An Overview of Cephalopods Relevant to the SEA 5 Area

A review on behalf of the Department of Trade and Industry

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1. Introduction

This review is a component of the information base of the Strategic Environmental Assessment (SEA 5) conducted by the Department of Trade and Industry.
Some of the general background material presented here is taken from the reports on cephalopods in the SEA 2 and 3 and SEA 4 areas (Pierce *et al.*, 2002, Pierce *et al.*, 2003).

The SEA 5 area (Figure 1) covers the Scottish east coast from the Farn Deeps at 55 ° 30’ across the Firth of Forth, the Moray Firth and the eastern coastal areas of the Orkney and Shetland Archipelagos up to 61° 30’ North. Its East-West boundaries extend from 1° East including the Dogger Bank, Long Forties and Fladen fishing areas over to the most western point in the Moray Firth (4° W).

The International Council for the Exploration of the Sea (ICES) have, for fisheries management purposes, divided the northern Atlantic ocean into fishery areas, divisions and sub-divisions. The SEA 5 area includes parts of ICES fishery areas IV (Northern divisions, IVa and IVb, Figure 1). The ICES divisions and sub-divisions are further subdivided into statistical rectangles, measuring 30' of latitude x 1º of longitude, for the purpose of catch reporting.

Cephalopods are short-lived molluscs, characterised by rapid growth rates, and are important predators and prey in oceanic and neritic environments. They can range in size from 1.5 cm in pygmy squid (Sepiolidae) to 20 m in giant squid (Architheutidae). Cephalopods exhibit the highest degree of development in invertebrate nervous systems, expressed through complex behaviour patterns such as the ability to learn and the display of complex colour changes. In contrast to other molluscs, most cephalopods lack an external shell, are highly mobile as adults and occupy similar ecological niches to predatory fish.

They are active predators at all stages of their life-cycle and generally regarded as opportunistic, taking a wide variety of prey. Cannibalism has been frequently recorded in cephalopod species. Cephalopods also sustain a number of marine top predators such as fish, birds and marine mammals, especially whales (e.g. Clarke, 1996, Croxall & Prince, 1996, Smale, 1996, Santos *et al.*, 2001a). Many species are powerful swimmers and carry out vast feeding and spawning migrations, thus influencing prey and predator communities strongly on a seasonal and regional basis.

As cephalopods are important elements in food webs they interact with commercial fisheries of finfish. Evidence exists that fishing pressure has changed ecological conditions and shifts in community structures have occurred with cephalopod stocks slowly replacing predatory fish stocks (Caddy & Rodhouse, 1998). Their commercial significance to world fisheries is of relatively recent, but growing, importance (Boyle and Pierce, 1994).

Two out of the three major divisions of the class Cephalopoda, the Decapoda (squid and cuttlefish) and the Octopoda, are represented in the SEA5 area.

According to Stephen (1944) frequently occurring cephalopod species in the North Sea are: *Eledone cirrhosa*, *Sepiola atlantica*, *Sepiola pfefferi*, *Sepietta oweniana*, *Rossia macrosoma*, *Rossia glaucopis*, *Sepia officinalis*, *Loligo vulgaris*, *Loligo forbesi*, *Alloteuthis subulata*, *Illex coindetii*, *Todaropsis eblanae* and *Todarodes sagittatus.* Infrequently occurring species are: *Bathypolypus arcticus*, *Benthoctopus piscatorum*, *Sepietta neglecta*, *Sepia elegans*, *Onychoteuthis banksi*, *Architeuthis monachus*, *Architeuthis harveyi*, *Sthenoteuthis caroli* and *Brachioteuthis riisei.*

The main commercial species in Scottish waters is the long-finned squid *Loligo forbesi* (Boyle and Pierce, 1994; Pierce *et al.*, 1994a,b, 1998). Since 1995, annual UK landings of loliginid squid have ranged between 1600 and 3200 tonnes, making the UK the second most important fishery nation for loliginid squid within the ICES region after France.

A substantial proportion of Scottish squid landings arise from the Moray Firth, which falls within both ICES area IVa and the SEA 5 area. Although squid is mostly a by-catch in UK waters, over the last decade a small directed fishery for *L. forbesi* developed in the Moray Firth in the autumn, off Fraserburgh. Usually only a few boats are involved but occasionally the fishery reaches substantial size. In 2003, this fishery produced exceptionally high landings to the extent that squid was one of the most important species in the Fraserburgh and Peterhead fish markets in the autumn and up to 100 trawlers were involved in the fishery at its peak (Iain Young, pers. comm.).

Other species of commercial interest, present in area SEA5, are squid species *Todarodes sagittatus*, *Todaropsis eblanae*, *Alloeuthis subulata* and the octopus *Eledone cirrhosa* though in much smaller numbers. Both *Todarodes sagittatus* and *Todaropsis eblanae* were part of a substantial fishery off Shetland and Norway in the 1980s (Joy, 1989; Hastie *et al.*, 1994) but are currently only occasionally landed in boxes of *L. forbesi* (Anonymous, 1999). Towards the most northern edge of area SEA5, specimens of species *Gonatus fabricii* may also sporadically occur in fishing hauls. This species is of considerable ecological interest as the main prey of large predators such as sperm whales (Santos *et al.*, 1999, 2002) and is attracting interest as a potential commercial resource in Norway and Greenland.

Inputs of pollutants to the marine environment include discharges associated with oil-production operations and industrial emissions and river discharges in coastal areas (Sheahan *et al.*, 2001, Ridgway *et al.*, 2003). Trace elements such as heavy metals and radionuclides contained in these discharges can accumulate in coastal and deeper waters leading to an increase of metal and radioactive burdens in biota and thus increasing contaminant loads for human consumption (Kunisaki, 2000, Bustamante *et al.*, 2000, 2003, Betti *et al.*, 2004).

Demersal shellfish and crustaceans tend to contain particularly high levels of metals. The high concentration of some metals in shellfish is a natural phenomenon, not necessarily related to pollution, but higher concentrations might be expect in polluted waters. Heavy metal accumulation rates in cephalopod species appear to be rapid (e.g. Craig, 1996) and various studies on cephalopods report high levels of cadmium (e.g. Caurant & Amiard-Triquet, 1995, Bustamente *et al.*, 1998a, Koyama *et al.*, 2000) and mercury (e.g. Frodello *et al.*, 2000). Since cephalopods represent an essential link in marine trophic chains the concentration of heavy metals in their tissues will consequently also play an important role in the bioaccumulation of these pollutants in their predators (Koyama *et al.*, 2000).

Other considerations in relation to environmental impact include the possible disruption of cephalopod spawning activity by exploration and drilling.

This report focuses mainly on the species of fishery importance: the loliginid squid *Loligo forbesi* and the ommastrephid squid *Todarodes sagittatus* and *Todaropsis eblanae* together with the octopus *Eledone cirrhosa*. Brief accounts of other commonly occurring cephalopod species are also provided.

We review the following topics:

- Life history and distribution
- Ecology
- Fisheries and trends
- Sensitivity to metal contamination
- Further conservation considerations

2. Life history and distribution

2.1. Long-finned squid

The squid species of major commercial importance in European fisheries belong to the Loliginidae or long-finned squids. These are species of the Continental Shelf that live on or near the sea bottom, sometimes ascending into midwater and to the surface (Nesis, 1987).

