, down to depths of around 15m. The crabs are abundant in kelp forests and investigations of their diet have shown that *Laminaria* and other algae form a major component, along with crustacean and molluscan prey (Norman and Jones, 1992; Friere and Gonzάlez-Gurrianάn, 1995). Velvet crabs are said to inhabit rock crevices during daylight hours but, unlike European lobsters and edible crabs, they do not appear to excavate shelters under stones. Velvets defend their crevices aggressively and it is possible that the availability of suitable crevices may determine population abundance in a given habitat. Tagging experiments showed that velvet crabs remained in the area where they were caught and released; they do not migrate.

Velvet crabs attain sexual maturity at about one year old and the size at which they mature varies spatially, depending on growth rate. Populations at Orkney were found to mature at a mean size of 51mm CW in males, and at a smaller size of 43mm CW in females (Hearn, 2001). The sex difference was reversed at Shetland, the females maturing at a mean size of 56mm CW, compared to 45mm CW in males (Tallack, 2002). The mature females moult in the autumn and mating takes place soon after, followed by spawning during the winter. After spawning the numbers of females in the catch declines to a minimal level in April-July. At this time the eggs of most ovigerous females are ready to hatch (Kinnear & Mason, 1987; Tallack, 2002). Female velvet crabs in Scottish waters probably spawn once per year, though further south, Norman (1989) postulated that large females, in their third year, could produce two broods per year.

The fecundity of velvet crab females is high and highly variable, with less obvious dependence on female size than in edible crabs. Estimates of fecundity ranged from 83,300 to 342,000 (female size, 66-76mm CW) in NW Scotland (Kinnear & Mason, 1987) and from 68,000 to 410,000 (female size, 61-89mm CW) at Shetland (Tallack, 2002). The larval phase of velvet crabs is similar to that of edible crabs in that there are six planktonic stages spanning about 40 days before metamorphosis and settlement of the first crab stage on the sea bed. Again, as in edible crabs, juvenile velvet crabs can be found under stones in the littoral zone (Norman, 1989), though it is unclear as to whether this zone is the main nursery area. Sea bird predation on velvet crabs at Shetland was reported by Tallack (2002). The size range of velvet crab prey was 46–55mm CW, estimated age 1-2 years.

Fisheries

The fishery in Scotland for this species is fairly recent, having developed in the mid 1980s to supply the Spanish market, following the collapse of the Spanish fishery. The Spanish fishery was unregulated and collapsed through recruitment failure. The main Scottish fisheries are on the west coast, but within the SEA5 zone there are small landings from the Moray Firth, at Buckie and Wick, and a substantial fishery in the Orkney Isles (640 out of a total of 893 tonnes in 2002). The method of fishing is by means of creels, baited with fresh fish and deployed in fleets of 20 or more traps. The coincident habitat distribution of velvet crabs and lobsters, and to some extent edible crabs, means that all three species are often caught together. Velvet crabs are mostly marketed and transported alive to the Continent, especially to Spain and Italy.

Landings

The trend in landings within the extended SEA5 zone, for the most recent 10 year period, is given in Table 7. Since 1994, landings have fluctuated between 750 and 900 tonnes and the SEA5 zone has accounted for virtually all North Sea landings into Scottish ports. The zone has contributed over 30% of total Scottish landings since 1998 and the value of this fishery is estimated to have been £1.4 million in 2002.

The seasonal pattern in landings is illustrated in Fig. 6. Velvet crabs are landed throughout the year but there is a marked peak in landings from October to December.

Table 7: Landings (tonnes) of velvet swimming crabs by UK vessels from the SEA5 zone, compared to the total for Scotland, 1993-2002. Data from Anon. (1997; 2002) and MLA database.

Year	Landings (tonnes)		SEA5 zone as a % of total
	SEA5 Zone	Scotland total	
1993	374	2362	15.8
1994	628	2732	23.0
1995	780	3713	21.0
1996	752	2788	27.0
1997	831	2816	29.5
1998	818	2436	33.6
1999	790	1882	42.0
2000	836	2425	34.5
2001	838	2243	37.4
2002	893	1986	45.0

Stock assessments

The only stock assessments on velvet swimming crabs appear to be those included in student projects on Orkney and Shetland populations by Tallack (1998; 2002). For the Shetland stock, Tallack (2002) obtained estimates of total mortality by different methods, and applied LCA to estimate stock sizes and predict the effects of changes in fishing effort and MLS. Mortality estimates were very high, especially in males. The results from the LCA were equivocal and heavily dependent on the choice of length frequency data used as a reference. The results confirmed the merit of increasing the MLS to 70mm CW and because of the uncertainties in the data it was suggested that fishing effort should probably be reduced as a precautionary measure.

Management and legislation

Vessels fishing for velvet swimming crabs will be included in the new UK creel fishing licence which will come into effect shortly. The only other management measure in force nationally is a MLS of 65mm CW. In Shetland, the MLS has been increased to 70mm CW and there is a closed season operating from May to September. Both these measures were introduced by the Shetland Shellfish Management Organisation (SSMO). The summer closed season was largely introduced because of the wastage of crabs due to high mortality during vivier transport to continental markets.

2.2.5 Shore crab

Biology

The shore, or green crab is extremely common in the inter-tidal zone all round the UK coastline, but is also found in much deeper water down to 200m. It is tolerant of brackish water and occurs in rock pools, salt-marshes and estuaries (Hayward & Ryland, 1995). Despite its common name, the species displays a wide range of colouration, from pale green to deep red and the two colour forms exhibit differences in physiology and behaviour (Reid & Aldrich, 1989). The green form reveals a tidal migration pattern, moving into the littoral zone to feed at high tide, while the red forms tend to remain in the sub-littoral zone. While much biological research has been carried out on this species, because of its relatively small size (73mm maximum CW), it has attracted little attention as a fishery resource. Consequently, the fisheries biology of this species has been somewhat neglected. A notable biological feature of this crab is the common presence of the parasitic cirriped, *Sacculina carcini*, particularly on sub-littoral specimens.

Table 8: Landings (tonnes) of shore crabs by UK vessels from the SEA5 zone, compared to the total for Scotland, 1993-2002. Data from Anon. (1997; 2002) and MLA database.

Year	Landings (tonnes)		SEA5 zone as a % of total
	SEA5 Zone	Scotland total	
1993	17 *	377	-
1994	143	487	29.4
1995	208	470	44.2
1996	190	354	53.7
1997	227	407	55.8
1998	264	462	57.1
1999	183	259	70.6
2000	242	304	79.6
2001	261	320	81.6
2002	296	362	81.8

* The low tonnage in 1993 is believed to be an artefact, due to under-reporting

Fisheries

The shore crab is mainly landed as a by-catch species in the inshore creel fishery for velvet swimming crabs. Catches, in velvet crab creels, of the larger shore crabs are retained to make up vivier lorry loads for transport to continental markets. The main fishery for this species takes place in the Orkney Islands, which currently accounts for over 90% of the landings from within the SEA5 zone. Shore crabs that are about to moult (known as ‘peelers’) are sought after as bait by anglers, though the extent of this practice is not well known (Fowler, 1992).

Landings

Landings of shore crabs by UK vessels from within the extended SEA5 zone are shown in Table 8. Since 1995, landings have varied from 183 to 296t. All North Sea landings are made from the SEA5 zone and, as can be seen from the Table, the zone has accounted for an increasing proportion of the total Scottish landings. The value of the SEA5 fishery was estimated to have been £146 thousand in 2002. Shore crabs are exploited throughout the year, with highest landings in October–December.

Stock assessments, management and legislation

As far as the author is aware, no stock assessments have been conducted on shore crabs. Apart from being included in the new creel fishing vessel licence, the fisheries for this species are unregulated.

2.2.6 Pink shrimp

Biology

Within the SEA5 zone, pink shrimps are found only on the Fladen ground where their distribution overlaps with the Norway lobster. The species also occurs further south, in the Farn Deeps off the Northumberland coast. These two North Sea populations represent the southern limit of the distribution of this species, for which the main fisheries are further north, off Greenland, Iceland, in the Barents Sea and off the coast of Norway. The same species also occurs off both the Atlantic and Pacific coasts of North America.

The distribution of the species is restricted to sea bed areas of fine mud in the depth range 80–650m (Howard, 1983). Unlike the Norway lobster, pink shrimps do not burrow but live on the mud surface. The shrimps are thought to migrate off the sea bed up into the water column at night since the largest trawl catches are taken during daylight hours. There is photographic evidence suggesting that the shrimps aggregate around the sea anemone, *Bolocera tuediae* (Howard, 1982). The biological basis for this apparent relationship is unclear but the shrimps may derive some protection from predators and possibly shelter from water currents.

Another interesting and unusual feature of pink shrimps is that their life-cycle involves a sex change in the males (Howard, 1983). Female shrimps are therefore of two types; primary females develop the characteristics of their sex from metamorphosis and remain female for life; secondary females develop after sex reversal from males. After mating once at an age of about 1.5 years (size 16-17mm CL at Fladen), the males gradually develop female characteristics and pass through a transitional phase before becoming secondary females. The main function of this phenomenon is thought to be simply to increase egg production in the population. There is evidence to show that the age/size of the males at the time of sex reversal varies from area to area, and even within a single population, can respond to changes in the level of mortality (Anon., 1994b). On the Fladen ground, the females spawn in the period October–December and carry the egg brood through the winter months until the larvae hatch out in the spring. The fecundity of female pink shrimps is relatively low compared to lobsters and crabs, varying from 300 to 1,500 eggs per female in the Farn Deep stock, but higher, up to 3,860 eggs in Greenland populations (Anon., 1977a). There are six planktonic larval stages lasting about three months, before the final stage metamorphoses into the juvenile shrimp which settles onto the adult benthic habitat. On the Fladen ground, pink shrimps are relatively short-lived with few of them surviving beyond the age of three. Mortality of shrimps is very high due to predation by fish, principally cod and hagfish (Anon., 1977a).

<u>Fisheries</u>

The Fladen pink shrimp stock is exploited mainly by vessels from Denmark and Scotland. Historically, the landings have fluctuated markedly due to recruitment variability and market demand. The size range of shrimp on the ground is small compared to other grounds and fishing can become uneconomic at Fladen when markets are adequately supplied by better quality shrimps from elsewhere. Most Scottish vessels fishing the Fladen ground are based at Buckie, Fraserburgh and Peterhead. The vessels use small mesh trawls in which the minimum mesh size must not be less than 35mm. With such small mesh trawls, there is a large by-catch of fish, including cod and haddock, and a high discard rate for undersized fish. This represents a potential problem in view of the present state of the North Sea cod stock (Anon., 2003b). This problem could be solved by the use of a rigid sorting grid mounted at an oblique angle in front of the trawl codend. This grid system works by deflecting fish out through an escape hole in the upper surface of the net, while allowing the shrimp to pass through the grid bars into the codend (Isaksen *et al.*, 1992). The design of grid sorting devices can be varied to achieve various gear selectivity objectives (Valdermarsen *et al.*, 1993). The use of such a sorting grid is mandatory in the Norwegian pink shrimp fishery and, recently, has also been introduced in the English brown shrimp fishery (see below). The shrimp fishery also contributes a small by-catch of Norway lobsters and these landings are included under 'other trawls' in Table 3.

<u>Landings</u>

The landings of pink shrimps from the SEA5 zone are derived from the NW corner of the Fladen ground (Fig. 7). A recent time series of landings from SEA5 is shown in Table 9, and compared with total landings from the whole Fladen ground by each country. It can be seen from Fig. 7 that the SEA5 zone coincides with a relatively small portion of the Fladen pink shrimp population, and this is borne out by the landings (Table 9). The SEA5 zone accounted for 3–36% of the pink shrimp landings by UK vessels into Scotland. The main fishery on the Fladen ground is that of Denmark and it is likely that a portion of the landings by Danish vessels will have come from SEA5, though no details are available. The Scottish landings have declined in recent years and were very small in 2002 due to lack of market demand. There was no directed fishery by Scottish vessels in 2002; the landings were all from the by-catch of fisheries for other species.

The seasonal pattern of landings is shown in Fig. 8. The fishery is mainly a summer one, with highest landings in the period April–August.

<u>Stock assessments</u>

Pink shrimp stocks in the North Sea, Norwegian Deeps and Skagerrak are assessed by an ICES international working group, though the Fladen ground stock is only assessed in detail occasionally. The last time the Fladen stock was assessed was in 1992 (Anon., 1992). As noted earlier, the fishery is prone to fluctuations in market demand, making it difficult to obtain adequate samples. Also, the life-span of the shrimps is very short, the landings usually consisting of two age groups, and the stock

Table 9: Landings (tonnes) of pink shrimps by UK vessels from the SEA5 zone, compared to the total landings reported by UK (Scottish), Danish and Norvegian vessels from the whole Fladen Ground, 1993-2002. Data from Anon. (2003b) and MLA database

Year	SEA5 zone	Whole Fladen Ground				SEA5 as % of UK
		UK	Denmark	Norway	Total	
1993	37	509	1521	38	2068	7.3
1994	8	35	1229	0	1264	22.8
1995	282	1298	4659	15	5972	21.7
1996	307	1893	3858	32	5783	16.2
1997	132	365	3022	9	3396	36.2
1998	100	1365	2900	3	4268	7.3
1999	54	456	1005	9	1470	11.8
2000	108	378	1482	0	1860	28.6
2001	51	397	1263	18	1678	12.8
2002	2	70	1147	9	1226	2.8

biomass is dependent on highly variable recruitment. Another feature of the stock dynamics is that natural mortality, due to predation by fish, is generally much higher than fishing mortality. All of these features make it extremely difficult to provide reliable advice concerning the management of the fishery.

Management controls and legislation

The only legislation in force is the trawl minimum mesh size of 35mm. It is possible that additional technical measures, such as the rigid grid device referred to earlier, will be introduced in the future to reduce the by-catch of fish, especially cod. Legislation, similar to what would be required for pink shrimp, was introduced in 2003 in England for the brown shrimp fishery (The Shrimp Fishing Nets Order 2002, SI 2002 No. 2870). This requires small mesh (16–31mm) trawls to be fitted internally with either a sloping panel of netting (referred to as a 'veil', with maximum mesh 70mm) or a rigid sorting grid (bar spacing 20mm). These devices should guide fish to an escape hole on the upper net surface. This legislation does not apply to Scotland.

2.2.7 Other species

Two other species of crustacean are caught occasionally in the SEA5 zone, namely, the brown shrimp, *Crangon crangon* (L.) and the squat lobster, *Munida rugosa* (Fabricius). The brown shrimp is common on sandy beaches and on sandy substrates in shallow water, from mid tide level down to 50m depth. The species is adapted to the littoral zone with the ability to bury below the sediment surface on the ebbing tide. In Scotland, the only directed fishery for brown shrimp is in the Solway Firth, but it has occasionally been landed from the Moray Firth. The usual method of fishing is by beam trawl. In the period 1993–2002, an average of 0.5 tonne/annum was reportedly landed by Scottish vessels fishing in the SEA5 zone but it is possible these data are an artefact due to misreporting of pink shrimps (J. Kinnear, pers. comm.).

Squat lobsters have a very discrete distribution in that they generally occur on the edge of Norway lobster grounds, where the mud substrate merges with harder stony ground. Like Norway lobsters, squat lobsters inhabit burrows, either disused burrows of the former species or their own, often excavated under stones (Howard, 1981). They can be found over a wide depth range from 15 to 600m. At present squat lobsters are mainly landed as a by-catch in the creel fishery for Norway lobsters on the west coast of Scotland but occasional landings are made in the North Sea by trawl, though catch rates tend to be low. In the period 1995–2002, small landings (<1 tonne) were made annually by Scottish vessels fishing in the SEA5 zone.

2.3 Bivalve molluscs

2.3.1 Giant scallop

The giant, or king, scallop is the most important exploited mollusc within the SEA5 zone. An accurate chart showing the distribution of scallops in the North Sea was given in Rogers & Stocks (2001, Fig. 3.2.17.1); these authors stressed the high economic value of the species and the importance of the fishery to the SEA exercise because of the heavy penetrative dredges used in fishing.

Biology

The report by Rogers & Stocks (2001) included a brief biological summary, which is expanded upon here only where necessary. The distribution chart referred to above shows that most North Sea scallop populations are located within the SEA5 zone (see landings section below). Scallops are found mainly on sand, muddy sand and shell gravel substrates at all depths from the sub-littoral down to over 100m. The scallop inhabits a shallow depression in the sediment with the left (flat) valve uppermost. While scallops are capable of swimming by means of water jets, this behaviour is more common in juveniles. As they become larger, adults tend to remain recessed and are more likely to respond to stimuli by withdrawing the mantle and closing the shell (Mason, 1983). There is evidence showing that scallops orientate to the direction of prevailing tidal currents in order to facilitate suspension feeding and disposal of faeces (Mathers, 1976). The food of scallops consists of suspended detritus material and phytoplankton which are filtered from the water by means of the gills. In turbid water, the high loading of suspended sediment particles may inhibit feeding and thereby affect growth and mortality.

The pertinent details concerning the reproductive cycle, spawning seasons and larval phase are given by Mason (1983) and summarised by Rogers & Stocks (2001). Because the swimming ability of scallops is limited, it is likely that the settlement of young scallops (spat) occurs on the same beds as the adults. The spat have been found attached by byssus threads to algae and filamentous bryozoans and hydroids, and also recessed in the sediment in the adult manner. The spat will also settle on man-made fibres, a property upon which the cultivation of scallops depends (Section 2.3.6).