In southern Europe, the main species caught is *Loligo vulgaris* but from the English Channel northwards catches are increasingly dominated by *Loligo forbesi*. Smaller loliginid squid of the genus *Alloteuthis* are also present in Scottish waters but are of no direct commercial value. Again there are two species, of which only *Alloteuthis subulata* is likely to occur in the SEA5 area.

Loligo forbesi

The veined squid *L. forbesi* (Steenstrup, 1856) is a neritic species occurring in coastal waters and continental shelf seas from 20° N (NW Africa) to 60° N (SW Norway) in the eastern Atlantic, including the North Sea and the Mediterranean Sea (Roper *et al.*

1984). It forms the basis of a significant by-catch fishery in UK waters (Pierce *et al.* 1994b) with annual landings as high as 3500 t (Collins *et al.* 1997).

Loligo forbesi is an annual species showing extended breeding seasons with, depending on the area, one or several pulses of recruitment. *Loligo forbesi* in Scottish waters spawns mainly from December to February although breeding animals are also recorded in May. Two main pulses of recruitment are found in April and November, with small numbers of recruits present throughout most of the year (Lum-Kong *et al.*, 1992; Boyle & Pierce, 1994, Pierce *et al.*, 1994b; Collins *et al.*, 1997, 1999). Comparing with earlier work of *Loligo forbesi* in the English Channel (Holme, 1974), which reports the existence of winter and summer breeding populations, it seems that the Scottish population is largely winter breeding.

Animals mature over a range of sizes with males generally growing bigger than females. The two recruitment periods identified for Scottish waters produce distinctive cohorts of two or three different size classes at maturity in female and male squid respectively (Collins *et al.*, 1997, 1999). Genetic evidence exists for separate offshore (Rockall bank) and shelf populations in Scottish waters (Shaw *et al.*, 1999).

Mature squid are recorded throughout Scottish waters in winter and eggs of *Loligo forbesi* have been recorded in trawls off Shetland (Lum-Kong *et al.*, 1992) and are regularly found on creel lines. Although spawning grounds have not yet been documented it has been indicated from the analysis of spatial patterns in fishery data that *Loligo forbesi* move from the West Coast of Scotland into the North Sea to spawn (Waluda and Pierce, 1998; Pierce *et al.*, 2001).

Although a short-lived species, fecundity in loliginid squids is surprisingly low, with female *Loligo forbesi* apparently producing only a few thousand eggs in their lifetime (Boyle *et al.*, 1995).

The main Scottish fishery for *Loligo forbesi* occurs in coastal waters and usually exhibits a marked seasonal peak around October and November, corresponding to the occurrence of pre-breeding squid (Howard, 1979; Howard *et al.*, 1987; Pierce *et al.*, 1994c). Analysis of fishery data collected between 1980 and 1990 indicated that *L. forbesi* was widely distributed on the continental shelf and also occurred on offshore banks – notably Rockall (Pierce *et al.*, 1994a,c).

Data from trawling surveys by R/V Scotia support a wide distribution and also highlight the patchy nature of its distribution. Research trawling surveys record squid in the SEA5 area in all seasons. However the spatial pattern of abundance varies with season with the majority of squid being caught in the Long Forties/North Dogger Bank grounds in winter, the outer Moray Firth in spring and in and around the Moray Firth and Firth of Forth in summer and autumn (Pierce *et al.*, 1998).

Recent analysis of long-term trends in abundance points to the possible influence of oceanographic conditions (as proxied by the NAO index) on squid abundance (Pierce & Boyle, 2003) and suggests that the relative importance of summer and winter breeding populations may show marked shifts on a decadal time-scale (Zuur & Pierce, 2004).

Alloteuthis subulata

Another loliginid squid frequently occurring in hauls alongside *L. forbesi* is the species *Alloteuthis subulata* (Lamarck, 1798). It is of no commercial value and therefore discarded from trawls and no data on abundance is recorded.
The genus *Alloteuthis* may however have an important ecological role in coastal food webs since it is the most commonly recorded cephalopod species (i.e. *Alloteuthis subulata*) in stomach contents of demersal fish in UK waters (Daly *et al.*, 2001) and plays an important role in the diet of demersal fish in Spanish waters (*Alloteuthis* sp., Velasco *et al.*, 2001).

The only recent study on the biology of this species in UK waters was by Nyegaard (2001), based on samples collected in the Irish Sea.

2.2. Short-finned squid

The two ommastrephid species *Todarodes sagittatus* and *Todaropsis eblanae* have been recorded regularly in the NE Atlantic and sporadically occur in trawls in area SEA 5 (and UK waters in general). Although routinely recorded in small numbers during discard trips (FRS Marine Laboratory, unpublished data), years of high abundance are probably infrequent.

The majority of ommastrephids are open ocean species during most of their life cycle. They often show seasonal spawning and feeding migrations on and off the continental shelf and diel vertical migrations from the seabed to the surface at night (Nesis, 1987).

Unlike loliginid squid, ommastrephids produce large numbers of small eggs, deposited on the bottom or in mid-water. Spawning areas of the species occurring in the SEA 5 area are not presently known.

Todarodes sagittatus

The European flying squid *Todarodes sagittatus* (Lamarck, 1798) is found in the Eastern Atlantic over an extended area from 40° W (Mid-Atlantic Ridge) to the European coast and from 13° S (Angola) up to the Arctic Ocean. It has been recorded from surface waters to depths of 4500 m (Collins *et al.*, 2001) although most specimens have generally been caught in waters less than 1000 m deep (Roper *et al.*, 1984).

Its feeding and spawning migrations are long, from a supposed spawning area in the mid-Atlantic to the coasts of northern Europe and back (Borges & Wallace, 1993). Breeding seems to be protracted with two peaks occurring, one in spring and one in autumn (Roper *et al.*, 1984). Evidence exists of two or more populations coexisting within the same area of distribution (Borges & Wallace, 1993).

In years of abundance *T. sagittatus* moves inshore during summer and autumn months, where it can be caught in large numbers (Wiborg and Gjøsæter, 1981; Sundet, 1985; Joy, 1989; Lordan *et al.*, 2001). Catches in northern coastal waters are made up mainly of female immature specimens which suggests that inshore migration here is mainly carried out by females and seems to be serving feeding purposes only (Wiborg *et al.*, 1982a,b; Sundet, 1985; Joy, 1989; Borges and Wallace, 1993; Boyle *et al.*, 1998).

Todarodes sagittatus is of no commercial interest to the Scottish fishery and is therefore usually discarded by fishing vessels (Joy, 1989). It was however taken as by-catch by demersal trawlers in the Shetlands when it appeared there in large numbers in the 1980's. At the same time Todarodes invaded coastal waters of Norway, the Faroe Islands and Southwest Iceland, which resulted in significant targeted fisheries in these areas (Sundet, 1985). Yearly invasions of Todarodes into Norwegian waters ceased and thus targeted fishery stopped in 1990. There were, however, catches of 352 t and 190 t reported from Norwegian waters in 1995 and 1997 respectively (presumed to be *T. sagittatus*) and small catches of 1 – 5 t per year were reported from Icelandic waters up to the year 2000 (Anon., 2002 and 2003).

Todaropsis eblanae

The lesser flying squid *Todaropsis eblanae* (Ball, 1841) is a demersal species found in the Mediterranean, throughout the Eastern Atlantic from 36°S (South Africa) to the Shetland Islands and in shelf waters of the South-Pacific (Gonzales *et al.*, 1994, Arkhipkin & Laptikhovsky, 2000). It is associated with muddy bottoms and has been recorded at depths ranging from 20 m to 700 m (Guerra, 1992). Males are recorded as being smaller on average than females (Hastie *et al.*, 1994).

In Scottish waters, *T. eblanae* is considered to take 1-2 years to reach maximum size. It shows a relatively short spawning season from late summer to early autumn although small numbers of mature squid are present throughout the year (Hastie *et al.*, 1994).

Todaropsis eblanae was regularly taken in trawl hauls off Aberdeen in the early 1990s. It is however generally listed as scarce in Scottish waters and most likely only occurs in higher numbers in years of high-salinity influx (Hastie *et al.*, 1994). No commercial landings of this species have been reported from the North Sea since 1995 (Anon., 2002)

2.3. Deep-water squid

Gonatus fabricii

The northern end of the SEA5 area overlaps the range of the Arctic squid *Gonatus fabricii* (see Bjørke, 1995). *Gonatus fabricii* is the most abundant oceanic squid of the Arctic and Sub-arctic waters of the North Atlantic (Nesis, 1987, Kristensen 1983). Juvenile squid (up to 50 mm mantle length) are caught in surface layers and specimens move to deeper waters as they grow larger (Bjørke, 1995). The few mature specimens caught were always collected from deeper waters ranging from 160 to

2700 m (Kristensen, 1984), with specimens larger than 200 mm mantle length always found deeper than 400 m (Bjørke & Gjøsæter, 1998).

Male squid mature at a smaller size (130 - 200 mm mantle length) than females (Arkhipkin & Bjørke, 1999, 2000). The life-span of *Gonatus fabricii* does probably not exceed 2 years in either sex (Arkhpkin & Bjørke, 2000).

Spawning takes place from December to April in the Norwegian Sea (Bjørke, 1995). Since very few mature specimens and no eggs have so far been found, Kristensen (1984) suggested that spawning probably takes place at depths greater than 200 m. Areas for spawning have not be identified but due to the wide distribution of catches of both larger and younger specimens, Bjørke & Gjøsæter (1998) considered areas for spawning and hatching also to be widely distributed. Findings from stomach content analysis in sperm whales (e.g. Santos *et al.*, 1999, 2002) and bottlenose whales (e.g. Lick & Piatkowski, 1998) showed larger *Gonatus fabricii* to play an important role in their diet. These findings supported suggestions by Wiborg (1979) that the distribution of these predators may coincide with spawning grounds for *Gonatus fabricii*.

Gonatus fabricii has never been the object of a directed fishery. However population estimations based on calculations from catches of juvenile *Gonatus* (2-3 million tonnes per year, Bjørke, 1995) and predation on adult *Gonatus* (e.g. 1.7 – 2.2 million tonnes by sperm whales, Santos *et al.*, 1999) raised interest in the species as a potential fishery resource for human consumption. So far however fishing experiments with pelagic trawls have been unsuccessful, due to the lack of knowledge on the location of adults and spawning aggregations.

2.4. Other cephalopods

Octopods are usually divided into two sub-orders (Cirrata and Incirrata), characterised by the presence or absence of tactile cirri on the sides of the suckers. Cirrate octopods are only found in deep water and are of no commercial value.

The only octopus of commercial value in the SEA 5 area is the incirrate “curled octopus” *Eledone cirrhosa* (Lamarck, 1798).

Eledone cirrhosa (Lamarck, 1798) is a benthic octopod with a wide distribution over shelf regions from the Mediterranean in the south to the Norwegian Lofoten Islands in the north. Although Collins *et al.* (2001) reports records of *E. cirrhosa* from depths of up to 490 m it is generally found between 50 and 300 metres on a wide variety of sea-bed types from soft mud to rocky bottom (Boyle, 1983). Its life spans between 18 and 24 months with individuals dying shortly after spawning. Sexual maturity is attained in late summer (from July to September) with spawning following shortly afterwards (Boyle, 1983).

This species is often taken in Scottish waters as by-catch in demersal fishing mainly for cod and haddock, but rarely landed due to the absence of a domestic market in Scotland. Stephen (1944) noted that catches of *Eledone* showed wide fluctuations, with large numbers of octopus stranded on the shore in some years.

The bobtail squid *Sepiola atlantica* is one of at least six sepiolid species present in the North Sea. A bottom living inshore species, its very small body size means it tends to be overlooked in catches and it has no commercial value. However, it may be very abundant - Stephen (1944) cites a record of 256 specimens being taken in a single trawl haul.

Finally, it is worth mentioning that the giant squid *Architeuthis* spp. is occasionally recorded in the North Sea, with specimens being stranded on the Aberdeenshire coast in the 1984 and in 1998, and one taken in a trawl off Shetland in 1987 (Collins, 1998).

3. Ecology: trophic interactions

Cephalopods are active predators at all stages of their life-cycle and generally regarded as opportunistic, taking a wide variety of prey (Nixon, 1987, Boyle 1990, Hanlon & Messenger, 1996). It is also known that many marine predators take large quantities of squid every year (Clarke, 1987). Cephalopods are heavily preyed upon, by fish (e.g Smale, 1996, Daly *et al.*, 2001), birds (e.g. Furness, 1994; Croxall & Prince, 1996) and most importantly marine mammals (e.g. Clarke, 1996, Santos *et al.*, 2001a.), especially whales.

There are few estimates of the amounts of cephalopods eaten by predators in the North-east Atlantic. Predation data combined with data on fishing effort led to estimates of a worldwide standing stock biomass of 193 - 375 Mt (based on sub-adult and adult specimens, Rodhouse & Nigmatullin, 1996). Voss (1973) estimated that marine mammals, prior to industrial whaling between the 1950s and 1990s, removed 60-70 million tonnes of cephalopods annually from the world's oceans.

For example, annual predation for cephalopods by overwintering sperm whales in Norwegian and Icelandic waters alone was estimated to be in the range of 550,000 to 996,000 tonnes per year (Santos, 2001a). These numbers suggest that important cephalopod populations must exist to support the sperm whales and other teuthophagous cetacean species, e.g., Northern bottlenose whales *Hyperoodon ampullatus* (Santos *et al.*, 1999, 2001b,d, 2002) in the area.

Although primarily a fish eater, the most common cetacean species in the SEA 5 area, the harbour or common porpoise (*Phocoena phocoena*), has often been found with remains of sepiolids and the small loliginid squid *Alloteuthis* in its stomach (Santos and Pierce, 2003, Santos *et al.*, 2004).

In fact most cetacean species found in NE Atlantic waters show remains of at least some cephalopods (e.g. *Loligo* sp.) in their stomach contents, e.g. bottlenose dolphin (*Tursiops truncatus*), striped dolphin (*Stenella coeruleoalba*), white beaked dolphin (*Lagenorhynchus albirostris*) and pilot whale (*Globicephala melas*) and Risso's dolphin (*Grampus griseus*) (Boyle and Pierce, 1994; González *et al.*, 1994; Santos *et al.*, 1994, 1995, 2001c).

Cephalopods play also an important part in the diet of seals. Both seal species common to UK waters, the grey seal (*Halichoerus grypus*) and harbour seal (*Phoca*

vitulina) seem to prefer octopus (i.e. *Eledone cirrhosa*) to any other cephalopod prey. Studies carried out in Scottish waters showed that octopus formed an important part of the summer diet of harbour seals in the Moray Firth (Tollit and Thompson, 1996) as well as appearing in diets of harbour seals in Orkney (Pierce *et al.*, 1990) and Shetland (Brown *et al.*, 2001).
However, sepiolids are also frequently recorded, with *Loligo forbesi* relatively rare in the diet (e.g. Brown and Pierce, 1997, 1998; Brown *et al.*, 2001; Pierce and Santos, 1996, 2003).