Fisheries

Within the SEA5 zone, the main fisheries take place around the Orkney and Shetland Isles, in the Moray Firth and off the east coast of Scotland. The SEA5 zone encloses about 70% of these scallop grounds. Although most fishing occurs in inshore waters, some exploitation takes place on grounds up to 100 miles off the coast (Fig. 9, see also Fig. 3.2.17.1 in Rogers & Stocks, 2001). The main fishing method used consists of arrays of mechanical dredges attached to a towing bar. Usually, two bars are deployed, one from each side of the vessel. The number of dredges towed per bar varies from 2 to 20, depending on vessel size and power. The standard dredge used in the Scottish fisheries is 0.75m (2.5ft.) wide and is fitted with a spring-loaded toothed bar, designed to penetrate into the sediment and lift out the recessed scallops, but at the same time, avoid coming fast on underwater obstructions. The scallops pass into a bag behind the toothed bar made from netting on top and 'chain-mail' below (belly) to withstand wear. Scallop dredges tend to be rather inefficient and catch only about 20-25% of scallops in their path (Mason *et al.*, 1979; Beukers-Stewart *et al.*, 2001; Lart *et al*., 2003).

Landings

Landings of scallops from the SEA5 zone, in the recent 10 year period are presented in Table 10. Also shown in the Table are the landings for each management area defined by the Marine Laboratory, Aberdeen for the purposes of stock assessment and for providing management advice (see below). Landings taken from the SEA5 zone have varied from around 2,000 to 6,200t. during the 10 years from 1993-2002. Comparison between the SEA5 zone landings and the total column in Table 10 confirms that the zone includes most of the landings from the four scallop management areas defined by the MLA for assessment purposes. It can be seen, however, areas outside the zone, in response to the falling catches in the main North East and East Coast stocks. Most of the landings are taken by vessels using mechanical dredge arrays, though SCUBA diving accounts for a small proportion of landings at Shetland and a relatively high proportion at Orkney, ranging from 22% (in 2001) to 100% (in 1993).

Table 10: Landings (tonnes) by UK vessels (dredging & diving) of scallops from the extended SEA5 zone, compared to the landings from the main MLA management areas, 1993-2002. Data from Howell et al. (2003) and MLA database

Year	SEA5 zone	MLA management areas				
		Shetland	Orkney	North East	East Coast	Total
1993	2811	577	36	1571	626	2810
1994	4979	630	202	2322	1808	4962
1995	6196	765	435	3044	1901	6145
1996	5168	674	363	3490	678	5205
1997	4869	933	285	2945	715	4878
1998	3973	926	339	1739	999	4003
1999	4569	755	453	1682	1809	4699
2000	2800	338	261	1516	720	2835
2001	2777	492	568	1745	298	3103
2002	1998	572	385	741	416	2114

The seasonal pattern of scallop landings is shown in Fig. 10; peak landings are recorded in April-July. The value of the scallop fishery in the SEA5 zone was estimated to have been £2.5 million in 2002.

In addition to the wild scallop fishery, small quantities of scallops are also produced by cultivation methods. This topic is covered briefly in Sections 2.3.6 and 3.1.

Stock assessments

Scottish scallop stocks are regularly (usually every two years) assessed by an internal workshop at the Marine laboratory, Aberdeen. The most recent assessment report was issued in 2003 (Howell *et al*., 2003), and of the four management areas within the SEA5 zone, detailed analysis was provided for Shetland, North East and East Coast. The main methods used were VPA (Shetland and NE) and research vessel surveys.

At Shetland, landings reached a peak of over 900t. in 1997-98 (Table 10), but have fallen recently, following the introduction of local management under a Regulatory Order. Fishing mortality is currently relatively low, to the point where the VPA is rendered less reliable. Estimates of spawning stock biomass from the VPA, and estimates of stock abundance from surveys, show a slightly declining trend in recent years but there is evidence for an improvement in the recruitment of young scallops.

In the North East management area, landings have fallen in recent years to about half the peak levels of the mid 1990s (Table 10). This fishery is heavily dependent on the level of recruitment. Both the VPA and survey data show that recruitment has been very variable; the peak landings in 1994-97 were the result of above average recruitment of 2 year-old scallops in 1991-94. This dependence on highly variable recruitment makes it very difficult to predict future yields. There are, however, signs of improved recruitment from the 2002 survey.

As in the North East, the East Coast fishery is also dependent on the level of recruitment. This fishery is fairly recent and developed on the basis of good spat settlement in 1988-90. Since then recruitment has declined, until very recently. In the last two surveys in 2001-2002, there was an indication that stock abundance and recruitment had improved, but it is too soon to say whether yields will improve.

There is a need for more research to identify sources of recruitment to the North Sea scallop stocks, which may possibly come from outside the main fishing areas (see Section 7).

Management and legislation

Vessels fishing for scallops have to be licensed and recent legislation has been introduced to control the number of dredges that can be used in different fishing zones around the Scottish coast. The limits are; 8 dredges per side in inshore waters (0-6 nautical miles), 10 dredges/side in territorial waters (6–12 nm) and 14 dredges/side in territorial waters (>12 nm). The use of large heavy ‘French’ type dredges is also restricted. Other measures being considered include limits on the width of dredges, and, to improve selectivity, on the diameter of the ‘chain-mail’ rings making up the belly of the dredge. There is a minimum legal size in force for scallops around the Scottish coast, which is currently 100mm in length.

In Shetland, the scallop fishery has been managed locally since 2000 by the SSMO under the terms of a Regulatory Order. Regulatory Orders can only be applied in inshore waters out to 6 nm. The SSMO control scallop fishing by restricting the number of vessel licences, by limiting the number of dredges to 14 (7/side), by limiting each vessel to two towing bars of maximum length 5.85m, and by a total prohibition on the use of ‘French’ dredges.

Like all bivalve molluscs, giant scallops are prone to various toxins acquired through ingestion of certain species of microscopic algae. Amnesic Shellfish Poisoning (ASP) has been a particular problem in North Sea scallops in recent years, resulting in areas being closed to fishing or a requirement that scallops harvested from ASP affected areas be processed to remove the gonad (where the highest toxicity is found) before being marketed (Howard *et al*., 2002). Details of the EU and national legislation governing this topic are given in Section 2.3.4.

2.3.2 Queen scallop

<u>Biology</u>

The queen scallop is much smaller than the giant scallop, growing to a maximum size of around 90mm in most areas, roughly half the maximum size of the latter species. Queen scallops at Shetland and the Orkney Isles grow to 110mm. Another species difference is that both shell valves in queen scallops are convex in shape whereas the left upper valve is flat in the giant scallop. Both scallop species occur over the same depth range, and in the same type of habitat, though queen scallops can also survive on harder gravel and shelly substrates because they do not recess into the sea bed (Mason, 1983). Queen scallops swim freely when disturbed, though their swimming endurance is limited (Chapman *et al*., 1979).

The life cycle of queen scallops is, in most respects, similar to the giant scallop (Mason, 1983; Rogers & Stocks, 2001). Queens attain sexual maturity at barely one year-old and spawn in the autumn for the first time, though the gonad is so small that this first spawning is not likely to contribute very much to population larval production. Around the Isle of Man, a second spawning occurs a year later and after that, there is evidence for three mass spawnings per year, the main one in the autumn (Aug.–Oct.) followed by two minor ones in winter (Jan.–Feb.) and early summer (May–July). The timings of these spawnings, and their relative importance, seems to vary with locality (Mason, 1983). The newly settled spat of queen scallops are generally much more abundant than those of the giant scallop, reflecting their much higher adult densities. Whereas a density of one giant scallop per 5-10 m^2 (Mason *et al*., 1979) would be considered high and of commercial interest, queen scallops are usually much more abundant. Divers have found them lying three or four deep in the Firth of Clyde, at densities of 500–1,000/m^2. The life-span of queen scallops is relatively short, 5-6 years in most areas, in contrast to the giant scallop which can live for up to 20 years.

<u>Fisheries</u>

The main queen scallop fisheries within the SEA5 zone are located in the Orkney and Shetland Isles (Fig. 11). As Fig 11 and Table 11 show, these fisheries are at a rather low level. The market demand for queen scallops tends to vary, giving rise to large fluctuations in landings throughout the UK. In Shetland, the fishery started in 1970 and annual landings reached almost 500t. by 1979, but declined thereafter. Since 1985, landings at Shetland have fallen well below 100t. per year. Methods of fishing for queen scallops vary from area to area and include modified scallop dredges, otter trawls and beam trawls. The latter method is most commonly employed in the Northern Isles (Mason, 1983).

Landings

Landings of queen scallops from the SEA5 zone are given in Table 11. Landings reached a peak of over 300t. in 1995 but since then, have declined sharply. The zone accounts for a relatively small proportion of Scottish landings (<3 % in most years – Table 11) as the most important queen scallop fisheries are in the Firth of Clyde and the north Irish Sea. Most landings are made during the winter months, October–March (Fig. 12). The queen scallop fishery within the SEA5 zone was estimated to be worth £47 thousand in 2002.

Table 11: Landings (tonnes) by UK vessels of queen scallops from the SEA5 zone, compared to the total for Scotland, 1993-2002. Data from Anon. (1997; 2002) and MLA database.

Year	Landings (tonnes)		SEA5 zone as % of total
	SEA5 zone	Scotland total	
1993	64	6336	1.0
1994	55	2424	2.3
1995	318	1883	16.9
1996	154	1901	8.1
1997	140	5233	2.7
1998	98	6912	1.4
1999	67	4962	1.4
2000	63	4159	1.5
2001	29	5533	0.5
2002	56	6766	0.8

The rapid growth rates found in queen scallops has led to the species being considered as a suitable candidate for cultivation (Section 2.3.6).

Stock assessments and management

No assessments have been undertaken for queen scallop stocks within the SEA5 zone. Given the relatively short life-span and high natural mortality, predicting the abundance of queen scallop stocks is difficult and the general strategy seems to be to fish stocks fairly hard when the market demand is there. Historically, queen scallop fisheries have tended to operate on a ‘boom or bust’ cycle without any management controls in place. In 2000, the EU Fisheries Council introduced a minimum legal size for queen scallops of 40mm, although this is below the size normally acceptable to markets.

2.3.3 Cockle

Cockles are found on inter-tidal beaches of sand, muddy sand and fine gravel. They are most abundant from mid-tide level to LWST. Cockles can tolerate low salinities and occur in sheltered bays and estuaries. The cockle lives just below the sediment surface and feeds on suspended material in the water, drawn in via a siphon tube. Feeding only occurs when the cockles are covered by the tide so that the fastest growth rates usually occur low down on the shore where exposure is minimal. Under favourable conditions, cockles can occur at very high densities of several 100 per m^2. At high adult densities, there appears to be an inverse relationship between adult density and recruitment of young cockles due partly to spatial exclusion (Hancock, 1973; Bannister, 1998).

Cockles mature during their second year and spawn in spring–early summer. The sexes are separate and each female cockle produces about 1 million eggs. The larvae spend about 30 days in the plankton before settling on the sea bed. Recruitment of young cockles is highly variable and most fisheries are dependent on the occasional heavy settlement of spat to sustain the population for several years afterwards. Cockles of all ages are prone to heavy mortalities, from predators such as shore crabs, brown shrimp, fish and wading birds, and from severely cold winters.

Fisheries
Within the SEA5 zone, cockles are found in fairly small areas and some of these areas have been exploited on a small scale periodically, including several beaches in the Firth of Forth, Findhorn Bay and the Culbin Bars in the Moray Firth, and at several beaches in the Orkney Islands, especially that at Otters Wick, on the Island of Sanday. Only the latter has a recorded history of exploitation and most of the landings reported below will probably have come from there. The cockles are marketed locally in Orkney. Exploitation of this resource is carried out by hand gathering, the cockles being removed from the sediment using hand-rakes. Other methods of harvesting on a larger scale include suction dredging and tractor dredging. These methods are now closely controlled in Scotland. Following widespread disquiet, the use of tractor dredging methods was banned under the Inshore Fishing (Scotland) Order in 1995. It is fair to say that in Scotland, cockle fishing, especially by mechanised dredges, is highly controversial because of perceived environmental damage and disturbance to bird populations (see below).

Table 12: Landings (tonnes) of cockles from the SEA5 zone, compared to the total for Scotland, 1993-2002. Data from Anon. (1997; 2002) and MLA database.

Year	Landings (tonnes)		SEA5 zone as % of total
	SEA5 zone	Scotland total	
1993	0	348	0
1994	31	452	6.8
1995	68	449	15.1
1996	86	110	78.2
1997	35	72	48.6
1998	85	110	77.3
1999	74	120	61.7
2000	76	101	75.2
2001	82	103	79.6
2002	88	98	89.8

Landings
The landings of cockles within the SEA5 are given in Table 12. No landings were reported in 1993, but from 1994 onwards, 31 to 88t. were landed annually. Most of these landings came from the Orkneys, in all probability from Otters Wick. In recent years, Orkney beaches have been the main source of cockles in Scotland following the

closure of the Solway fishery in the mid 1990s. Peak landings from SEA5 were made in the period, February–April (Fig. 13).

Stock assessments

The Otters Wick stock was surveyed in 1993, 1994 and 1996 by Alex Simpson, a biologist employed by the Orkney Islands Council. At that time about 20 people were engaged in a hand-gathering fishery. The survey showed a biomass of around 500 tonnes of cockles but the age distribution was dominated by only one age group of 4 year-olds, the survivors of a good spat settlement in 1992. The next most abundant age group were 10 year-olds, survivors from the 1986 spat settlement. The fact that other age groups were absent, or present in very small numbers, indicated that spat settlement had been very poor in most years. This irregular pattern of recruitment makes it more difficult to manage the fishery. There have been no recent surveys of the Otters Wick beach or of any other exploited cockle beach in the Orkney Islands (Alex Simpson, pers. comm.).

With the closure of the Solway Firth fishery in the early 1990s, itinerant cockle gatherers have sought to open up new fisheries elsewhere in Scotland, often in areas of high conservation and heritage value. Examples within the SEA5 zone are Findhorn Bay and the Culbin Bars in the Moray Firth and more recently, various beaches within the Firth of Forth. The Moray Firth sites were surveyed by McKay *et al*. (1994); part of the Culbin West Bar area, near Nairn, is a Nature Reserve. The survey showed the presence of cockles at these sites but the cockle biomass (1,250t.) at the time of the survey was considered inadequate for a commercial fishery and subsequently, little or no fishing took place.

Recently, some beaches in the Firth of Forth have been visited by groups of hand gatherers, again displaced from the Solway. This development proved controversial because one of the beaches at Burntisland is a SSSI and the Firth of Forth is designated as a European Special Protection Area (SPA) for birds and a designated RAMSAR site. As a result of this, the Scottish Executive granted a Special Nature Conservation Order (SNCO) prohibiting commercial cockle fishing in the area east of the Forth rail bridge, extending to Dunbar on the south side, and to Elie on the north side of the Firth. This action was taken as a precaution, and subsequent to the closure, a survey of beaches in the Firth of Forth has been carried out to determine whether there is scope for developing a controlled cockle fishery compatible with nature conservation interests (Davis *et al*., 2003). The beaches surveyed were Cramond, Burntisland, Aberlady/Gosford Bays. Dunbar, Largo Bay and Gullane Bay. Of these, the first three beaches accounted for 97% of the overall stock biomass of 1,250t. Part of Aberlady Bay is a Nature Reserve and the Dunbar site includes the John Muir Country Park.

Management and legislation

As mentioned above, cockle exploitation is highly controversial in Scotland and following the over–exploitation of stocks in the Solway and at Barra by mechanised dredging methods (suction dredging by vessels and tractor dredging), these methods are now tightly controlled. Even the more benign hand-raking methods can be controlled at short notice through SNCO legislation, as in the Firth of Forth case above. The Scottish Executive is keen to promote the local management of cockle beds and other inshore shellfish resources, and this is discussed further in Section 3.1.

The Otters Wick, and other Orkney beaches are exploited by hand-raking but the fishery is largely self-regulating.

2.3.4 Mussels

Biology

The common mussel is found all around the Scottish coast, generally attached to hard inter-tidal substrates such as rocks, boulders and stones by means of byssus threads. In sheltered water, large ‘rafts’ of mussels may attach to each other rather than to the underlying substrate. Mussels also occur in the shallow sub-littoral zone and they will settle on man-made materials and structures, including oil and gas production platforms (Ralph & Goodman, 1981) and ships. In this type of habitat, mussels can be found down to depths of about 12m. Settlement on ropes, especially deployed for the purpose, forms the basis of an important mussel culture industry (see Section 2.3.6). Like cockles, mussels are suspension feeders, taking food particles from the plankton through siphon tubes. Growth rates are partly determined by the degree of exposure since feeding ceases when the mussels are uncovered by the tide. Also, on shores exposed to wave action more energy from food is diverted to producing thicker shells.

In mussels the sexes are separate. Sexual maturity is reached at one year-old and an average sized mussel can produce around 5 million larvae (Bannister, 1998). Spawning usually occurs in late spring to early summer and the larval phase lasts for about 30 days. Settlement may occur in two or three phases (Bayne, 1976; McKay & Fowler, 1996). The level of spat settlement is highly variable and is likely to depend on many factors, including pre-settlement winter temperatures, larval dispersal by wind–driven water currents, predation, water quality and availability of settlement sites (Bannister, 1998). The size of the adult spawning stock does not appear to be a major factor in determining spat abundance. Mussels provide food for many predators, including shore crabs, dog-whelks, starfish and birds such as eider duck and oystercatcher.