Stomach content analysis of seabirds in the northeast Atlantic has shown that birds primarily feed on ommastrephid squid rather than loliginid species (Boyle and Pierce, 1994; Furness, 1994). Numbers of squid taken by seabirds in the northeast Atlantic were low in comparison with seabird populations from the Southern hemisphere. Since numbers were also low compared to populations from the northwest Atlantic for the same species of seabird, these differences were most likely due to a variation in prey availability (Furness, 1994).

Cephalopods have been found in the diet of a wide variety of fish species, although generally as a small proportion (ICES, 1988; Hislop *et al.*, 1983, 1991; Daan, 1989; Hislop, 1997; Daly *et al.*, 2001; Velasco *et al.*, 2001). Smale (1996) found that the importance of cephalopods in the diet of fish increased with increasing size of the predator and was higher in shelf waters rather than coastal waters. Although cephalopods are routinely eaten by many fish, they are major component of the diet in relatively few species such as monkfish (*Lophius piscatorius*) and some shark species. Few studies actually identified cephalopod remains. Hislop *et al.* (1991), as well as Pedersen (1999), however noted that loliginid *Alloteuthis* spp. comprised the main cephalopod prey in whiting in the North Sea.

Cephalopods themselves are active predators feeding on a wide variety of prey. The diet of *Loligo forbesi* has been studied in Scottish waters by several authors (Boyle and Pierce, 1994; Pierce *et al.*, 1994c; Collins and Pierce, 1996). Fish was found to be the main prey category with crustacean, cephalopod and polychaete species present in the diet to varying degrees. In all studies, *L. forbesi* was found to consume a wide variety of fish and crustacean species. In Scottish waters *Loligo forbesi* appeared to primarily feed on gadid and ammodytid species (Pierce *et al.*, 1994c, Collins & Pierce, 1996, Pierce & Santos, 1996, Stowasser, 1997). Within the family Gadidae, *Trisopterus* spp., whiting (*Merlangius merlangus*), and haddock (*Melanogrammus aeglefinus*) were the species most readily identified.

Apart from regional differences, diets showed seasonal variation (e.g. Pierce *et al.*, 1994a, Collins *et al.*, 1994) and were found to be dependent on squid size (Collins & Pierce, 1996). Ontogenetic shifts occurred from a crustacean-dominated diet in juvenile squid to a predominance of fish in the diet of adult squid.

Dietary studies on *Todarodes sagittatus* have been carried out in Norwegian waters (e.g. Wiborg and Gjøsæter, 1981, Wiborg *et al.*, 1982a, Breiby and Jobling, 1985), Iceland (Jonsson, 1998), Scotland (Joy, 1990) and Ireland (Lordan *et al.*, 2001). Fish was the most important and diverse prey type found in all studies, closely followed by Euphausiid and Decapod shrimps with other Crustacean species present in minor proportions. Cannibalism and feeding on other cephalopod species was found for most studies. Between-area variation in diet has led to the suggestion that *T. sagittatus* is an opportunistic predator (Lordan *et al.*, 2001).

Todaropsis eblanae is also considered a generalist predator, feeding on the prey that are most abundant. As with other cephalopod species the dominant prey is dependent on prey availability, squid size and season. Nevertheless, the diet is primarily piscivorous with crustaceans and cephalopod prey being present to a lesser extent.

Thus the most important prey are blue whiting (*Micromesistius poutassou*) off Northwest Spain (Rasero *et al.*, 1996) and pearlsides (*Maurolicus muelleri*), silvery pout (*Gadiculus argenteus*), blue whiting and argentine (*Argentina* sp.) together with the euphausid *Meganyctiphanes norvegica* in Irish waters (Lordan *et al.*, 1998). Ontogenetic variation in diet was recorded from Irish waters (Lordan *et al.*, 1998), with small squid taking mainly crustaceans (euphausids) while bigger squid predominantly ate fish and cephalopods.

So far no feeding study exists on the diet of *Gonatus fabricii*.

The octopus, *Eledone cirrhosa* is benthic and feeds mainly on crustaceans and molluscs (Montiero, Porteiro and Gonçalves, unpublished data) with crustaceans predominating (Boyle, 1983). They are known to take large Crustacea including lobster (*Homarus gammarus*), edible crab (*Cancer pagurus*) and Norway lobster (*Nephrops norvegicus*) from creels set for these species (Boyle, 1983).

4. Fisheries and trends in abundance

Data on cephalopod landings from the ICES area are compiled by the ICES Working Group on Cephalopod Fisheries and Life History (WGCEPH) (e.g. Anon., 2003, Table 1). However, these compilations are based on ICES fisheries sub-divisions, with the SEA 5 area covering only the western part of major fisheries subdivisions IVa and IVb in the North Sea. Thus we have reconstructed trends for the SEA 5 area by reference to the source fishery databases.

General patterns in cephalopod landings can be inferred from data presented in the WGCEPH report (Anon., 2003). No landings of short-finned squid or cuttlefish are reported by Scotland and landings of octopus (i.e. *Eledone cirrhosa*) decreased from a maximum of 18 t per year in 1999 to only 1 tonne landed in 2002 in Scottish waters (Table 1). Loliginid squid thus represent the only significant landings of cephalopods in Scotland in recent years.

Fishery data provide the best available information on cephalopod distribution and abundance. Since most cephalopods are landed in the UK as a by-catch of trawling, landings per unit effort (LPUE) can be used as an index of species abundance (see Pierce *et al.*, 1994d) and such data are available on a monthly, by ICES rectangle, basis.

4.1. Squid

In general, squid catches in the UK, as in most northern European countries, are a by-catch of demersal trawl and seine net fisheries (Boyle and Pierce, 1994). In the SEA5 area however exists a small directed fishery close inshore in the Moray Firth between Nairn and Macduff. This directed fishery is strongly seasonal (September to November) and used to be undertaken by around 20 small trawlers of between 10 and 17 metres in length (Anon., 2000). Within the last two years however numbers of trawlers taking part in this fishery increased dramatically up to 100 vessels contributing at any given time (Ian Young, pers. comm. 2004). Squid catches from the Moray Firth may contribute over 90% of the total cephalopod landings from Area IVa (Northern North Sea) (Pierce *et al.*, 1994d).

Scottish landings of loliginid squid ranged between 203 and 1355 tonnes in the years 1994 -2002 with corresponding values of between £ 0.34M and £ 2.19M (Scottish Sea Fisheries Statistics, 2002). After a peak in catches in 1998, landings decreased but seemed to follow an upward trend again since 2002 (Table 2, Figure 3). Historical fishery data from the Scottish fleet indicates that loliginid squid catches appear to fluctuate cyclically with a periodicity of between 12-18 years. As the total area of fishing effort in Scottish waters exceeds the area from where squid are caught and effort in general is not targeted at squid, these fluctuations seem to represent real fluctuations in squid abundance (Pierce *et al.*, 1994d).

Landings from the SEA 5 area represent a very significant part of the total UK landings for loliginid squid. Approximately 480 tonnes of loliginid squid was landed from catches in the SEA 5 area in 2002, around 21 % of the UK total for this category for the same year (Figure 4). The proportion of landed catches arising from the SEA 5 area in previous years was very similar in 2000 (20 %) and slightly lower in 2001 (13 %). Landings of French boats fishing in area SEA5 are probably negligible.

Month-to-month trends in loliginid squid landings from the SEA5 area follow a similar trend to Scottish totals in that peak landings occur in the winter (Figure 5). The proportion of landings arising from catches in SEA 5 shows a consistent annual cycle, with 70 % to 90 % of Scottish squid landings from August to October coming from this area. Since these high catches occur at the same time of the targeted fishery in the Moray Firth it is likely that in these months the squid landings largely derive from this area.

The spatial distribution of landed catches of loliginid squid is illustrated in Figures 6 to 10.

4.2. Octopus

Due to a combination of low catches by individual boats and poor market prices in northern Europe the octopus *Eledone cirrhosa* in usually not landed in Scottish ports (Daly *et al.*, 2001). In the UK as a whole, landings of octopus reached 176 tonnes in 2002 according to ICES data (Anon., 2003), with only two tonnes landed in Scotland. The UK fishery databases contain no information on octopus landings for the whole of the UK in 2002. This discrepancy is far greater than seen for other cephalopod categories (i.e. squid and cuttlefish) and may be due to octopus landings being included into the category "other shellfish" (161 tonnes). Also landings by smaller boats and landings into minor harbours might not be entering these databases.

In fact, only very few catches of octopus were recorded in the SEA 5 area during 2000 - 2002. Since the amounts involved were extremely small (few kg's), these results do no more than confirm the presence of octopus in the SEA 5 area.

5. Sensitivity to environmental contamination

5.1. Heavy metal contamination

A wide variety of wastes are produced during oil and gas production. Large quantities of drill cuttings, including drilling mud, specialty chemicals (i.e. drilling fluids) and fragments of reservoir rock are being deposited on the sea floor (Breuer *et al.*, 2004). Discharges of chemicals by the oil industry amounted to 180,000 t into the UK sector of the North Sea in 1999 (Sheahan *et al.*, 2001) and at present it is estimated that 12 million t of cuttings are on the bottom of the Northern and Central North Sea (OLF, 2000).

Contamination risks from drill cuttings are based on higher concentrations of certain trace metals (Arsenic, barium, cadmium, chromium, copper, iron, mercury, nickel, lead and zinc) and hydrocarbons than those found in background sediments (Neff *et al.*, 1987, see Table 3).
Most of the metals released with drill cuttings, are primarily present as trace impurities in barite (used as a weighting agent in drilling fluids), bentonite (the major ingredient in water based muds), and the formations of sedimentary rocks being penetrated by the drill. As seen in Table 3, the average concentrations of some of the metals in marine sediments exceed their concentrations in drilling fluids.

Although a broad spectrum of trace metals has been found in sediment samples taken from the vicinity of well sites, barium is the only metal found consistently at elevated concentrations following drilling - probably due to the high concentrations present in drilling fluids (Menzie, 1983; Daan & Mulder, 1996).

Olsgard & Gray (1995) however noted that in cases where water-based muds replaced oil-based drill-cuttings, a clear reduction in environmental contamination and biological impact could be seen. Current legislation in the North Sea prevents discharge of cuttings containing more than 1 % oil and in recent years oil-based muds have been largely replaced by less harmful alternatives, reducing the significance of drill cuttings as a source of contamination (Sheahan *et al.*, 2001)

A survey on oil pollution in coastal areas of the UK also named accidental spills from off-shore and land-based oil- and gas installations and other industrial sites as sources of contamination. Bunkering operations in ports and fishing vessel casualties and, to a minor extent, tanker source spillages were primary reported circumstances leading to pollution incidents in coastal waters (ACOPS, 1999).

In the southern North Sea, the strong tidal currents disperse the drill cuttings. In the deeper waters of the Northern North Sea however the tidal currents are much weaker and the drill cuttings accumulate around platforms to form so-called cutting piles. A study carried out at the “North West Hutton” platform (Northern North Sea) found that metals were leaching from cutting piles and were present in high concentrations in the water column directly above the pile (Edwards, 1998).

As trace elements, some of the metals released from cutting piles (e.g. copper, selenium, zinc) are biologically essential for the metabolism of organisms, but toxic in high doses. Other metals such as cadmium and mercury play no biological role. Cadmium for example derives its toxicological effect from the fact that it closely resembles zinc in its chemical properties and therefore is readily taken up by the body. The main danger of heavy metals to an organism lies in their tendency to being stored in the tissue faster than broken down or excreted, i.e. they bioaccumulate to harmful levels in the tissue.

Previous studies have examined the adverse effects contaminants contained in cutting piles can have on the benthic communities surrounding oil drilling platforms (e.g. Gray *et al.*, 1990, Daan & Mulder, 1996).

Initial effects of pollution included severe reductions in organisms that are key components of the benthic communities and also food for bottom-living fish, and are thus ecologically important (Olsgard & Gray, 1995). With increasing distance from the pile the concentrations of contaminants decreased. Gray *et al*. (1990) and Olsgard & Gray (1995) however found effects of contaminants on community structure up to 5 and 6 km distance from the platform respectively.

Due to increasing decommissioning of platforms in the near future (Bellamy & Wilkinson, 2001) the disturbance of sediments surrounding these platforms will result in an increased exchange of porewater and solids with the seabed surface, exposing organisms to elevated doses of potentially harmful substances (Breuer *et al.*, 2004).

5. 2. Radionuclide contamination

Apart from heavy metals, radionuclides (anthropogenic and naturally occurring) discharged by the nuclear industry and offshore oil- and gas installations, may also have a contaminating effect on marine biota.

The main contribution to anthropogenic marine radioactivity is still from global fallout from nuclear testing performed in the atmosphere. Due to global atmospheric transports and precipitation patterns the fallout is maximal at mid-latitudes between 30º and 60º and minimal at the equator and poles. Less nuclear tests on the Southern hemisphere and the limited stratospheric exchange between hemispheres cause 76 % of fallout to occur in the Northern Hemisphere (Aarkrog, 2003).

In areas like the Irish and North Seas the concentrations of anthropogenic radionuclides in the marine environment have also been significantly influenced by waterborne discharges from European nuclear reprocessing plants, notably Sellafield in the UK and Cap de la Hague in France (Livingston & Povinec, 2000). Anthropogenic radionuclides with possible radiological impact are Strontium- 90 (^{90}Sr), Caesium – 137 (^{137}Cs), Plutonium – 238, 239, 240 (^{238}Pu, ^{239}Pu, ^{240}Pu), Iodine

– 129 (^{129}I), Technetium – 99 (^{99}Tc) and Americium - 241 (^{241}Am). Most of these radionuclides show low solubility in seawater and high particle reactivity. This means in coastal regions they are rapidly removed from the water column and absorbed in sediments (Livingston & Povinec, 2000). For example most of the plutonium discharged by Sellafield remains in a relatively narrow coastal zone incorporated into sediments. However initial discharges from Sellafield in the late 70’s were so large that suspended particles of plutonium could be measured in seawater at distances of 100s of kilometres in the North Sea (Kershaw *et al.*, 1995). A study carried out by the Ministry of Agriculture and Food in 1993 (MAFF) considered the plutonium input from the Dounreay Fast Breeder in Scotland to be negligible.
The annual report of the United Kingdom Atomic Energy Authority (UKAEA, 2001) found the input of all anthropogenic radionuclides from the Dounreay Fast Breeder to be well below the limits recommended by the ICRP (International Commission on Radiological Protection) and UK government.