Fisheries

Within the SEA5 zone, marketable sized mussels are found in the Firth of Forth, near Musselburgh, in the Eden, Tay, Dee and Ythan estuaries, in the Montrose Basin, on the Culbin Bars in the Moray Firth, in the Inverness, Cromarty and Dornoch Firths and in Loch Fleet (McKay & Fowler, 1996). Currently, the only significant fishery is located in the Dornoch Firth. Elsewhere, small quantities are probably collected by hand for bait. In some areas the presence of pearls (of no commercial value!) excludes mussels from being harvested for human consumption. There is evidence to suggest that digenean trematode parasites of eider and black scoter ducks, which include the mussel as an intermediate host, act as agents for promoting pearl formation (Stunkand & Uzmann, 1958).

The Dornoch Firth fishery was given by the Scottish King, Robert the Bruce, to the people of Tain in 1312. Following two reorganisations of local government, the company now responsible for the fishery is Highland Fresh Mussels Ltd., part of the Highland Council, Inverness. The fishing is carried out all year round using dredge gear towed by a fishing vessel. The company have just taken delivery of a new dredging vessel (D Morris, pers. comm.).

A fishery in the Montrose Basin was operated by J & J Johnston of Montrose. The fishery first developed to supply bait for a local haddock and cod line fishery (McKay & Fowler, 1996), but the fishery is now much reduced from its peak in 1992, when nearly 600t. were landed. Because of poor water quality, mussels from the Basin have to be purified, by relaying in clean water or by depuration, before they can be marketed for human consumption.

Landings

Landings of mussels from the SEA5 zone are given in Table 13. Nearly all of the landings come from the Dornoch Firth and are registered with the Fishery Office at Wick. The fishery operates throughout the year, with above average landings in March–June (Fig. 14). The Dornoch Firth currently provides the only significant wild mussel fishery in Scotland. The value of this fishery has varied from £160–320 thousand in the period 2001-2003 (D Morris, pers. comm.).

Table 13: Landings (tonnes) of mussels from the SEA5 zone, compared to the total for Scotland, 1993-2002. Data from Anon. (1997; 2002) and MLA database

Year	Landings (tonnes)		SEA5 zone as % of total
	SEA5 zone	Scotland total	
1993	1734	1734	100
1994	1154	1157	99.7
1995	1087	1087	100
1996	926	927	99.9
1997	713	713	100
1998	518	518	100
1999	229	229	100
2000	864	864	100
2001	826	853	96.8
2002	659	735	89.6

In addition to the wild fishery, mussels are also cultivated in some sheltered areas, particularly in the Shetland Isles (see Section 2.3.6).

Stock assessment

The mussel beds in the Dornoch Firth are surveyed annually to estimate the abundance and quality of the mussels. This information, which is confidential, is used to decide the annual yield and other management actions such as reseeding of beds (McKay & Fowler, 1996; D Morris, pers. comm.).

Management and legislation

There is no public right to fish for mussels (or oysters) in Scotland. These rights were removed in the mid 19th Century so that for much of the Scottish coast, mussels belong to the Crown and the right to conduct mussel fishing is administered by the Crown Estate Commissioners (CEC). There are, however, many areas where the Crown has ceded rights to private landowners or communities, for example the Dornoch Firth fishery already referred to above. Very often there is no public record of the leases and in any case the CEC are not at liberty to provide information about them for reasons of confidentiality.

The Dornoch Firth (with Loch Fleet) and the Montrose Basin are classified as Special Protection Areas (SPA) for birds and designated RAMSAR sites; the Dornoch Firth is also a candidate for a marine Special Area of Conservation (SAC) under the EC Habitats Directive.

Management of mussel fisheries is clearly the responsibility of the resource owner or tenant and fishery legislation has to be modified to reflect this (see exemptions in Appendix A). Mussels, like other bivalve molluscs, are subject to the EU Shellfish Hygiene Directive 91/492/EEC which lays down the health conditions for the production and marketing of live bivalve molluscs. The provisions of this legislation include classification of areas according to faecal bacteria concentrations, testing for shellfish toxins (Paralytic Shellfish Poisoning - PSP, Diarrhetic Shellfish Poisoning - DSP, Amnesic Shellfish Poisoning -ASP), heavy metals and other contaminants. The Directive is implemented by national legislation, The Food Safety (Fishery Products and Live Shellfish) (Hygiene) Regulations 1998.

2.3.5 Other species

Sub-littoral beds of the larger horse mussel, *Modiolus modiolus* are also found in Scottish waters, though no commercial exploitation has taken place. Any fishery for this species would be controversial because of the high conservation value of the diverse horse mussel bed community and the slow regeneration time for this species (McKay & Fowler, 1996).

There are large numbers of bivalve mollusc species that burrow into sediments, similar to the cockle, but in many cases much deeper down. Examples include the razor shells (*Ensis arcuatus* and *E. siliqua*) and palourdes (*Venerupis senegalensis* and *Paphia rhomboides*), which are already exploited to some extent (33t. of razor shells, worth £82 thousand, were landed in Scotland in 2002), and many other species for which there may be future market potential. A survey of these resources around the Scottish coast was undertaken in 1989 using a specially adapted suction dredging vessel (McKay, 1992). A total of 39 species of bivalve mollusc were caught during the survey, and it was thought that markets might be found for 15 of them. In addition to the four species mentioned above, the potentially marketable species were *Glycymeris glycymeris*, *Lucinoma borealis*, *Spisula solida*, *Lutraria angustior*, *L. lutraria*, *Arctica islandica*, *Circomphalus casina*, *Dosinia exoleta*, *D. lupinus*, *Chamelea gallina* and *Mya truncata*. Within the SEA5 zone, locations in the Moray Firth and the Orkney Islands each yielded some of the above species, with the latter area offering the best prospects for a fishery.

A major problem with fisheries for deep burrowing bivalves is that, inevitably, the method of fishing causes environmental damage initially, with large trenches excavated in the sediment. Depending on site exposure to wave action and water currents, however, recovery from the environmental effects can be quite rapid (Hall *et al*., 1990). The use of suction dredge and water jet methods of fishing are banned in all the areas listed in Appendix A.

2.3.6 Shellfish farming

For three of the above bivalve species, giant and queen scallops, and mussels, production from fishing is supplemented by culturing them. In addition, the native oyster, *Ostrea edulis*, and the introduced Pacific oyster, *Crassostrea gigas*, are also farmed in Scotland. Although expanding slowly, the shellfish farming industry in Scotland is still relatively small. Within the SEA5 zone, most shellfish farming is confined to the sheltered waters of the Orkney and Shetland Isles. Information about production of farmed shellfish in Scotland is available from annual shellfish farm production surveys conducted by the MLA (e.g. Pendrey & Fraser, 2003). In 2002, there were 72 active shellfish farms in Shetland and 12 in Orkney, producing mainly mussels (1,246t.) with small quantities of pacific oysters, giant and queen scallops (Table 14). The total value of farm production from the Northern Isles in 2002 was estimated to have been £1.33 million, of which 99% was accounted for by Shetland mussel production.

Table 14: Shellfish farm production from the SEA5 zone (Orkney and Shetland) in 2002. Data modified from Pendrey & Fraser (2003).

Species	Units	Orkney	Shetland
Pacific oysters	No. (‘000s)	16	0
	Weight (tonnes)	1.2	0
	Value (£)	3,200	0
Mussels	No. (‘000s)	-	-
	Weight (tonnes)	0	1264
	Value (£)	0	1,308,300
Giant scallops	No. (‘000s)	0	20
	Weight (tonnes)	0	2.4
	Value (£)	0	11,000
Queen scallops	No. (‘000s)	0	50
	Weight (t)	0	2.0
	Value (£)	0	2,500

2.4 Gastropod molluscs

2.4.1 Whelk

<u>Biology</u>

The common whelk is widely distributed around the Scottish coast on all types of substrate, from rocky shores to soft sediments, ranging in depth from LWST to 100m. The species is tolerant of brackish water and can be found in river estuaries. Small whelks often occur in rock pools. The whelk is carnivorous and feeds on both dead and living animal flesh. It is strongly attracted to baited pots, the main method of fishing. The whelk moves slowly by means of a large muscular foot, the under surface of which is lubricated with slime.

It is estimated that whelks live for at least 10 years. In the southern North Sea, they attain sexual maturity at 2-3 years of age when about 50mm long. The sexes are separate, the male being readily distinguished by a large penis on the right side of the head. The females commence spawning in November, producing clusters of yellowish egg capsules which are attached to stones or shells on the sea bed. The capsules may contain up to 3,000 eggs but only a small proportion of these, usually around 15 (up to a maximum of 25) develop into offspring. The remainder of the eggs are known as 'nurse' eggs and these supply food for the developing embryos. The young fully formed whelks emerge from their capsules in Feb.–March.

Fisheries

Some fishing for common whelks takes place around the whole Scottish coast, though mostly in the North Sea and the Northern Isles (Fig. 15). Whelks are often caught in mobile dredge gear but the main method of fishing consists of baited pots made from perforated 5 gallon plastic containers fitted with a single entrance funnel at one end and weighted with concrete. The pots are usually baited with trash fish or fish offal and fished in fleets of 20 or more pots. Many fishermen make their own pots by recycling old plastic drums. Although small quantities of whelks are marketed locally, most are exported to the Far East, particularly Japan.

Landings

The landings of whelks from the SEA5 zone, compared to the whole of Scotland in 1993-2002, are shown in Table 15. The SEA5 landings have varied from 200 to 1,700 tonnes and these represent a high proportion of total Scottish landings in most years. The SEA5 zone accounts for nearly all whelk landings from the North Sea. It can be seen from Fig. 15 that most of the landings come from the inshore waters of the Moray Firth, Orkney and Shetland Isles, though there is some exploitation further offshore. The seasonal pattern of landings in Fig. 16 shows a clear peak during the early summer months, May–July. The value of the whelk fishery within the SEA5 zone is estimated to have been £269,000 in 2002.

Table 15: Landings (tonnes) of whelks from the SEA5 zone, compared to the total for Scotland, 1993-2002. Data from Anon. (1997; 2002) and MLA database.

Year	Landings (tonnes)		SEA5 zone as % of total
	SEA5 zone	Scotland total	
1993	200	842	23.8
1994	342	797	42.9
1995	664	1119	59.3
1996	1699	3555	47.8
1997	1063	1897	56.0
1998	868	1074	80.8
1999	1152	1300	88.6
2000	1117	2274	49.1
2001	1007	1611	62.5
2002	609	856	71.1

Stock assessments, management and legislation

No assessments have been carried out to determine the state of whelk stocks around the Scottish coast and the fishery is largely unregulated, except at Shetland. The EU have introduced a Community-wide MLS regulation which is set at 45mm shell length. This is really too low to serve any conservation benefit since it is below the size of maturity mentioned earlier. The SSMO at Shetland have introduced a much more appropriate MLS regulation, set at 75mm overall length. Whelk fishing vessels are also covered by the SSMO licensing scheme but, elsewhere in the UK, whelks may be excluded from the provisions of the new creel fishing licence regulations, referred to in Section 2.2.2.

2.4.2 Periwinkle

Biology

The winkle is one of the commonest shellfish species around the Scottish coast. The species is found on all rocky, boulder and pebble shores, except in the most exposed areas (McKay & Fowler, 1996). Winkles are most abundant from mid-tide level down to LWST and occasionally occur in the sub-littoral zone, usually on kelp fronds. Winkles are herbivores, grazing on diatoms and small algae, and also on decaying algae on the shore. A main predator on winkles is the shore crab.

Winkles, in which the sexes are separate, reach sexual maturity at 2-3 years of age, at shell height of about 12mm and spawn from January to July, producing egg capsules which are planktonic. Each female may produce 10,000 to 100,000 eggs and these are contained in capsules, each of which may contain a number of eggs. Spawning is thought to be synchronised with spring tides. The young winkles hatch out after about 5 weeks (McKay & Fowler, 1996). Winkles are intermediate hosts for a number of parasitic trematodes which can adversely affect survival, growth and egg production.

Fisheries

Winkles are harvested by hand at low tide and stored in ‘onion sacks’ for collection by the buyers. The best time to gather winkles is during the largest spring tides and the timing of low water has a marked influence on fishing patterns. In the North Sea, for example, gatherers can collect on two low tides per day, whereas only one tide is available during daylight on the west coast of Scotland. Most of the catch is exported to Continental Europe, especially Spain and France.

Landings

Information on landings is obtained from the buyers on a voluntary basis. As there is no statutory obligation to provide this data, there are doubts about its reliability. Since the fishery, to a large extent, operates in the ‘black economy’, it is likely that the official landings figures are under reported, possibly by a factor of two (McKay & Fowler, 1996). This must be borne in mind in relation to the landings from the SEA5 zone, given in Table 16.

There has been a gradual decline in reported landings, both from SEA5 and throughout Scotland which may reflect the general improvement in the Scottish economy and unemployment level. The seasonal pattern of landings is shown in Fig. 17; most landings are made in the spring and autumn months, coinciding with the lowest spring tides. Because of uncertainties in the official landings, it is difficult to estimate their true value, although a conservative estimate of value in 2002 would be about £86,000.

Stock assessment, management and legislation

No assessments have been carried out to determine the condition of winkle stocks around the Scottish coast and the fishery is completely unregulated. The absence of any regulatory framework contributes to the rather relaxed view about collecting reliable landings data. Also, there is no reliable information on the number of people involved in the fishery.

Table 16: Landings (tonnes) of periwinkles from the SEA5 zone, compared to the total for Scotland, 1993-2002. Data from Anon. (1997; 2002) and MLA database.

Year	Landings (tonnes)		SEA5 zone as % of total
	SEA5 zone	Scotland total	
1993	386	1707	22.6
1994	296	2053	14.4
1995	260	2138	12.2
1996	272	2032	13.4
1997	113	2406	4.7
1998	52	1675	3.1
1999	65	1002	6.5
2000	95	928	10.2
2001	83	603	13.8
2002	68	108	63.0

2.4.3 Other species

The red whelk, *Neptunea antiqua* (L.), has been landed by trawlers occasionally but no separate landing statistics are available. The species occurs from 15 to 1,200m depth, mainly on soft muddy sand substrates. Red whelks require careful processing to remove the highly toxic salivary gland containing the poison tetramine (Reid *et al.*, 1988).

It should be mentioned here that the collection of live bait for recreational sport fishing represents another activity in which invertebrates are exploited. This topic was reviewed by Fowler (1992). The number of sea anglers in the UK was estimated to exceed two million, of whom about 60% dig their own bait. Up to date figures for the SEA5 zone are not known. The main species sought are ragworms, *Nereis* sp., the lugworm, *Arenicola marina* and ‘peeler’ crabs, referred to in Section 2.2.5 (see also Cook, 2002). A conservative estimate suggests that the value of these resources to sport angling in the UK as a whole is of the order of £10 million. Bait digging can cause conservation problems, not so much in terms of the bait resources, but in terms of conflict with other beach users, disturbance of bird populations and damage to other beach fauna. Some local authorities in Scotland, for example in Fife and East Lothian, have bye-laws to control bait digging, particularly in nature reserves.

3. Future shellfish fisheries management and legislation

From the detailed accounts for each species given in Section 2, it will be apparent that the majority of shellfish fisheries within the SEA5 zone are virtually unregulated. While species such the Norway lobster and giant scallops are controlled to some extent in terms of fishing effort, by a TAC in the former species and by technical measures in the latter, the fisheries for all other species are inadequately regulated, usually by a MLS alone, or not regulated at all. Species for which the fisheries are virtually unregulated include shore crab, queen scallop, whelk, and periwinkle. Mussels, as we have seen, are unique in so far as the fisheries are controlled by private ownership or lease. It is for this reason that the best managed shellfish fishery within SEA5 is undoubtedly the Dornoch Firth mussel fishery. In the past, cockle fisheries have not been well managed and as a result have proved highly controversial, such that, with some exceptions, the regulatory authorities have simply closed the fisheries down.

A possible solution to the problem of controlling inshore shellfish fisheries is to promote better management at a local level, as we have seen in the Shetland Islands.

3.1 Local management

In the future it is likely that much of the control and management of inshore shellfish fisheries will be devolved to local groups of stakeholders. The Sea Fisheries (Shellfish) Act 1967 can be used to grant (a) Regulatory Orders to encourage better shellfish fishery management and (b) Several Orders to encourage enhancement of shellfish resources through farming and ranching.

Regulatory Orders (ROs) are relatively common in England but fairly new to Scotland. The first to be introduced was in Shetland, where from 2000, the management of local resources of lobsters, all crab species, giant scallops, queen scallops, whelks, mussels, cockles, oysters and razor-shells was devolved to the Shetland Shellfish Management Organisation (SSMO). The Regulatory Order applies to Shetland inshore waters out to 6 nautical miles from baselines. Since the Shetland Order was granted, several other applications have been, or are being, submitted to the Scottish Executive. Of major significance is an application from an organisation, named the Highland Shellfish Management Organisation (HSMO), for a Regulatory Order to cover the inshore waters out to 6 nautical miles adjacent to the whole Highland Regional Council coastline, stretching from Nairn in the Moray Firth round to Cuil Bay, Loch Linnhe in the west. This is an enormous area, far larger than was ever envisaged for Regulatory Orders and it is fair to say that the application is proving to be highly controversial. The size of the area is so large that the application may be in danger of negating all the potential advantages of local management. The application will almost certainly have to go to a public enquiry.