Although recent years have seen the improvement of waste treatments, thus decreasing discharges of the plutonium-chain based waste products, Sellafield is still a major source to the output of potentially harmful radionuclides such as iodine and technetium. These are highly soluble in seawater, have very long half-life times, are transported over long distances from the source and easily accumulate in seafood (STOA, 2001, Aarkrog, 2003).

MARINA II, a recent study carried out for the European commission, considered discharges of naturally occurring radioactive materials (NORM) by the fertiliser industry (mainly Radon – 226 (^{226}Ra), Lead – 210 (^{210}Pb) and Polonium - 210 (^{210}Po) and discharges from oil- and gas production (mainly ^{226}Ra, ^{228}Ra and ^{210}Pb) on the continental shelf in the North Sea and evaluated consequences to the marine environment (Betti *et al.*, 2004). The study concluded that since the European production of phosphoric acid has declined within the last 20 years due to increased imports and improvement of effluent treatments, the main contributor of non-nuclear α-emitters into the marine environment derives from produced water in offshore oil production (95 % in 1999). Roberts & Jones (1993) found that gamma radiation emitting from radionuclides contained in cutting piles was roughly twice that of the surrounding seabed. Breuer *et al.* (2004) however concluded that the ingestion of significant quantities of seafood exposed to radioactive contaminants from drill cuttings is not likely to occur.

Anthropogenic ^{137}Cs and normally occurring ^{210}Po are the most representative radionuclides of each of the two classes of marine radioactivity on a global scale and thus the subject of many contamination studies (e.g. Dahlgaard, 1996, Watson *et al.*, 1999, Heldal *et al.*, 2003). Of naturally occurring radionuclides in the sea ^{210}Po is the most important source of radiation for human consumption (Dahlgaard, 1996). It is found in relatively high concentrations in seafood and is about two orders of magnitude higher in collective doses than anthropogenic radionuclides (e.g. Cherry *et al.*, 1994, Heyraud *et al.*, 1994, Betti *et al.*, 2004).

Livingston & Povinec (2000) found that, comparing the average annual individual doses for ^{137}Cs and ^{210}Po in marine foods, the radiological impact of anthropogenic compared to normally occurring radionuclides was negligible.

5.3. Sensitivity of cephalopods to heavy metals

Cephalopods represent an important link in marine food webs as they are eaten by many marine top predators such as mammals, birds and fish (e.g. Clarke, 1996, Croxall & Prince, 1996, Smale, 1996, Santos *et al.*, 2001a.). Studies on trace metal contents in cephalopod tissues indicated bioaccumulation especially in the digestive gland (hepatopancreas) (Martin & Flegal, 1975, Schipp & Hevert, 1978, Miramand & Bentley, 1992, Caurant & Amiard-Triquet, 1995, Bustamante *et al.*, 1998a,b, 2002). The high availability of trace metals in cephalopods indicates their importance as vectors in the transfer of contaminants up the food chain.

Like many other molluscs, cephalopods naturally accumulate high levels of a number of trace metals including cadmium, copper and zinc (Martin & Flegal, 1975, Finger & Smith, 1987). Very high levels of copper were found in the digestive gland of several cephalopod species (*Octopus vulgaris, Eledone moschata* and *Sepia officinalis*). Although copper is essential to marine molluscs, these studies revealed digestive gland copper levels one hundred times higher than the mean values found for vertebrate liver and 105 times that of seawater (Rocca, 1969).

Loligo opalescens from Monterey Bay, California showed copper levels three orders of magnitude higher than concentrations found in other molluscs (Martin & Flegal, 1975). Bustamente *et al.* (1998b) found relatively low levels of copper but highly elevated levels of cadmium in the digestive gland of two octopod species in waters off the Kerguelen islands. Since in molluscs in general, copper and cadmium bind on the same metalloprotein in the digestive gland, some competition between the two metals may occur.

Cadmium, mercury and zinc have been shown to accumulate largely in the digestive gland of cephalopod species. High concentrations of cadmium have been found in the digestive glands of *Todarodes pacificus, Illex coindetii*, *Loligo opalescens*, *Loligo forbesi*, *Ommastrephes bartrami*, *Symplectotheutis oualaniensis*, *Octopus salutii*, *Graneledone* sp., *Benthoctopus thielei* (Tanaka *et al.*, 1983, Bustamante et al, 1998b, Storelli & Marcotrigiano, 1999, Craig & Overnell, 2003). Even in studies from areas like the Faroer and Kerguelen islands, which are relatively untouched by anthropogenic pollution, high cadmium concentrations were found in both cephalopods and their predators, whales (Caurant & Amiard-Triquet, 1995, Bustamante *et al.*, 1998a,b).

A feeding study on the bioaccumulation of cadmium in digestive gland and whole body tissue of *Sepioteuthis lessoniana* concluded that cadmium was accumulated from food rather than from surrounding seawater and that digestive gland was the main retention organ in the body (Koyama *et al.*, 2000).

The potential for bioaccumulation and biomagnification of metals in the food chain is illustrated by results from a survey conducted by the Marine Laboratory Aberdeen (FRS, 1998). The mean concentrations of trace metals in squid (presumably *Loligo forbesi*), a fish (whiting) and various marine mammals are presented in Table 4. The Food Standards Committee's maximum recommended limits are also given for comparisons. In squid, levels of cadmium were thirty times those in whiting and exceeded recommended safe limits for food. The presence of biomagnification could clearly be seen from highly elevated levels in cadmium in the marine mammals and the teuthophagous species compared to the piscivorous species.

5.4. Sensitivity of cephalopods to radionuclides

As for heavy metals the danger of radionuclides lies in their accumulation in living tissues and the consequent transport and further concentration to toxic levels along the food chain.

Studies on anthropogenic radionuclides in UK waters found that concentrations declined over the last decade and reflected decreasing emissions from the Sellafield plant in the same period (STOA, 2001 and table 5). Watson *et al.* (1999) found activity concentration of both plutonium and caesium in seals and porpoises to decrease with increasing distance from the source (Sellafield) and found elevated concentrations in animals of higher trophic levels and higher weights within the same species.

Concentrations of plutonium and americium were found to be high and mainly unchanged over the course of 10 years in shellfish from the Irish Sea. In contrast concentrations in fish were hardly detectable and low in crustaceans. Levels furthermore declined over the course of ten years for both taxa in concordance with decreasing emissions from the Sellafield reprocessing plant (Ryan *et al.*, 1999).

A food web study from the Norwegian and Barents Sea found radiocaesium concentrations to be low for this area (Heldal *et al.*, 2003). However concentrations were found to multiply from lowest levels in krill and squid *Gonatus fabricii* by a factor of 10 to highest values found in harbour porpoise (*Phocoena phocoena*).

Studies on naturally occurring radionuclides in marine organisms found polonium concentrations to be dependent of the diet of the organism (Cherry *et al.*, 1989, Carvalho & Fowler, 1993). High concentrations were found in benthic molluscs and marine mammals through bioaccumulation from lower trophic levels. Both fish and squid (*Loligo vulgaris reynaudii*) showed lower levels than either shellfish or marine mammals (Cherry *et al.*, 1994, Heyraud *et al.*, 1994, Dahlgaard, 1996, Betti *et al.*, 2004). Contamination levels in molluscs seemed to be related to reproductive cycles in *Mytilus galloprovincialis* (Charmasson et al., 1999) and ontogenetic changes in feeding in the case of *Loligo vulgaris reynaudii* (Heyraud *et al*., 1994).