Several Orders differ from ROs in that they are designed to provide sea bed rights in order to encourage enhancement of shellfish resources through farming and ranching. There are eight Several Order sites in Scotland at present, all situated on the west coast (Pendrey & Fraser, 2003). These are mostly being used to farm giant scallops. After an initial period in which the young scallops are grown in suspended cages to protect them from predators, the scallops are laid on the sea bed until ready for harvesting. It is for this final stage that a Several Order is required to provide security for the stock. It is likely that in the future, there will be a significant increase in the production of giant scallops by culture and ranching methods, to supplement and perhaps partly replace the wild scallop fishery in some areas. These methods could also be used to reseed wild scallop beds in the event of a decline in natural recruitment (Brand *et al*., 1991). Various countries are experimenting with this approach, including Canada, Ireland, Northern Ireland, Isle of Man and Jersey in the Channel Islands. In Northern Ireland and the Isle of Man, compensation funds, made available to fishermen, following the installation of pipelines have been, or are being used to pay for the reseeding of giant scallop stocks in the Irish Sea (A Brand, pers. comm.).

3.2 Reduction of fish by-catch

Because the fisheries for Norway lobster and pink shrimp employ nets with small meshes, there is inevitably a large by-catch of demersal fish, a high proportion of which are under-sized and therefore discarded. With some North Sea fish stocks in a poor state, it is increasingly likely that there will be a diversion of fishing effort towards the Norway lobster, particularly on the Fladen Ground. This switch will be of little benefit to fish stocks unless Norway lobster trawls are made more selective in order to reduce the fish by-catch. A similar situation will arise in the pink shrimp fishery where the mesh size of trawls is even smaller than for Norway lobsters. Already, vessels fishing for Norway lobsters are required to fit a square mesh panel in the top of the net to aid the escape of fish before they reach the codend (Section 2.2.1). Experiments by Briggs (1992) and Robertson & Shanks (1994) showed how such a panel could reduce the by-catch of undersized haddock and whiting in Norway lobster fisheries, but it is unclear whether this measure is totally effective when used commercially by the industry. Gosden *et al.* (1995) suggested, from the analysis of discard rates before and after their introduction, that square mesh panels had had no significant beneficial effect in the Scottish Norway lobster trawl fisheries.

Given the uncertainties regarding square mesh panels, other methods may be needed to reduce the demersal fish by-catch in Norway lobster and pink shrimp trawls. Some of these were mentioned earlier in Sections 2.2.1 and 2.2.6. Much research has been carried out on the use of separator trawls by the MLA and the Sea Fish Industry Authority (SFIA) (Main & Sangster, 1982; 1985; Ashcroft, 1983; 1984). In these gears, the net is divided horizontally into two parts by an extra panel of netting and the two halves each terminate in separate upper and lower codends. Because of different swimming behaviour patterns in the trawl shown by Norway lobsters and fish species such as haddock and whiting, the net achieves a good separation of the catch with the lobsters entering the lower codend and most of the haddock and whiting retained in the upper one. Norway lobsters swim backwards by means of alternate extensions and contractions of the abdominal muscles, a method generally known as 'tail-flip' swimming (Newland *et al.*, 1988). Other types of fish, such as flatfish, dogfish and skate, and unfortunately most of the cod, tend to enter the lower codend with the Norway lobsters so that the separation of fish is only partially achieved. It is envisaged that a separator trawl would operate with different mesh sizes in the two halves of the net, appropriate for the two main components of the catch.

Where the main problem is the by-catch of cod, it is likely that separator trawls will not produce the desired reduction and some form of internal rigid grid device will be required (Isaksen *et al.*, 1992; Valdermarsen *et al.*, 1993; Section 2.2.6). The use of such devices is mandatory in the pink shrimp fishery in Norwegian waters and has just been introduced, as one of two options for reducing fish by-catch, in the brown shrimp fisheries in England. It seems likely that devices of this type will be more widely used in the future to reduce the fish by-catch in fisheries targeting pink shrimps and Norway lobsters.

4. Impact of gas and oil exploration on fisheries

This topic has been comprehensively dealt with by Rogers & Stocks (2001) and their analysis is pertinent to the extension of oil and gas exploration into SEA5. In addition, the wider subject of impacts on ecosystems has been well covered by the SEA2 Consultation document (Anon., 2001) and, in the case of contaminants, by Sheahan *et al*. (2001). In this Section, the discussion will highlight some specific shellfish issues in relation to oil and gas exploration.

4.1 Seismic surveys

Most studies on the biological effects of seismic sound energy have concentrated on marine mammals and fish, groups which have sensitive hearing organs and which, in many cases, employ sound as part of social behaviour (Hawkins & Myrberg, 1983). Invertebrates, on the other hand, have been little studied in terms of bioacoustics and there is a dearth of information relating to the effects on them of seismic sound waves. Some crustacean species generate low frequency sounds which presumably serve a communicatory function, for example, the spiny lobsters (Palinuridae) and the snapping shrimps (Alpheidae). Because invertebrates lack air-filled cavities, it is almost certain that they would respond to the particle motion component of sound rather than to sound pressure, and as a consequence their sensitivity to sound is likely to be inferior to that of fish. Crustaceans have a variety of hair-like sense organs that are potentially capable of responding to mechanical stimuli, including sound, but similar structures have not been identified in bivalve and gastropod molluscs. These mollusc groups are therefore unlikely to change their behaviour in response to seismic sound waves, though they could show physiological reactions and anatomical damage. Surprisingly, even the highly mobile predatory cephalopod molluscs (squid, octopus) are thought to be insensitive to sound (Young, 2001).

A recent study examined the effect of seismic sound energy on the snow crab, *Chionoecetes opilio* off the coast of Newfoundland (Christian *et al*., 2003). This report includes a useful bibliography and presents the results of a comprehensive investigation on the behaviour, physiology and anatomy of snow crab in relation to seismic surveys. Behaviour studies included comparison of crab catch rates in baited traps before and after seismic transmission, and studies of crab behaviour in cages and on the seabed, monitored by underwater TV camera and acoustic telemetry. The sound sources used were seismic air-guns of 10, 20 and 40 cubic inch (in^3) capacity, either singly ($40in^3$) or in a larger seven gun array of $200in^3$. The sources were set at a depth of 2m and were fired 200 times with a 10 second time interval, replicating operational survey practices. This type of air-gun array is by far the most commonly used seismic sound source (Anon., 2001).

The results from the crab fishing trials showed that the catch rate of snow crabs was higher after periods of seismic transmission than during control periods beforehand, though, because of bad weather, there was a considerable time interval between pre – seismic and post-seismic fishing (Christian *et al*., 2003). This result could therefore reflect a seasonal variation in crab abundance or catchability, rather than a direct effect of sound. In preliminary behaviour experiments in a laboratory, it was found that snow crabs showed a characteristic ‘startle’ response to sounds generated by striking two metal bars together. When, however, caged snow crabs were observed by TV camera during seismic transmission from the 200in^3 array at a range of 50m, no 'startle' responses, nor any other behaviour changes, were detected.

A second series of seismic sound tests was conducted to monitor changes in the physiology and anatomy of snow crabs (Christian *et al*., 2003). Both 40in^3 sources and 200in^3 arrays were tested at different ranges (between 2 and 175m) from snow crabs but no consistent effects could be demonstrated on concentrations of serum protein, solutes, enzymes and relative numbers of different haemocyte types. Similarly, microscopic examination of snow crab exoskeleton, appendages, statocysts, hepatopancreas and heart, showed no pathological changes that could be attributed to seismic sound transmission. None of the snow crabs died during these tests, in some of which, the source was positioned only 2 m away. Also, no subsequent mortalities were reported when crabs experiencing the greatest seismic exposures (2-4m range) were retained in laboratory aquaria for five months after the tests. Kosheleva (1992) similarly found no adverse effects on benthic invertebrates, including crab species, following exposure to a single air-gun at a range of 0.5m.

It was concluded from these investigations that seismic sound transmission had no obvious effects on the behaviour, fishing success or the health of adult snow crabs. Some additional experiments were carried out on fertilized eggs stripped from ovigerous female crabs. Eggs, exposed to a single air-gun source at a range of 2m showed some differences from controls when examined after 12 weeks. Firstly, there was a small increase in egg mortality in the seismic treatment group, and secondly, there appeared to be a reduction in the rate of egg development. Both of these differences were statistically significant. It should be noted, however, that the effects were apparent with the eggs exposed at a range much closer to the source than would occur in the natural situation, where eggs are attached to the abdomens of bottom living females.

Within the SEA5 zone, the main crustacean resource likely to experience exposure to seismic sound energy is the Norway lobster, and as far as the author is aware no studies have been conducted on this species in relation to such stimuli. Some studies have been made on behavioural and physiological responses of Norway lobsters to sound stimuli by Goodall (1988) and Goodall *et al*. (1990; 1991). These studies make it possible, to determine whether seismic sound would be detectable by Norway lobsters, and to offer tentative predictions as to their likely behavioural responses in the field.

The study by Goodall *et al*. (1990) obtained acoustic thresholds to low frequency sound using a reflex abdominal extension response, resulting in lifting the abdomen in readiness to escape by tail-flip swimming (Section 3.2). This work showed that the Norway lobster was sensitive to the particle displacement component of sound, with a threshold of 0.89µm which was independent of frequency within the range 20-200Hz. Similar levels of threshold response have been reported for other species (Hawkins & Myrberg (1983); 0.1 µm at 100Hz for the crayfish *Procambrus clarkii* and 0.6µm at 100Hz for another crayfish *Cherax destructor*. For comparison, the hearing organs in the cod and other fish species are much more sensitive, by about four orders of magnitude, and sensitivity does vary with sound frequency (Chapman & Hawkins, 1973).

The acoustic threshold for Norway lobsters can be compared with the acoustic output from typical seismic air-gun sources given in the snow crab report by Christian *et al*. (2003). A $40in^3$ air-gun generated a peak-to-peak sound pressure of about 220 decibels relative to 1 micro-pascal at a range of 1m (220dB re 1µPa). The equivalent source level for the $200in^3$ air-gun array was about 20 dB higher than for the $40in^3$ air-gun. At a water depth of 100m, assuming spherical spreading of the sound waves, the sound pressures from each air-gun source should fall by 40 dB, giving 180 and 200dB re. 1µPa for the $40in^3$ and $200in^3$ sources respectively.

The particle displacement amplitude (d, cm) of sound for a given pressure (p, µbar) can be estimated from the far-field plane wave equation: $d = p/(2\pi f\Omega c)$, where f is the sound frequency (assumed to be 28Hz for air-gun sources) and Ωc is the specific acoustic impedance of the medium (= $1.54 \times 10^5 g.cm^{-2}\ s^{-1}$ for sea water). Using the conversion 1Pa = 10µbar, the equivalent sound pressures at 100m depth from the $40in^3$ and $200in^3$ sources are 10^4 and 10^5µbar respectively, and from the plane wave equation, the equivalent particle displacement amplitudes are estimated to be 3.69 and 36.9µm respectively. These amplitudes are factors of 4 and 40 above the expected threshold for an acoustic response from Norway lobsters at a water depth of 100m. These calculations are given simply to illustrate the fact that crustacean species, such as the Norway lobster, are sufficiently sensitive to acoustic stimuli to be able to detect seismic sound transmissions in their normal environment. It is also possible, from the experiments of Goodall *et al*. (1990), that detection would lead to an escape response in Norway lobsters, either through tail-flip swimming or, more likely, withdrawal into a vacant burrow. These responses to seismic stimuli are likely to be transient, however, and have no lasting effect on normal behaviour rhythms and trawl catches.

The conclusion from the snow crab work (Christian *et al*., 2003), supported by earlier studies, is that seismic survey transmissions over open water are unlikely to have any lasting effects on the behaviour, catchability and health of invertebrate species.

4.2 Alien species

The problem of alien marine species introductions has concentrated on the transport of potentially harmful phytoplankton in ship's ballast water (Anon., 1998). Another source of such introductions is the transport of sessile species attached to ships and oil platforms. An example of this occurred in 1994 when clusters of the Magellan mussel, *Aulacomya ater*, were caught at 90m depth, in the Moray Firth during a routine research vessel survey (MLA, unpublished observations). This species of mussel occurs widely along the coasts of Peru and Chile, and in the Falkland Islands, where its inter-tidal and shallow water habitat is similar to that of the common mussel, *Mytilus edulis*. The source of the Magellan mussels was not positively identified but they were likely to have fallen from a barge, ship or oil platform anchored in the area.

4.3 Contaminants

The shellfish species considered in this report are generally considered to be particularly vulnerable to the uptake of environmental contaminants (Cooper, 1988; ESGOSS, 1994; Young, 2001). All of the species are relatively sedentary, varying from largely sessile species (common mussel) to active species that to varying extents are restricted to local movements (lobsters, scallops, velvet crabs). The only species known to undertake significant migrations is the edible crab, especially the females. The general lack of mobility is obviously an important factor in the accumulation of environmental contaminants by shellfish.

Bivalve molluscs, such as the common mussel and giant scallop, are filter feeders taking in particulate food with a respiratory current of sea water. They can accumulate algal toxins, giving rise to the shellfish toxicity problems referred to earlier, and also chemical contaminants such as trace metals, hydrocarbons and organochlorines. It appears that molluscs such as the common mussel do not regulate persistent chemical compounds but accumulate them in body tissues. This, for some time, has made the mussel a favoured organism for contaminant monitoring programmes ('Mussel Watch') by national and international authorities (e.g. Davies, 1980; ICES, 1974). Testing of bivalve molluscs in Scottish waters for various contaminants is routinely carried out to comply with the requirements of the EU Shellfish Hygiene Directive, referred to in Section 2.3.4, and the Commission Regulation 466/2001 (McIntosh *et al*., 2002; 2003).

The mode of feeding in periwinkles (Section 2.4.2), by browsing on algae in the littoral zone, can result in contaminant accumulation, such that this species has been routinely monitored close to the Sullom Voe Oil Terminal at Shetland. Widdows *et al*. (1985) found increased concentrations of hydrocarbons in the tissues of winkles collected from sites near the Terminal and also adverse biological responses in terms of growth and embryo development.

Contamination problems can also arise in crustaceans, either indirectly through feeding or directly from the environment. Evidence from the *Braer* accident revealed that shellfish species can be very seriously affected by an oil spill. The *Braer* grounding occurred in January, 1993 and resulted in about 85,000 tonnes of light crude oil being released into the marine environment in the south of Shetland (ESGOSS, 1994). Because of the nature of the oil and the weather conditions prevailing at the time, much of the oil was deposited on the sea bed in deep basins of fine sediment. A fishery exclusion zone was established by the Scottish Office to prohibit the taking of farmed and wild fish, and shellfish, from the contaminated area. This zone was maintained for as long as hydrocarbon (PAH) levels remained above background levels in samples of fish and shellfish analysed by the Marine Laboratory, Aberdeen.

By the end of April 1993, tests showed that the zone restrictions could be lifted in the case of species of wild fish but positive tests on shellfish meant that the prohibition remained in force for this group. It was not until the beginning of October 1994, that the fishing prohibition was lifted for some shellfish species but four species still showed evidence of contamination, namely mussels, Norway lobsters, giant and queen scallops. The latter two species were eventually removed from the prohibited list in February 1995, more than two years after the *Braer* went aground, but it was not until May 2000 that the zone restrictions were finally removed for mussels and Norway lobsters, over seven years after the oil spillage. To some extent, the *Braer* incident was atypical, in that its main impact was in sub-tidal areas, rather than coastal, and in the degree to which it impacted on shellfish fisheries, albeit in a relatively small area.

The persistence of oil contamination in the fine sediments found in deep basins, as happened in the *Braer* incident, is to be expected since many of the components of oil are hydrophobic and tend to adhere to particulate matter. Walsham *et al*. (2002), in their study of hydrocarbons in sediment samples on the Fladen ground, point out that finer sediments with high proportions of clay/silt particles tend to accumulate higher levels of hydrophobic elements. It is also possible that these components are distributed downwards into the sediments by the burrowing mega-fauna so characteristic of muddy habitat such as the Fladen, and other Norway lobster grounds. This bioturbation effect may have contributed to the persistence of PAH contamination in Norway lobsters in the *Braer* exclusion zone. Atkinson (1986) provides a useful review of mud-burrowing by mega-faunal species, including the Norway lobster.

As pointed out by Sheahan *et al*. (2001), produced water discharges are major sources of trace metals and Pierce *et al*. (2003) stress that bottom dwelling shellfish often contain high concentrations of such pollutants. High levels of certain metals is a natural phenomenon because they are required for metabolic purposes. In crustaceans, for example, metals such as zinc, copper and manganese are essential elements in certain enzymes, in the blood pigment haemocyanin and in the structure of the exoskeleton. Thus, for these metals, there are mechanisms for their take up, metabolism and excretion (Rainbow, 1988). For other metals, there appears to be no metabolic need but they are nevertheless taken up, examples being cadmium, mercury and lead. These elements accumulate in body tissues as there appears to be no pathway for excreting them. Instead, decapods such as Norway and European lobsters, crabs and shrimps appear to store these metals in a detoxified form without ill effect. The main concern then, in a fisheries context, is that the metal content can exceed recommended limits for human consumption.

Of interest is some work carried out by Davies & McKie (1983) on mercury concentration in the abdominal musculature of Norway lobsters from the Firth of Clyde (close to the sewage sludge dumping ground off Garroch Head). Results indicated that muscle tissue from females and the largest males contained much higher levels of mercury than smaller males. Differences in growth rate can account for this. This was confirmed when the different growth rates between the sexes was used to convert the carapace lengths of all the lobsters to age, resulting in a linear relationship for the combined data in which there was no obvious sex difference. Additional work in other areas, Firth of Forth, Sound of Jura and the Arran Basin, produced similar results (MLA, unpublished data). From examination of 168 females from all sites, three contained levels of mercury above the Food Standard Committee limit of 0.5 mg/kg but all of the 209 males were below the limit.

In view of the above findings regarding both hydrocarbon and trace metal contamination in Norway lobsters, it is surprising that little monitoring of this species appears to have been done on the Fladen ground in proximity to mature oil fields. The problem of sampling close to installations could perhaps be overcome by using baited creels, an effective method widely employed on the west coast of Scotland.

5. Offshore wind-farms

Potential sites for offshore wind farms are likely to be at some distance from the coast, to minimise visual impact and noise on land, and in fairly shallow water with gently shelving topography (Seys, 2002). The main impact on fishing will arise from the disruption to activity during construction and after commissioning, it being assumed that turbines, sub-stations and cables will have surrounding exclusion zones, as for oil and gas production platforms. The effects on shellfish populations are likely to be site specific and are difficult to predict. To inform the debate on this aspect, further monitoring of existing operational offshore wind farms, mainly in Scandinavian waters, is highly desirable. Although all developments involve a preliminary environmental impact assessment (EIA), there are few studies providing information on what actually happens after a wind farm is commissioned.

The first planned offshore wind farm in Scotland is at Robin Rigg in the Solway Firth, where the proposal is for up to 60 turbines (Robin Rigg, 2003). The main fishery in this area is for the brown shrimp, *Crangon crangon*, though annual landings are relatively small (<100t. in recent years). The Solway is probably a nursery area for edible crab and green crab, and also for several species of flatfish. The Robin Rigg Act allows for scour protection works at the base of turbines which are likely to be colonised by fauna such as mussels and periwinkles. In some areas, there may be scope for scour protection works to serve as artificial reefs providing suitable habitat for the European lobster, as mentioned in Section 2.2.2. Wickins & Barker (1998) have developed models for optimising artificial reef design for this species.

Underwater noise output from turbines could present an environmental problem, not so much from air-borne transmission, since 99% of this is reflected by the sea surface, but through vibrations conducted into the water via the turbine structure. The possible impact of this on marine mammals, fish and shellfish requires investigation.

6. Conclusions

The SEA5 review differs from previous assessments in that the zone includes a large coastal fringe, along the whole east coast of Scotland and the Northern Isles, and contains a diverse range of habitats, from inter-tidal rocky shores and sandy beaches, to the shallow sub-littoral and deepwater mud basins offshore. These habitats support a wide range of invertebrate resources, of which six species of crustacean, four species of bivalve mollusc and two species of gastropod mollusc form the basis of a thriving shellfish fishing industry in Scotland. The landings of shellfish from the SEA5 zone were worth around £30 million in 2000-2002.

The landings are dominated by the Norway lobster, *Nephrops norvegicus* which occurs in four main areas, one of which, the Fladen ground, is in close proximity to mature oil fields. The fishery for this species in the North Sea is likely to increase, with diversion of effort from the demersal fisheries for cod and other whitefish. Much of this expansion should take place at Fladen where the stock is at present under-exploited. It is likely, however, that trawl gear used in the Norway lobster (and pink shrimp) fisheries will be required to be more selective in order to reduce the by-catch of demersal fish, especially cod, and the wastage through discarding of under-sized fish.

The Norway lobster fisheries are managed by the EU through annual TACs and national quotas, in addition to a range of technical measures. By contrast, most other shellfish fisheries are poorly regulated at present, or not regulated at all. It is unlikely that this state of affairs will be allowed to continue and there are strong pressures to resolve this problem by introduction of local management regimes, through Regulatory Orders. This solution has already happened in Shetland, is close to being adopted in the Solway Firth and is being considered for much of the Scottish coast in the Highland area.

Most of the species considered here are most abundant in the inter-tidal zone or in inshore sub-tidal waters. These are the areas most likely to see wind farm developments, though it is difficult to determine the effects these might have on inshore fisheries. Each case would have to be considered on merit. It is suggested here that consideration be given to wind farm designs that, in some areas, could act as artificial reefs, particularly for European lobsters.

All the species considered in the report are relatively sedentary, living within or on the sea bed and of limited mobility. Even active species, such as the Norway and European lobsters tend to spend most of their time in shelters and emerge infrequently to forage for food. The only exception is the edible crab which is known to undertake extensive migrations, particularly the females. The general lack of mobility in the majority of species does tend to make them vulnerable to environmental disturbance and pollution. A good example of this was provided by the grounding of the *Braer* oil tanker at Shetland in 1993. It took over seven years for the hydrocarbon contamination in two species, Norway lobster and common mussel, to fall to background levels so that the fishery exclusion zone could be finally removed.

7. Suggestions for further research

During the course of this review, it became obvious that the early stages in the life-cycle of some species was one aspect of their biology where information was lacking. Firstly, in the edible crab, *Cancer pagururs*, more information is needed on the migrations and over-wintering areas of the females (Section 2.2.3), and also on the role of the inter-tidal zone as a nursery area for juvenile crabs. Because berried females reduce their feeding activities, they are seldom caught in baited creels so that information from the fishery can not locate where the females are aggregated. This information is lacking for crab populations within the SEA5 zone, but is needed in order to assess fully the risks to this species from environmental disturbance and other fishing activities (Howard, 1982; Bennett, 1995). A research programme, involving studies of larval production and distribution, surveys of adults by underwater TV camera and tagging experiments, would be valuable in helping to address this problem.

The role of the inter-tidal zone in the juvenile phase of edible crabs also merits further study. It is known that large numbers of juveniles occur in the littoral zone, either concealed under stones or buried in softer sediments, sand, shell gravel. It is not known whether the littoral zone represents a genuine nursery area or is merely the periphery of a broader area of juvenile distribution extending into deeper water. The same lack of understanding also applies to other species, such as the velvet and shore crab (Sections 2.2.4, 2.2.5). Research is needed to provide information on the distribution and abundance of juvenile crabs in coastal waters, particularly in relation to possible wind farm developments.

The giant scallop, *Pecten maximus*, is another species requiring more research on the early stages in the life-cycle, particularly in the SEA5 zone. As we saw in Section 2.3.1, the scallop populations in the North East and East coast management areas suffer from irregular recruitment of young spat. These stocks are unusual in this respect since in other areas the pattern of recruitment is more uniform giving rise to a a broader age structure and a more stable fishery. There is a need to investigate the dynamics of spat production and subsequent recruitment in the North Sea scallop stocks. The sources of spat need to be identified bearing in mind they may come from outside the area. Studies of larval distribution and abundance, of water currents and DNA typing would be worthwhile. Also the behaviour of spat at the time of settlement needs further study. There is evidence suggesting that the spat settle on filamentous hydroids and algae to which they attach by the byssus threads, but other studies have shown very small scallops on the sea bed along with the adults (Mason, 1983). Thus, there is scope for further investigation of this important life-cycle stage. It is also possible that the abundance of predators (the main ones being crabs and starfish) on the grounds is a key factor in determining the survival of young recruits. Also, the early sea bed phase may be particularly vulnerable to the effects of fishing gear towed over the grounds.

Finally, consideration should be given to the monitoring of contaminant levels in the Norway lobster on the Fladen ground, where there are many mature oilfields. This work should be undertaken in conjunction with sediment sampling (Walsham *et al.*, 2002). It is likely that this ground will develop into the most important fishery for the crustacean in Scottish waters.

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9. References

Anon. (1977a): Report of the Working Group on assessment of *Pandalus borealis* stocks: Conwy 24-26 may, 1977. ICES CM 1977/K:10

Anon. (1977b): ICES crustacean Working Group reports 1977. Coop. Res. Rep. No. 83, pp. 1-107

Anon. (1979): Report of the *Homarus* Working Group. ICES CM 1979/K:8, pp. 1-45

Anon. (1992): Working Group on the *Nephrops* and *Pandalus* stocks. ICES CM 1992/Assess:18

Anon. (1994a): Assessments on crab and lobster stocks. Marine Laboratory, Aberdeen Internal Report

Anon. (1994b): Report of the Study Group on life histories and assessment of *Pandalus* stocks in the North Atlantic. ICES CM 1994
Anon. (1997): Scottish Sea Fisheries Statistics 1997, Scottish Office Agriculture, Environment and Fisheries Department, pp. 29
Anon. (1998): Ballast water project. Marine Laboratory, Aberdeen Biennial Review 1995-1997, pp. 25-26
Anon. (2001): Strategic Environmental Assessment of the mature areas of the offshore North Sea SEA2. Consultation document. Report to the Dept. of Trade and Industry
Anon. (2002): Scottish Fisheries Statistics, Scottish Executive, pp. 1-22
Anon. (2003a): Report of the Working Group on *Nephrops* stocks. ICES CM 2003/ACFM:18
Anon. (2003b): Report of the *Pandalus* assessment Working Group. ICES CM 2004/ACFM:05
Ashcroft, B. (1983): Trials of prawn/fish separator trawl and survey of new prawn grounds in the South Central North Sea ICES Area IVb. Sea Fish Industry Authority Tech. Rep. No. 230, pp. 1-20
Ashcroft, B. (1984): Trials of prawn/fish separator trawls on fishing grounds in the Irish Sea ICES Area VIIa. Sea Fish Industry Authority Tech. Rep. No. 253, pp. 1-23
Atkinson, R.J.A. (1986): Mud-burrowing megafauna of the Clyde Sea Area. In: The environment of the Estuary and Firth of Clyde. Proc. Roy. Soc. Edin., 90B, 351-361
Bailey, N., Howard, F.G., Chapman, C.J. (1986): Clyde *Nephrops*: biology and fisheries. Proc. Roy. Soc. Edin., 90B, 501-518
Bannister, R.C.A., Edwards, E. (1995): Lobster stocking: Progress and potential. MAFF Information pamphlet, pp.1-11
Bannister, C. (1998): Analysing cockle and mussel stocks. Part 1- the Wash. Shellfish News No. 6, 25-29
Bannister, R.C.A., Addison, J.T. (1998): Enhancing lobster stocks: A review of recent European methods, results, and future prospects. Bull. Mar. Sci. 62, 369-387
Bennett, D.B. (1995): Factors in the life history of the edible crab (*Cancer pagurus* L.) that influence modelling and management. ICES mar. Sci. Symp. 199, 89-98
Beukers-Stewart, B.D., Jenkins, S.R., Brand, A.R. (2001): The efficiency and selectivity of spring-loaded scallop dredges: A comparison of direct and indirect methods of assessment. J. Shellfish Res. 20, 121-126
Brand, A.R., Wilson, U.A.W., Hawkins, S.J., Allison, E.H., Duggan, N.A. (1991): Pectinid fisheries, spat collection and the potential of stock enhancement in the Isle of Man. ICES Mar. Sci. Symp. 192, 79-86
Briggs, R.P. (1991): An assessment of nets with a square mesh panel as a whiting conservation tool in the Irish Sea *Nephrops* fishery. Fisheries Research, 13, 133-152
Brown, J., Hill, A.E., Fernand, L., Bennett, D.B., Nichols, J.H. (1995): A physical retention mechanism for *Nephrops norvegicus* larvae. ICES CM 1995/K:31
Chapman, C.J., Hawkins, A.D. (1973): A field study of hearing in the cod, *Gadus morhua* L. J. Comp. Physiol. 85, 147-167
Chapman, C.J., Main, J., Howell, T., Sangster, G.I. (1979): The swimming speed and endurance of the queen scallop *Chlamys opercularis*[+] in relation to trawling.

Progress in Underwater Science 4, pp. 57-72 (New Series). Ed. by J.C. Gamble, J.D. George. Pentech Press.

Chapman, C.J., Howard, F.G. (1979): Field observations on the emergence rhythm of the Norway lobster *Nephrops norvegicus*, using different methods. Mar. Biol. 51, 157-165

Chapman, C.J. (1980): Ecology of juvenile and adult *Nephrops*. In: The biology and management of lobsters, vol. II (Eds. J.S. Cobb, B.F. Phillips), pp.143-177. Academic Press

Christian, J.R., Mathieu, A., Thomson, D.H., White, D., Buchanan, R.A. (2003): Effect of seismic energy on snow crab (*Chionoecetes opilio*). Report for National Energy Board, Calgary, Canada, pp. 1-56

Cook, W. (2002): Crab shelter research project. Shellfish News No. 13, 13-14

Cooper, V.A. (1988): Effects on invertebrates. In: Pollution of the North Sea An Assessment. W. Salomons, B.L. Bayne, E.K. Duursma, U. Forstner (Eds.). Springer – Verlag, p. 604-611

Davies, I.M. (1980): Evaluation of a ‘Mussel Watch’ project for heavy metals in Scottish coastal waters. Mar. Biol., 57, 87-93

Davies, I.M., McKie, J.C. (1983): Mercury concentration in the Norway lobster (*Nephrops norvegicus*). ICES CM 1983/E:44, p. 1-4

Davis, S.E.B., Howell, T.R.W., Donald, J.W., Drewery, J., Martin, J., Campbell, R. (2003): Survey of Firth of Forth cockle grounds 2003. FRS Marine Laboratory, Aberdeen Report No. 21/03, pp. 1-10

Edwards, E. (1978): The edible crab and its fishery in British waters. Fishing News Books.

ESGOSS (1994): The environmental impact of the wreck of the Braer. Scottish Office, Edinburgh

Field, R.H., Chapman, C.J., Taylor, A.C., Neil, D.M., Vickermen, K. (1992): Infection of the Norway lobster *Nephrops norvegicus* by a *Hematodinium*-like species of dinoflagellate on the west coast of Scotland. Dis. Aquat. Org., 13, 1-15

Field, R.H., Hills, J.M., Atkinson, R.J.A., Magill, S., Shanks, A.M. (1998): Distribution and seasonal prevalence of *Hematodinium* sp. infection of the Norway lobster (*Nephrops norvegicus*) around the west coast of Scotland. ICES J. Mar. Sci., 55, 846-858

Friere, J., Gonzólez- Gurrianón, E. (1995): Feeding ecology of the velvet swimming crab *Necora puber* in mussel raft areas of the Ría de Arousa (Galicia, NW Spain). Mar. Ecol. Progress Ser. 119, 139-154

Fowler, S.L. (1992): Survey of bait collection in Britain. Joint Nature Conservation Report No. 107, pp. 1-53

Goodall, C.A. (1988): The sensory detection of water borne vibrational stimuli and their motor effects in the Norway lobster, *Nephrops norvegicus* L. PhD Thesis, University of Glasgow, pp. 1-161

Goodall, C.A., Chapman, C.J., Neil, D.M. (1990): The acoustic response threshold of the Norway lobster, *Nephrops norvegicus* (L.) in a free sound field. In Frontiers in Crustacean Neurobiology. Advances in Life Sciences. Birkhauser Verlag Basel, 106-113

Goodall, C.A., Neil, D.M., Chapman, C.J. (1991): Restricting a locomotory response to water-borne vibrational stimuli leads to the expression of a behavioural hierarchy in the Norway lobster, *Nehprops norvegicus* (L.). In: Locomotor neural mechanisms in arthropods and vertebrates. D.M. Armstrong, B.M.H. Bush, Eds. Chapter 11, pp. 117-124. Manchester University Press

Gordon, J.D.M. (2003): Fish and fisheries in the SEA4 area. Strategic Environmental Assessment – SEA4, Technical Report for DTI

Gosden, S.J., Stewart, P.A.M., Newton, A.W. (1995): Assessment of the effects on discard rates of introducing square mesh panels in the Scottish *Nephrops* trawl fishery. Scottish Fisheries Working Paper No. 3/95

Hall, S.J., Basford, D.J., Robertson, M.R. (1990): The impact of hydraulic dredging for razor clams *Ensis* sp. on an infaunal community. Neth. J. Sea Res., 27, 119-125

Hall, S.J., Basford, D.J., Robertson, M.R., Raffaelli, D.G., Tuck, I. (1991): Patterns of recolonisation and the importance of pit-digging by the crab *Cancer pagurus* in a subtidal sand habitat. Mar. Ecol. Prog. Ser., 72, 93-102

Hallbäck, H., Warén, A. (1972): Food ecology of lobster, *Homarus gammarus*, in Swedish waters. Some preliminary results. ICES CM 1972/K:29

Hancock, D.A. (1973): The relationship between stock and recruitment in exploited invertebrates. Rapp. P-v. Reun. Cons. int. Explor. Mer, 164, 113-131

Hawkins, A.D., Myrberg, A.A.Jnr. (1983): Hearing and sound communication underwater. In Bioacoustics, a comparative approach (ed. B. Lewis). Academic press, London, pp. 347-405

Hayward, P.J., Ryland, J.S. (Eds.) (1995): Handbook of the marine fauna of North-West Europe. Oxford University Press.