5.5. Conclusions on contamination effects

No adverse affects of high cadmium concentrations in cephalopod tissues to the organism itself were found and it was suggested that cephalopod species, as seen in other marine invertebrates, use a detoxification strategy through metal-binding proteins (Bustamente *et al.*, 2002). Since there seems to be no damaging effect on the organism, the main ecological implication of heavy metal bioaccumulation in cephalopod species therefore is, that marine species feeding on cephalopods will show higher heavy metal loads in their tissues than species feeding on other invertebrates or fish. The human consumption of cephalopods in especially southern European countries and Asia will also be affected by these high concentrations of heavy metals. As with heavy metals the effects of radioactive contamination will be dependent on proximity to the source and trophic level of the organism investigated.

5.6. Further conservation considerations

The only serious impacts involving cephalopod species in the SEA5 area would be the disturbance of spawning grounds due to displacement of bottom sediments. Loliginid squid aggregate to spawn and although no actual spawning grounds have been positively identified in the SEA5 area, squid in spawning conditions are caught every year in the area, especially during January to March (Pierce et al., 1994a, Boyle et al., 1995).

Loligo forbesi is an annual species so that failure to reproduce and recruit would endanger the survival of the population. Since spawning most likely occurs over an extended area the population is less dependent on any single spawning site and localised disturbance would not affect breeding success of the whole population. However, the concentration of a high proportion of Scottish squid catches in the SEA5 area could reflect a high concentration of spawning activity.

At the northern end of area SEA5 and in coastal areas like the Moray Firth it is possible that drilling activities and extensive fisheries could impact on spawning grounds of *L. forbesi*. High turbidity is known to disrupt spawning behaviour in *Loligo vulgaris reynaudii* in South African waters while low oxygen levels can limit distribution (Augustyn, 1991). However cephalopod diversity is unlikely to be significantly affected by such disturbance since drilling operations are very localised.

6. Conclusions

- Cephalopod species of commercial importance in the SEA 5 area are *Loligo forbesi*, the ommastrephid squids *Todarodes sagittatus* and *Todaropsis eblanae* and the octopus *Eledone cirrhosa*. No commercial catches of *T. sagittatus, T. eblanae* and *E. cirrhosa* are currently reported from this area. Many other cephalopod species are present.

- Loligo is mainly fished as by-catch apart from a (usually) small targeted fishery in the Moray Firth from August to October every year. Both ommastrephids and Eledone are generally discarded.

- High accumulation rates for heavy metals are found in cephalopods and their predators. The release of oil drilling fluids into the environment could therefore lead to increased metal concentrations along the food chain.

- The concentration of anthropogenic and naturally occurring radionuclides is relatively low in squid. The accumulating effect of radionuclides along the food chain however can have damaging effects on higher trophic levels. Toxicity for both anthropogenic and naturally occurring radionuclides is highest the closest to the source. Thus a more toxic effect of radionuclides could probably be found for more benthic cephalopod species (i.e. octopods, sepiolids) or eggs and juveniles in spawning areas should they be identical with areas of drilling and reprocessing operations.

- Any impact on squid and squid fisheries in the SEA5 area is likely to be greater than for other SEA areas due to the high importance of the area for fisheries. In particular, disruption of spawning areas in the SEA5 area might have a significant effect on the “Scottish” squid population.

- It is nevertheless likely that the overall impact on cephalopod populations by a possible extension of oilfield operations would be minor.

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8. References

Aarkrog, A. 2003. Input of anthropogenic radionuclides into the World Ocean. Deep-Sea Research II, 50, 2957 - 2606.

ACOPS. 2000. Oil pollution survey around the coasts of the United Kingdom (1999), Summary. pp. 3. London: Advisory Comittee on Protection of the Sea.

Anonymous, 2000. Data Collection for Assessment of Cephalopod Fisheries. First Progress Report Study Project 99/063.

Anonymous, 2002. Report of the Working Group on Cephalopod Fisheries and Life History. International Council for the Exploration of the Sea CM 2002/G:04.

Arkhipkin, A. I. & Bjørke, H. 1999. Ontogenetic changes in morphometric and reproductive indices of the squid Gonatus fabricii (Oegopsida, Gonatidae) in the Norwegian Sea. Polar Biology, 22, 357 - 365.

Arkhipkin, A. I. & Bjørke, H. 2000. Statolith shape and microstructure as indicators of ontogenetic shifts in the squid Gonatus fabricii (Oegopsida, Gonatidae) from the Norwegian Sea. Polar Biology, 23, 1 - 10.

Arkhipkin, A. I. & Laptikhovsky, V. V. 2000. Age and growth of the squid Todaropsis eblanae (Cephalopoda: Ommastrephidae) on the north-west African shelf. Journal of the Marine Biological association of the UK, 80, 747 - 748.Anonymous, 1999. Data Collection for assessment of Cephalopod fished stocks. Final Project Report CFP CT 96 081.

Augustyn, C.J., 1990. Biological studies on the chokka squid *Loligo vulgaris reynaudii* (Cephalopoda: Myopsida) on spawning grounds off the south-east coast of South Africa. South African Journal of Marine Science 9**,** 11-26.

Bellamy, D. & Wilkinson, P. 2001. OSPAR 9/83: an environmental turning point or a flawed decision ? Marine Pollution Bulletin, 42, 87 - 90.

Betti, M., Aldave de las Heras, L., Janssens, A., Henrich, E., Hunter, G., Gerchikov, M., Dutton, M., van Weers, A. W., Nielsen, S., Simmonds, J., Bexon, A. & Sazykina, T. 2004. Results of the European Commission Marina II Study Part II - effects of discharges of naturally occurring radioactive material. Journal of Environmental Radioactivity, In press, pp. 23.

Bjørke, H. & Gjøsæter, H. 1998. Who eats the larger Gonatus fabricii (Liechtenstein) in the Norwegian Sea ? : International council for the exploration of the sea.

Bjørke, H. 1995. Norwegian investigations on *Gonatus fabricii* (Lichenstein). International Council for the Exploration of the Sea CM 1995/K:12

Bjørke, H., 2001. Predators of the squid *Gonatus fabricii* (Lichtenstein) in the Norwegian Sea. Fisheries Research 52, 113–120.

Borges, T. C. and Wallace, J. C., 1993. Some aspects of the fishery biology of the ommastrephid squid *Todarodes sagittatus* (Lamarck, 1798) from the Northeast Atlantic. In: T. Okutani, R. K. O'Dor and T. Kubodera (editors), Recent Advances in Cephalopod Fisheries Biology. Tokai University Press, Tokyo, pp. 25-36.

Boyle, P.R. (Editor), 1983. *Eledone cirrhosa*. In: Cephalopod Life Cycles Volume 1. Academic Press, London, 475 pp.

Boyle, P.R. and Pierce, G.J., 1994. Fishery biology of northeast Atlantic squid: an overview. Fisheries Research 21, 1-15.

Boyle, P.R., 1990. Cephalopod biology in the fisheries context. Fisheries Research. 8, 303-321.

Boyle, P.R., Collins, M.A. and Williamson, G.R., 1998. The cephalopod by-catch of deep-water trawling on the Hebrides slope. Journal of the Marine Biological Association of the United Kingdom 78, 1023-1026.

Boyle, P.R., Pierce, G.J. and Hastie, L.C., 1995. Flexible reproductive strategies in the squid *Loligo forbesi*. Marine Biology 121, 501-508.