Hearn, A. (2001): The biology and fishery of the velvet swimming crab, *Necora puber* (L.) (Brachyura, Portunidae) in the Orkney Islands. PhD thesis, Heriot-Watt University, Edinburgh

Howard, A.E. (1980a): Substrate and tidal limitations on the distribution and behaviour of the lobster and edible crab. Progress in Underwater Science, 5, 165-169

Howard, A.E. (1980b): Substrate controls on the size composition of the lobster (*Homarus gammarus*) populations. J. Cons.Int. Explor. Mer. 39, 130-133

Howard, A.E. (1982): The distribution and behaviour of ovigerous edible crabs (*Cancer pagurus*), and consequent sampling bias. J. Cons. Int. Explor. Mer, 40, 259-261

Howard, A.E., Bennett, D.B. (1979): The substrate preferences and burrowing behaviour of juvenile lobsters (*Homarus gammarus* (L.)). J. Nat. Hist. 13, 433-438

Howard, A.E., Nunny, R.S. (1983): Effects of near-bed current speeds on the distribution and behaviour of the lobster, *Homarus gammarus* (L.). J. Exp. Mar. Biol. Ecol. 71, 27-42

Howard, F.G. (1981): Squat lobsters. Scot. Fish. Bull. No. 46, 13-16

Howard, F.G. (1982): Of shrimps and sea anemones; of prawns and other things. Scot. Fish. Bull. No. 47, 39-40

Howard, F.G. (1983): The United Kingdom fishery for the deepwater shrimp *Pandalus borealis* in the North Sea. Scot. Fish. Res. Rep. No. 30, pp1-16

Howard, G., Bresnan, E., Petrie, J. (2002): The marine biotoxin programmes for Scotland: 2001-2002. Shellfish News No. 13, 34-36

Howell, T.R.W., Davis, S.E.B., Donald, J., Bailey, N., Tuck, I. (2003): Report of Marine Laboratory scallop stock assessment. Fisheries Research Services Internal Report No. 07/03, pp. 1-133

ICES (1974): Report of the Working Group for the international study of the pollution of the North Sea and its effects on living resources and their exploitation. ICES Coop. Res. Rep. No. 39

Isaksen, B., Valdemarsen, J.W., Larsen, R.B., Karlsen, L. (1992): Reduction of fish by-catch in shrimp trawl using a rigid separator grid in the aft belly. Fish. Res. 13, 335-352

Jensen, A.C., Collins, K.J., Free, E.K., Bannister, R.C.A. (1994): Lobster (*Homarus gammarus*) movement on an artificial reef: the potential use of artificial reefs for stock enhancement. Crustaceana 67, 198-221

Jones, R. (1974): Assessing the long-term effects of changes in fishing effort and mesh size from length composition data. ICES CM 1974/F:33

Kinnear, J.A.M., Chapman, C.J. (1974): The use of ultrasonic transmitters to monitor the movements of large decapod crustaceans. DAFS Marine Laboratory Internal Report, No. 12, pp.1-4

Kinnear, J.A.M., Mason, J. (1987): A preliminary study of an unfished population of the velvet swimming crab *Liocarcinus* * *puber* (L.). ICES CM 1987/K:6

Kosheleva, V. (1992): The impact of air guns used in marine seismic explorations on organisms living in the Barents Sea. Fisheries and Offshore Petroleum Exploitation 2nd International Conference, Bergen, Norway, 6-8 April 1992. In Turnpenny, A. & Nedwell, J.R. 1994. The effects on marine fish, diving mammals and birds of underwater sound generated by seismic surveys. Fawley Aquatic Research Laboratories Ltd. pp. 40

Lart, W. et al. (2003): Evaluation and improvement of shellfish dredge design and fishing effort in relation to technical conservation measures and environmental impact. ECODREDGE FAIR CT98-4465, Final Report to the EU

Lizarraga-Cubedo, H.A. (2004): Factors affecting the fluctuations of the European lobster populations in Scottish waters. PhD thesis, University of Aberdeen

Lizarraga-Cubedo, H.A., Tuck, I, Bailey, N., Pierce, G.J., Kinnear, J.A.M. (2003): Comparisons of size at maturity and fecundity of two Scottish populations of the European lobster, *Homarus gammarus*. Fish. Res. 65, 137-152

Main, J., Gangster, G.I. (1982): A study of separating fish from *Nephrops norvegicus* L. in a bottom trawl. Scottish Fisheries Research Report No. 24, pp. 1-8

Main, J., Sangster, G.I. (1985): Trawling experiments with a two-level net to minimize the undersized Gadoid by-catch in a *Nephrops* fishery. Fish. Res. 3, 131-145

McIntosh, A.D., Davies, I.M., Megginson, C., Webster, L., Moffat, C.F. (2002): Measurement of chemical contaminants in shellfish from Scottish waters. FRS Marine Laboratory Report No. 08/02

McIntosh, A.D., Webster, L., Bredzinski, X., Moffat, C.F. (2003): Measurement of chemical contaminants in shellfish from Scottish waters. FRS Marine Laboratory Contract Report No. 02/03

McKay, D.W. (1992): Report on a survey around Scotland of potentially exploitable burrowing bivalve molluscs. Marine Laboratory, Aberdeen Fisheries Research Services Report No. 1/92, pp. 1-10

McKay, D.W., Howell, T., Shanks, A., Thain, S., Keith, F. (1994): Report on cockle stocks in the Findhorn Bay/Nairn area. Scottish Fisheries Working Paper No. 1/94, pp. 1-4

McKay, D.W., Fowler, S. (1996): Review of the exploitation of the mussel, *Mytilus edulis*, in Scotland. Scottish Natural Heritage Review No. 68, pp. 1-41

McKay, D.W., Fowler, S. (1996): Review of winkle *Littorina littorea* harvesting in Scotland. Scottish Natural Heritage Review No. 69, pp. 1-33

Mathers, N.F. (1976): The effects of tidal currents on the rhythm of feeding and digestion in *Pecten maximus* (L). J. Exp. Mar. Biol. Ecol., 24, 271-283

Mason, J. (1983): Scallop and queen fisheries in the British Isles. Fishing News Books Ltd., pp. 1-143

Mason, J., Chapman, C.J., Kinnear, J.A.M. (1979): Population abundance and dredge efficiency studies on the scallop, *Pecten maximus* (L.). Rapp. P.-v. Reun. Con. int. Explor. Mer, 175, 91-96

Newland, P.L., Chapman, C.J., Neil, D.M. (1988): Swimming performance and endurance of the Norway lobster *Nephrops norvegicus*. Mar. Biol. 98, 345-350

Nichols, J.H., Thompson, B.M. (1988): Quantitative sampling of crustacean larvae and its use in stock size estimation of commercially exploited species. Symp. Zool. Soc. Lond. No. 59, 157-175

Norman, C.P. (1989): Ecology of the velvet swimming crab *Liocarcinus* puber* (L.) (Brachyura: Portunidae). PhD thesis, Plymouth Polytechnic

Norman, C.P., Jones, M.B. (1992): Influence of depth, season and moult stage on the diet of the velvet swimming crab *Necora puber* (Brachyura, Portunidae). Est. Coast. Shelf. Sci. 34, 71-83

Pendrey, D.J., Fraser, D.I. (2003): Scottish Shellfish Farm Production Survey, 2002. Fisheries Research Services, Aberdeen

Pierce, G.J., Begona Santos, M., Mente, E., Wang, J., Stowasser, G., Boyle, P.R. (2003): An overview of cephalopods relevant to the SEA4 Area. Strategic Environmental Assessment – SEA4 – cephalopods. A review on behalf of the Dept. of Trade and Industry

Rainbow, P.S. (1988): The significance of trace metal concentration in decapods. Symp. Zool. Soc. Lond. No. 59, 291-313

Ralph, R., Goodman, K.S. (1981): Marine growth on North Sea oil and gas platforms. Progress in Underwater Science 6, 51-56

Reid, D.G., Aldrich, J.C. (1989): Variations in response to environmental hypoxia of different colour forms of the shore crab, *Carcinus maenas*. Comp. Biochem. Physiol., 92A, 535-539

Reid, T.M.S., Gould, I.M., Mackie, I.M., Ritchie, A.H., Hobbs, G. (1988): Food poisoning due to the consumption of red whelks (*Neptunea antiqua*). Epidem. Inf. 101, 419-424

Robertson, J.H.B., Shanks, A.M. (1994): The effect on catches of *Nephrops*, haddock and whiting of square mesh window position in a *Nephrops* trawl. ICES CM 1994/B:32

Robin Rigg (2003): Robin Rigg Offshore Wind Farm (Navigation and Fishing) (Scotland) Act 2003

Rogers, S., Stocks, R. (2001): North Sea fish and fisheries. Strategic Assessment Report - SEA2, Technical Report 003

Seys, J. (2002): Blowing in the wind, the future of wind turbines at sea. Ocean Challenge, 12, 40-43

Sheahan, D., Rycroft, R., Allen, Y., Kenny, A., Mason, C., Irish, R. (2001): Contaminant status of the North Sea. Strategic Environmental Assessment – SEA2, Technical Report 004

Shelton, R.G.J., Kinnear, J.A.M., Livingstone, K. (1979): A preliminary account of the feeding habits of the edible crab *Cancer pagurus* L. off N.W. Scotland. ICES CM 1979/K:35

Stunkand, H.W., Uzmann, J.R. (1958): Studies on digenic trematodes of the genus *Gymnophallus* and *Parvatrema*. Biol. Bull. 115, 276-302

Tallack, S.M.L. (1998): The stock and fishery of the velvet swimming crab *Necora puber* in Orkney. MSc thesis, Herriot-Watt University, Edinburgh

Tallack, S.M.L. (2002): The biology and exploitation of three crab species in the Shetland Islands, Scotland: *Cancer pagurus*, *Necora puber* and *Carcinus maenas*. PhD thesis, UHI Millenium Institute, Inverness and the Open University, Milton Keynes

Thomas, H.J., Davidson, C. (1962): The food of the Norway lobster, *Nephrops norvegicus* (L.). Mar. Res. No. 3, pp. 1-15

Thompson, B.M., Lawler, A.R., Bennett, D.B. (1995): Estimation of the spatial distribution of spawning crabs (*Cancer pagurus* L.) using larval surveys in the English Channel. ICES mar. Sci. Symp. 199, 139-150

Todd, C.D., Bentley, M.G. (1991): Torness artificial reef project (1988-1991). Report prepared for the Scottish Office Agriculture and Fisheries Department. Gatty Marine Laboratory, University of St Andrews, Fife (Unpublished report)

Tully, O. (2001): Impact of the v-notch technical conservation measure on reproductive potential in a lobster (*Homarus gammarus* L.) fishery in Ireland. Mar. Freshwater Res. 52, 1551-1557

Valdermarsen, J.W., Lehmann, K., Riget, F., Boje, J. (1993): Grid devices to select shrimp size in trawls. ICES CM 1993/B:35

Walsham, P., Webster, L., Fryer, R.J., McIntosh, A.D., Moore, D.C. (2002): The effects of oil exploration and production in the Fladen ground: Composition and concentration of hydrocarbons in sediment samples collected in 2000 and their comparison with sediment samples collected in 1989. Fisheries Research Services Report No. 14/02, pp. 1-17

Wickins, J.F., Barker, G.C. (1998): Artificial reefs – homes for *Homarus*? Shellfish News No. 6, 16-18

Widdows, J., Dixon, D., Donkin, P., Evans, S.V., Farrer, S., Livingstone, D.R., Lowe, D., Moore, M.N., Pipe, R. (1985): Sub-lethal biological effects monitoring in the region of Sullom Voe, Shetland. August 1984. Shetland Oil Terminal Environmental Advisory Group (SOTEAG). Aberdeen, Shetland

Young, I.A.G. (2001): An overview of cephalopods relevant to the SEA2 area. Strategic Environmental Assessment – SEA2, Technical Report 009

$^{+}$ =*Aequipecten opercularis*

* = *Necora puber*

Appendix A: List of areas within the SEA5 zone closed to the use of mobile gear fishing methods under the terms of the Inshore Fishing Order 1989 and subsequent amendments.

Area (No.)*	Miles from MHWS	Period of closure	Exemptions	Main aim of closure
Thurso and Dunnet Bays (19)		All year		Fish nursery area, static gear reserve
Sinclair Bay (20)		All year		Fish nursery area
The Berry-Costa Hd., Orkney (21)	2	May – Sept.		Fish nursery, static gear reserve
Dornoch Firth (22)		All year	Dredging mussels**	Fish nursery area
Cromarty Firth (23)		All year	Dredging cockles & mussels	Fish nursery area (herring)
Inverness Firth (24)		All year	Dredging cockles & mussels	Fish nursery area (herring)
Aberdeen-Mons Craig (25)	1	Oct.- March		Fish nursery area, static gear reserve
Mons Craig- Doolie Ness (26)	2	All year		Static gear reserve
Doolie Ness- Lang Craig (27)	1 1/2	Oct.-March April-Sept.	Montrose Basin	Static gear reserve
Lang Craig- Arbroath (28)	2	All year		Static gear reserve
St Andrews Bay, Tay Estuary (29)		All year		Fish nursery, static gear reserve
St. Abbs- Scot. /Engl. Border (30)	1	All year		Static gear & voluntary marine nature reserve

* No. given is the relevant paragraph in Schedule 1 of the 1989 Order.

** Mechanical dredge only, not suction dredging; the latter method is not permitted in any of the areas listed above.

Figures: Figures mentioned in the text.

Fig. 1: Chart of northern North Sea showing the SEA5 zone and the selection of ICES statistical rectangles used to aggregate landings data.

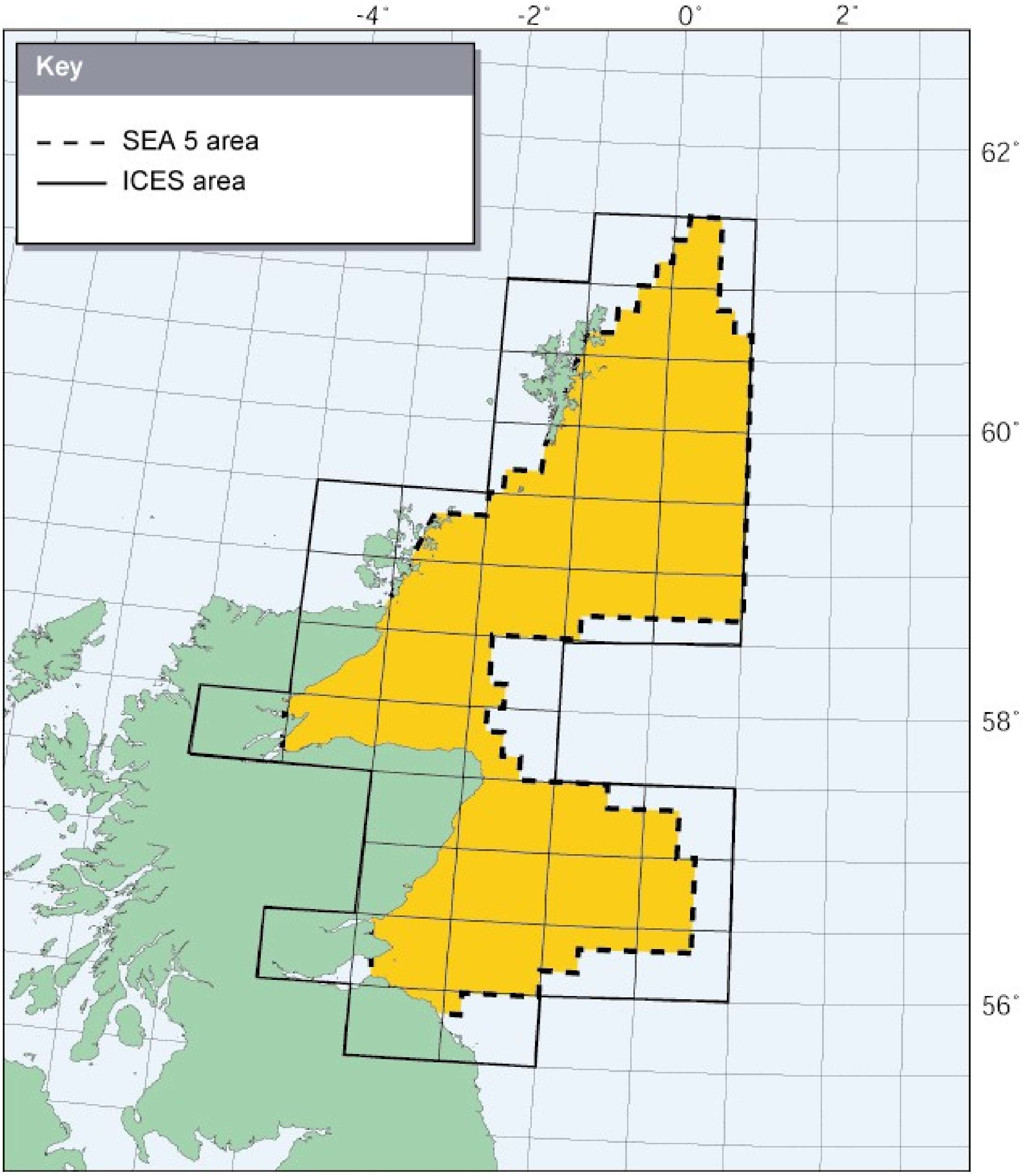

Fig. 2: Seasonal landings of Norway lobsters (tonnes) from extended SEA5 zone by UK vessels, averaged over the 10 year period, 1993-2002.

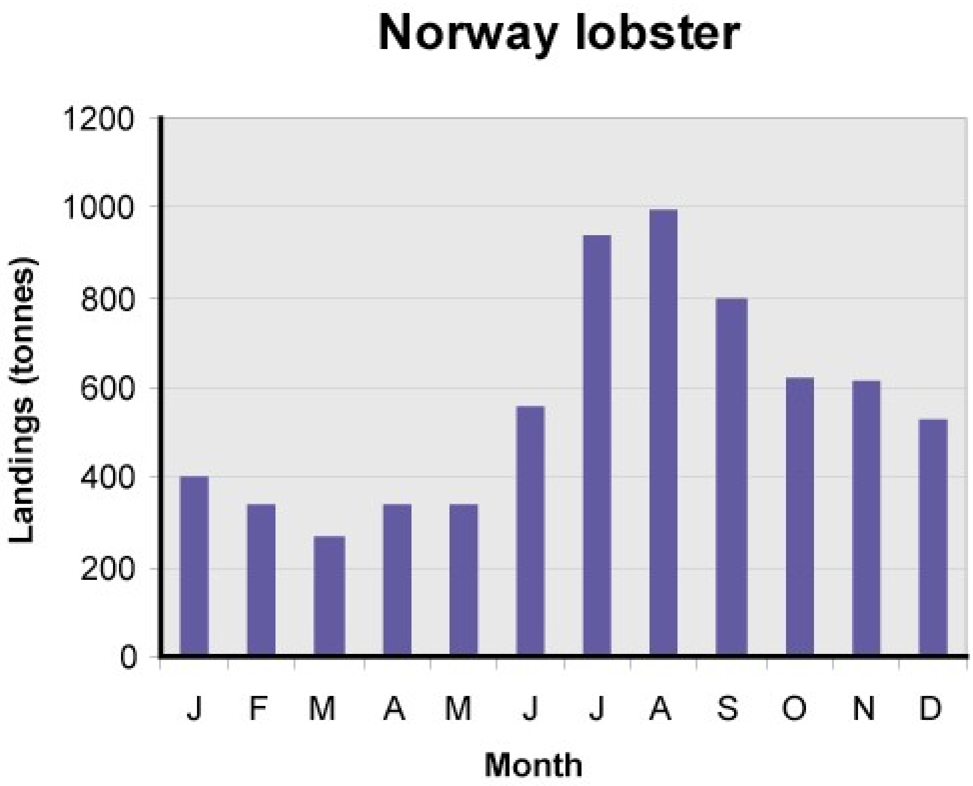

Fig. 3: Seasonal landings of European lobsters (tonnes) from extended SEA5 zone by UK vessels, averaged over the 10 year period, 1993-2002.

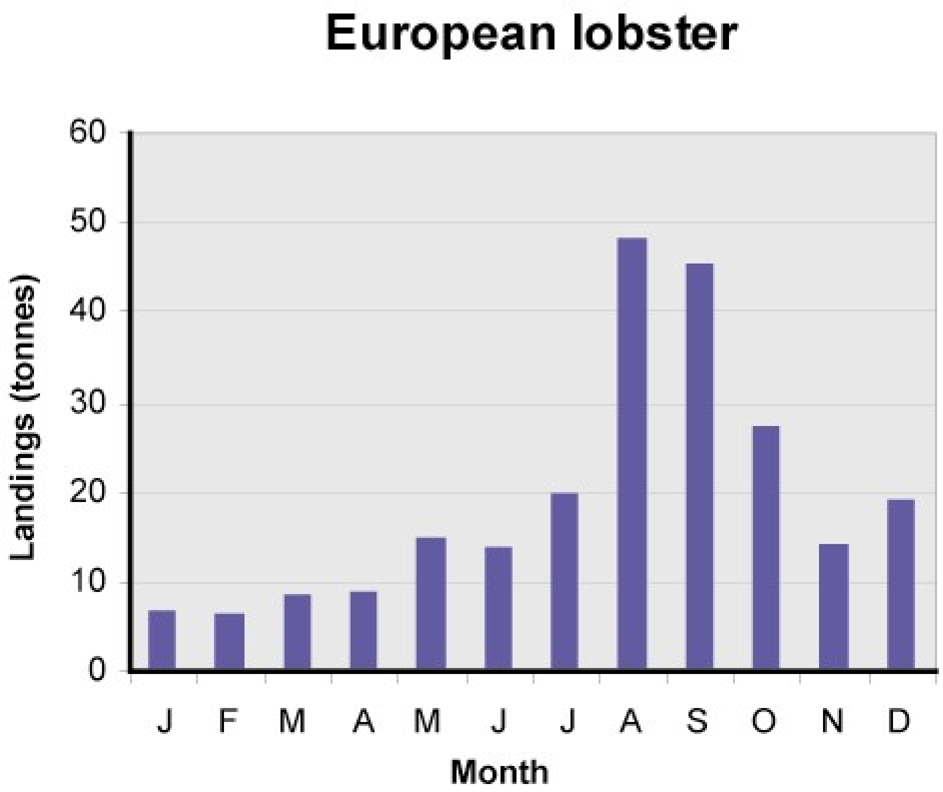

Fig. 4: Distribution of edible crab landings by UK vessels from extended SEA5 zone. Data based on ICES statistical rectangles and averaged over the three year period, 2000-2002.

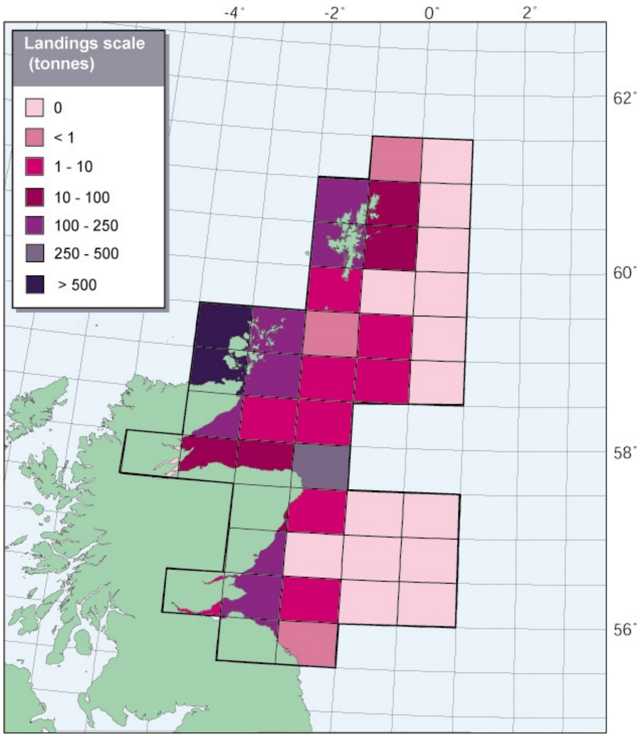

Fig. 5: Seasonal landings of edible crab (tonnes) from extended SEA5 zone by UK vessels, averaged over the 10 year period, 1993-2002.

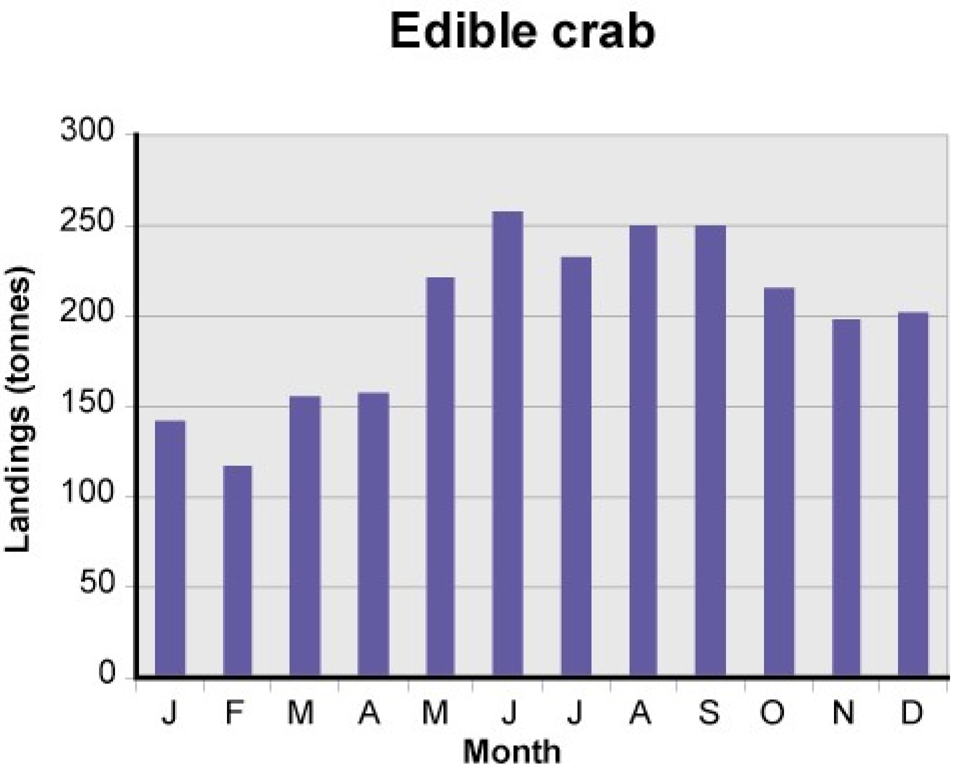

Fig. 6: Seasonal landings of velvet swimming crab (tonnes) from extended SEA5 zone by UK vessels, averaged over the 10 year period, 1993-2002.

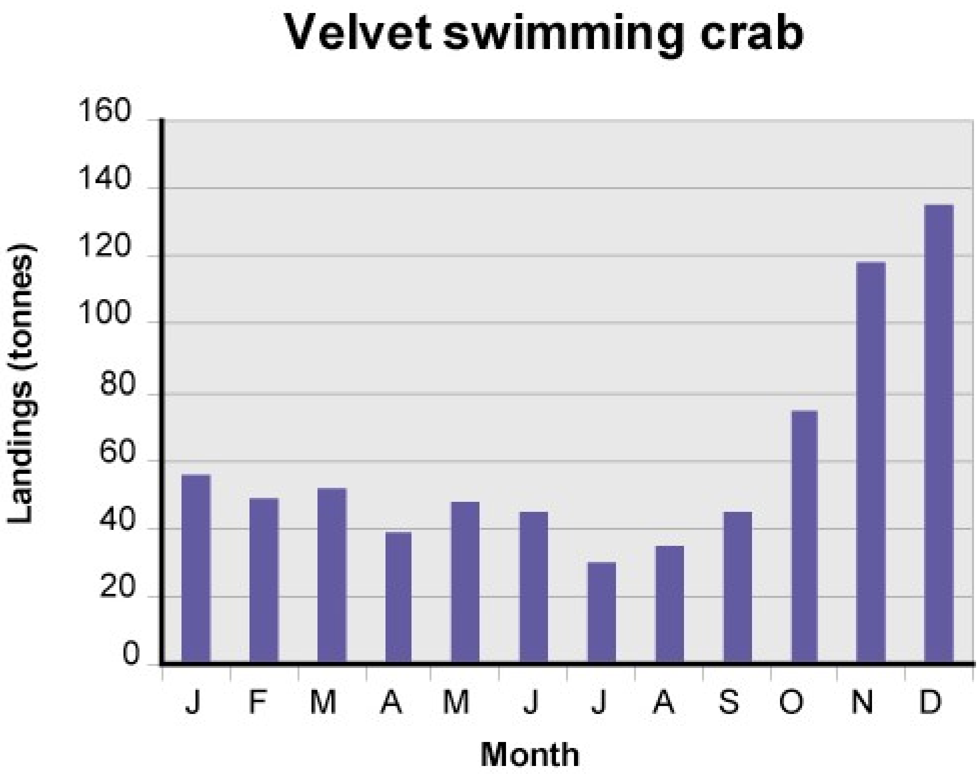

Fig. 7: Distribution of pink shrimp landings by UK vessels from extended SEA5 zone. Data based on ICES statistical rectangles and averaged over the two year period, 2000-2001.

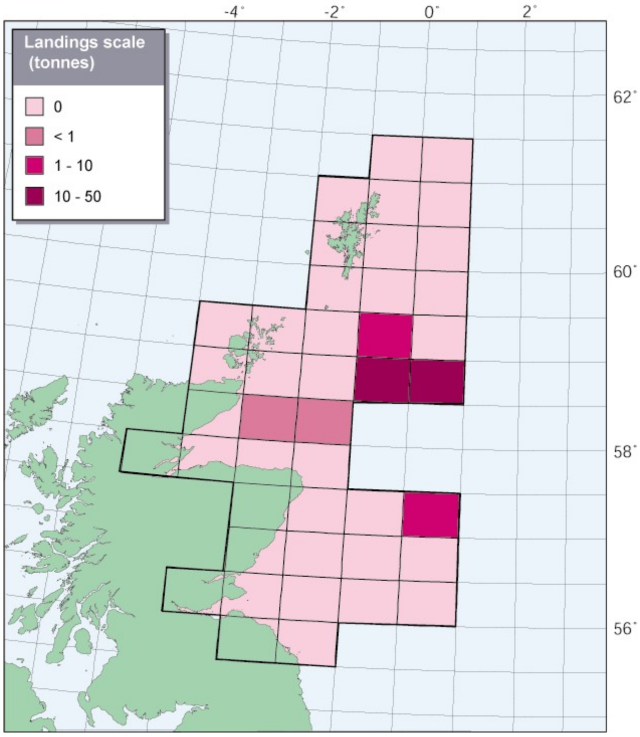

Fig. 8: Seasonal landings of pink shrimp (tonnes) from extended SEA5 zone by UK vessels, averaged over the 10 year period, 1993-2002.

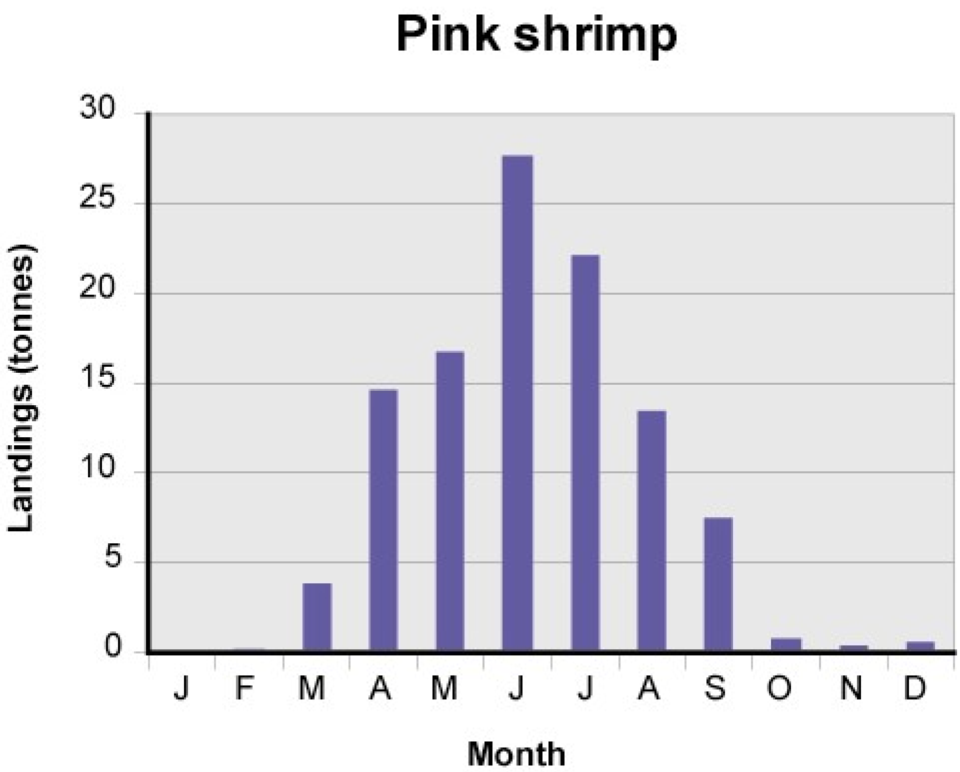

Fig. 9: Distribution of giant scallop landings by UK vessels from extended SEA5 zone. Data based on ICES statistical rectangles and averaged over the three year period, 2000-2002.

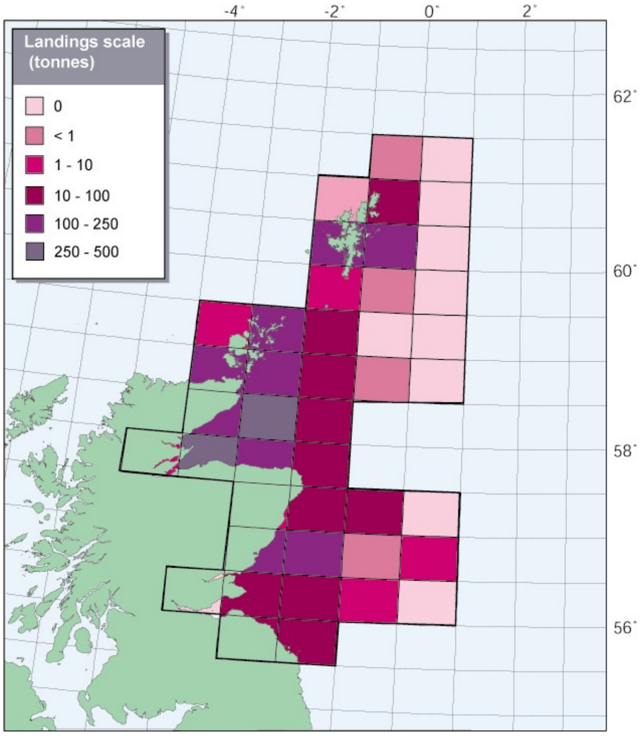

Fig. 10: Seasonal landings of giant scallop (tonnes) from extended SEA5 zone by UK vessels, averaged over the 10 year period, 1993-2002.

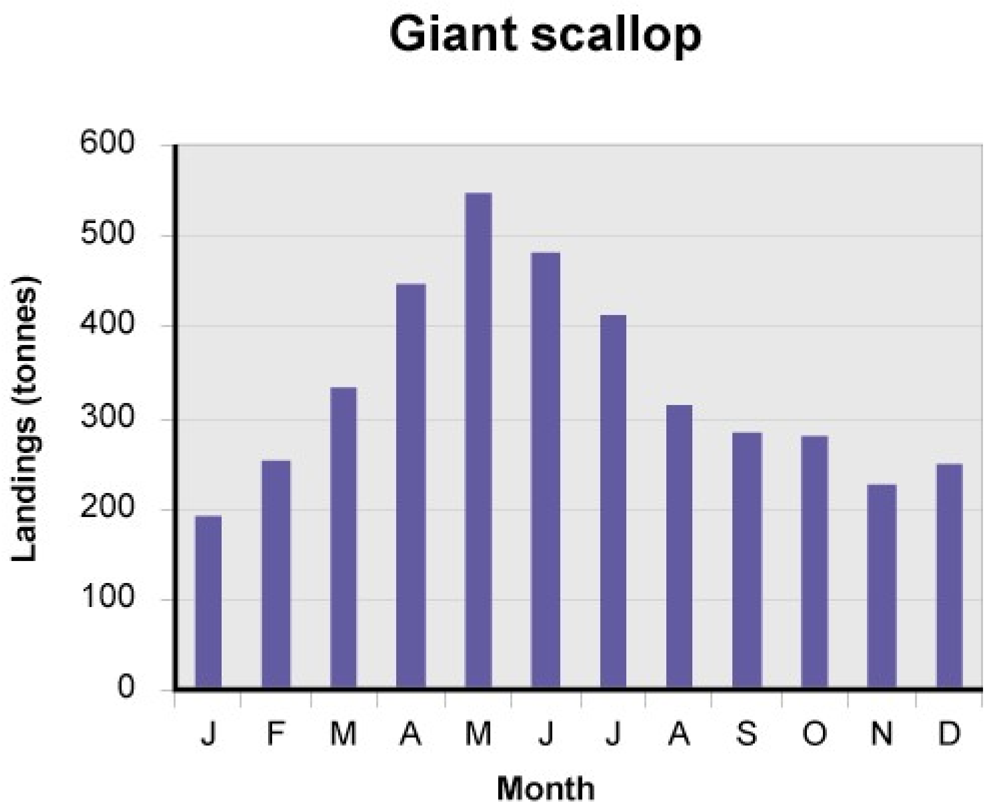

Fig.11: Distribution of queen scallop landings by UK vessels from extended SEA5 zone. Data based on ICES statistical rectangles and averaged over the three year period, 2000-2002.

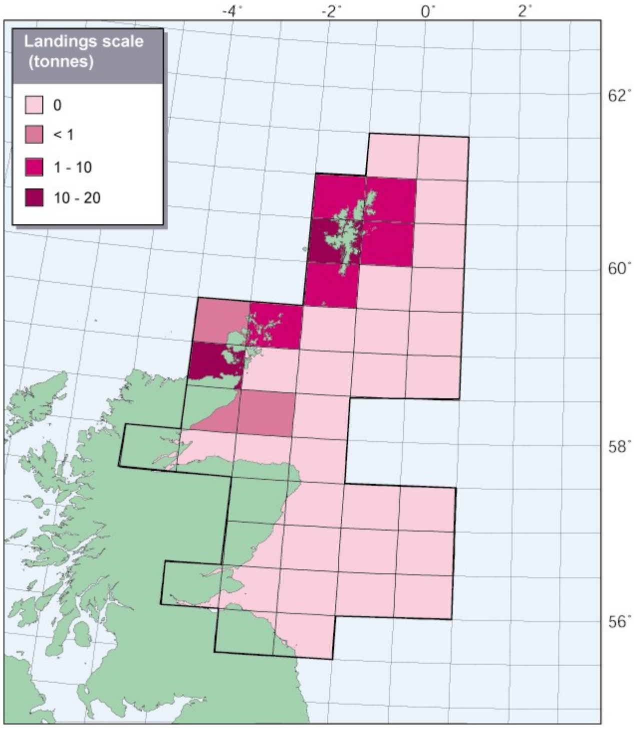

Fig. 12: Seasonal landings of queen scallop (tonnes) from extended SEA5 zone by UK vessels, averaged over the 10 year period, 1993-2002.

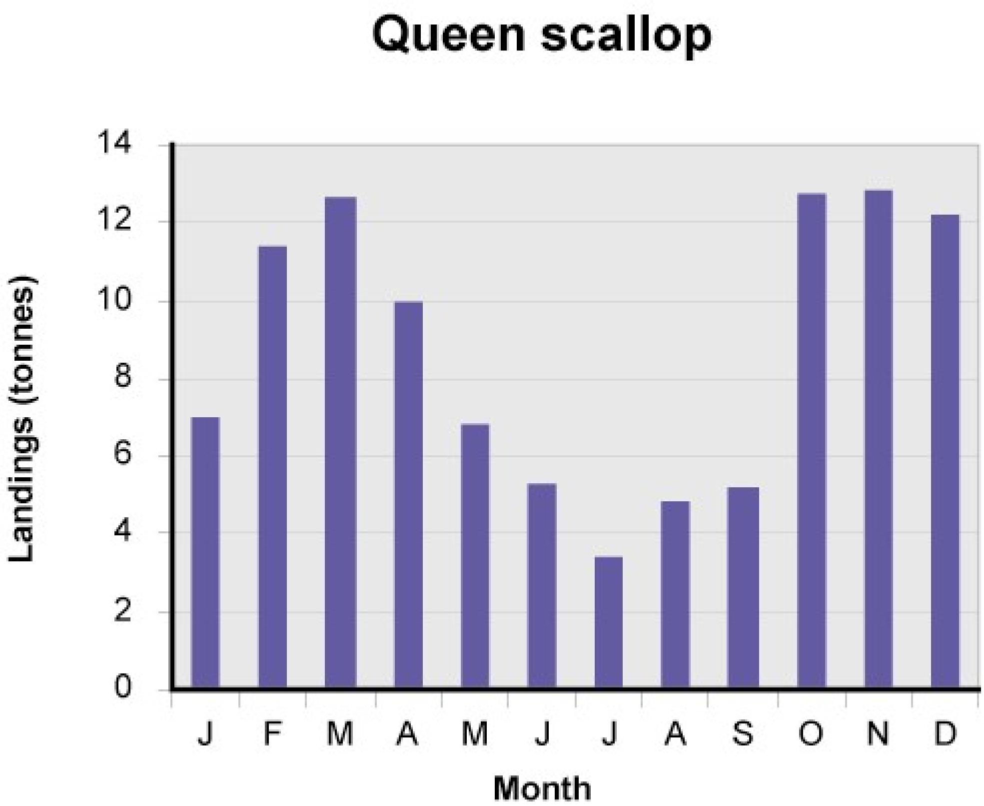

Fig. 13: Seasonal landings of cockle (tonnes) from extended SEA5 zone by hand gathering, averaged over the 10 year period, 1993-2002.

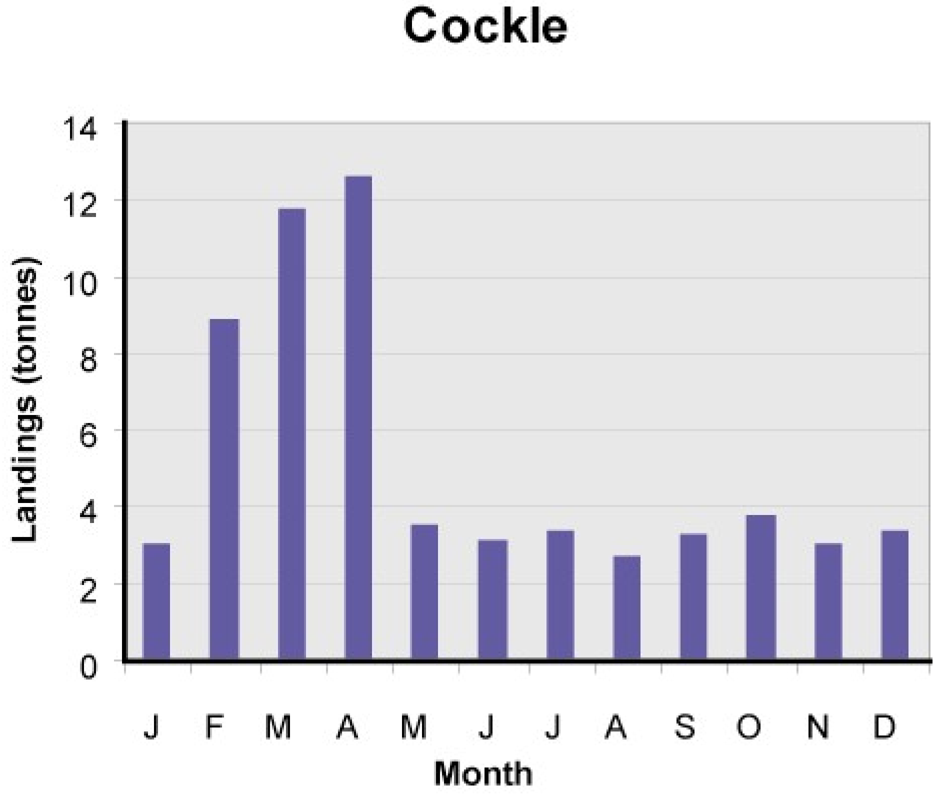

Fig. 14: Seasonal landings of mussel (tonnes) from extended SEA5 zone by UK vessels, averaged over the 10 year period, 1993-2002.

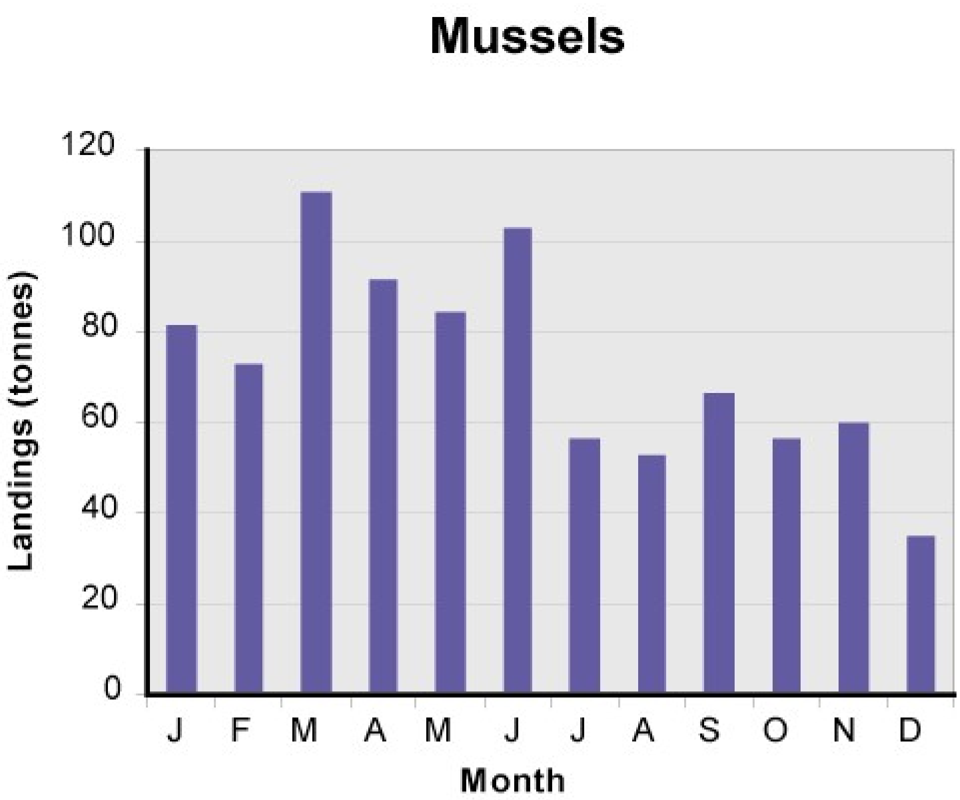

Fig.15: Distribution of common whelk landings by UK vessels from extended SEA5 zone. Data based on ICES statistical rectangles and averaged over the three year period, 2000-2002.

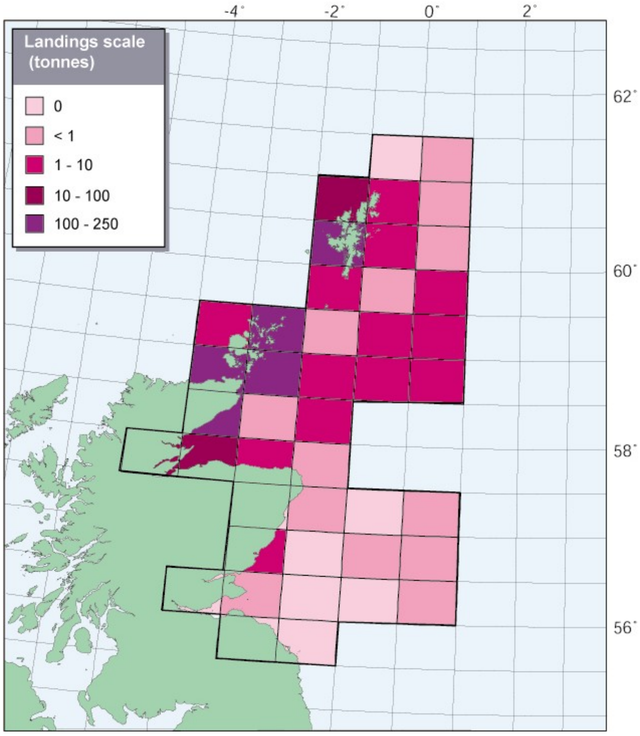

Fig. 16: Seasonal landings of common whelk (tonnes) from extended SEA5 zone UK vessels, averaged over the 10 year period, 1993-2002.

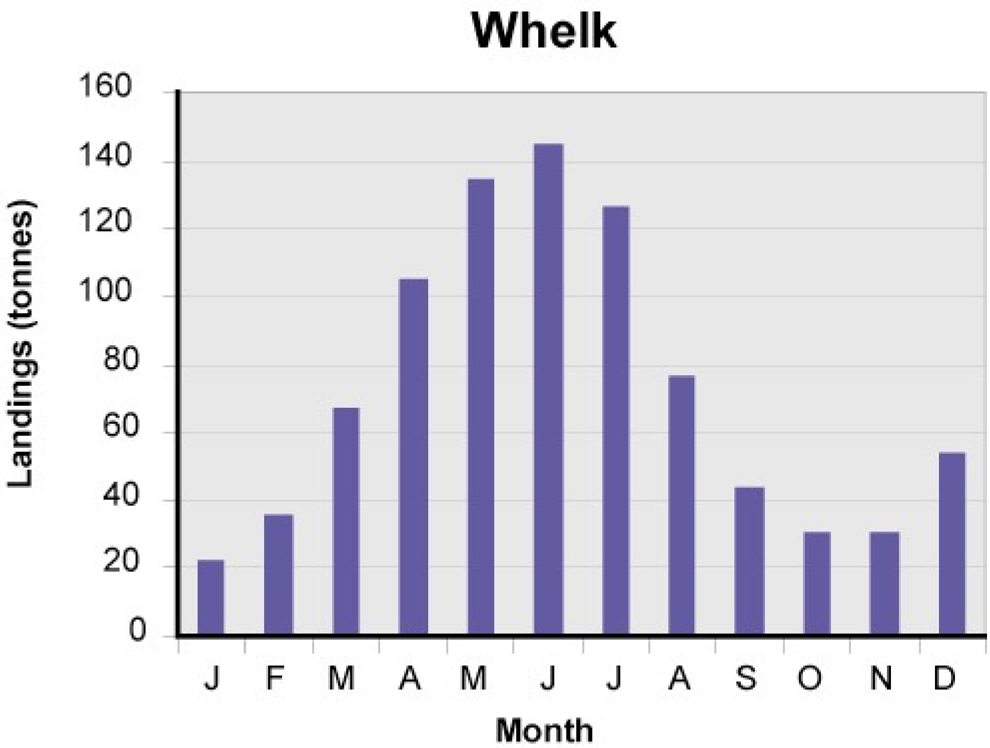

Fig. 17: Seasonal landings of periwinkle (tonnes) from extended SEA5 zone by hand gathering, averaged over the 10 year period, 1993-2002.