Breiby, A. and Jobling, M., 1985. Predatory role of the flying squid (*Todarodes sagittatus*) in north Norwegian waters. Northwest Atlantic Fisheries Organisation Scientific Council Studies 9, 125-132.

Breuer, E., Stevenson, A. G., Howe, J. A., Carroll, J. & Shimmied, G. B. 2004. Drill cutting accumulations in the Northern and Central North Sea: a review of environmental interactions and chemical fate. Marine Pollution Bulletin, 48, 12 - 25.

Brown, E.G. and Pierce, G.J., 1997. Diet of harbour seals at Mousa, Shetland, during the third quarter of 1994. Journal of the Marine Biological Association of the United Kingdom 77, 539-555.

Brown, E.G. and Pierce, G.J., 1998. Monthly variation in the diet of harbour seals in inshore waters along the southeast Shetland (UK) coastline. Marine Ecology Progress Series 167, 275-289.

Brown, E.G., Pierce, G.J., Hislop, J.R.G. and Santos, M.B., 2001. Interannual variation in the summer diets of harbour seals (*Phoca vitulina*) at Mousa, Shetland (U.K.). Journal of the Marine Biological Association of the United Kingdom 81, 325-337.

Bustamante, P., Caurant, F., Fowler, S.W. and Miramand, P., 1998a. Cephalopods as a vector for the transfer of cadmium to top marine predators in the northeast Atlantic Ocean. The Science of the Total Environment 220, 71-80.

Bustamante, P., Cherel, Y., Caurant, F. and Miramand, P., 1998b. Cadmium, copper and zinc in octopuses from Kerguelen Islands, Southern Indian Ocean. Polar Biology 19, 264-271.

Bustamante, P., Cosson, R.P., Gallien, I., Caurant, F. and Miramand, P., 2002. Cadmium detoxification processes in the digestive gland of cephalopods in relation to accumulated cadmium concentrations. Marine Environmental Research 53, 227-241.

Bustamante, P., Garrigue, C., Breau, L., Caurant, F., Dabin, W., Greaves, J. & Dodemont, R. 2003. Trace elements in two odontocete species (Kogis breviceps and Globicephala macrorhynchus) stranded in New Caledonia (South Pacific). Environmental Pollution, 124, 263 - 271.

Bustamante, P., Grigioni, S., Boucher-Rodoni, S., Caurant, F. & Miramand, P. 2000. Bioaccumulation of 12 trace elements in the tissue of the nautilus Nautilus macromphalus from New-Caledonia. Marine Pollution Bulletin, 40, 688 - 696.

Caddy J.F. and Rodhouse P.G., 1998. Cephalopod and groundfish landings: evidence for ecological change in global fisheries? Reviews in Fish Biology and Fisheries 8, 431-444.

Carvalho, F. P. & Fowler, S. W. 1993. An experimental study on the bioaccumulation and turnover of polonium-210 and lead-210 in marine shrimp. Marine Ecology Progress Series, 102, 125 - 133.

Caurant, F. & Amiard-Triquet, C. 1995. Cadmium contamination in Pilot whales Globicephala melas: source and potential hazard to the species. Marine Pollution Bulletin, 30, 207 - 210.

Charmasson, S., Barker, E., Calmet, D., Pruchon, A.-S. & Thébault, H. 1999. Long-term variations of man-made raionuclide concentrations in a bio-indicator Mytilus galloprovincialis from the French Mediterranean coast. The Science of the Total Environment, 237-238, 93 - 103.

Cherry, R. D., Heyraud, M. & James, A. G. 1989. Diet prediction in common clupeoid fish using polonium-210 data. Journal of Environmental Radioactivity, 10, 47 - 65.

Cherry, R. D., Heyraud, M. & Rindfuss, R. 1994. Polonium-210 in teleost fish and marine mammals: Interfamily differences and a possible association between polonium-210 and red muscle content. Journal of Environmental Radioactivity, 24, 273 - 291.

Clarke, M. R. 1987. Cephalopod biomass - estimation from predation. In: Cephalopod life cycles. Comparative Reviews (Ed. by Boyle, P. R.), pp. 221-238. London, Orlando: Academic Press.

Clarke, M.R., 1986. Cephalopods in the diet of Odontocetes. In: M.M. Bryden and R.J. Harrison (editors), Research on Dolphins, Clarendon Press, Oxford, pp. 281-321.

Clarke, M.R., 1996. Cephalopods as prey. III. Cetaceans. Philosophical Transactions of the Royal Society London Series B 351, 1053-1065.

Collins, M. A. 1998. A female giant squid (Architeuthis) stranded on the Aberdeenshire coast. Journal of Molluscan Studies, 64, 489-492.

Collins, M. A., De Grave, S., Lordan, C., Burnell, G. M. & Rodhouse, P. G. 1994. Diet of the squid Loligo forbesi Steenstrup (Cephalopoda: Loliginidae) in Irish waters. ICES J. Mar. Sci., 51, 337-344.

Collins, M.A. and Pierce, G.J., 1996. Size selectivity in the diet of *Loligo forbesi* (Cephalopoda: Loliginidae). Journal of the Marine Biological Association of the United Kingdom 76, 1081-1090.

Collins, M.A., Boyle, P.R., Pierce, G.J., Key, L.N., Hughes, S.E. and Murphy, J., 1999. Resolution of multiple cohorts in the *Loligo forbesi* population from the west of Scotland. ICES Journal of Marine Science 56, 500-509.

Collins, M.A., Pierce, G.J. and Boyle, P.R., 1997. Population indices of reproduction and recruitment in *Loligo forbesi* (Cephalopoda: Loliginidae) in Scottish and Irish waters. Journal of Applied Ecology 34, 778-786.

Collins, M.A., Yau, C., Allcock, L. and Thurston, M.H., 2001. Distribution of deep-water benthic and bentho-pelagic cephalopods from the north-east Atlantic. Journal of the Marine Biological Association of the United Kingdom 81, 105-117.

Craig, S. & Overnell, J. 2003. Metals in squid, Loligo forbesi, adults, eggs and hatchlings. No evidence for a role for Cu- or Zn-metallothionein. Comparative Biochemistry and Physiology Part C, 134, 311 - 317.

Craig, S., 1996. Total mercury concentration in the cephalopods, *Loligo forbesi* (Steenstrup), *Todaropsis eblanae* (Ball), and *Todarodes sagittatus* (Lamark). Zoology Honours Thesis. University of Aberdeen.

Croxall, J.P. and Prince, P.A., 1996.Cephalopods as prey. I. Seabirds. Philosophical Transactions of the Royal Society London Series B 351, 1023-1043.

Daan, N. (Editor.), 1989. Data base report of the stomach sampling project 1981. Co-operative Research Report No. 164. International Council for the Exploration of the Sea.

Daan, R. and Mulder, M., 1996. On the short-term and long-term impact of drilling activities in the Dutch sector of the North Sea. ICES Journal of Marine Science 53, 1036-1044.

Dahlgaard, H. 1996. Polonium-210 in mussels and fish from the Baltic-North Sea Estuary. Journal of Environmental Radioactivity, 32, 91 - 96.

Daly, H.I., Pierce, G.J., Santos, M.B., Royer, J., Cho, S.K., Stowasser G., Robin, J.-P. and Henderson, S., 2001. Cephalopod consumption by fish in UK waters. Fisheries Research 52, 51-64.

DEFRA, 2003. e-Digest of Environmental Statistics. At: http://www.defra.gov.uk/environment/statistics/index.htm

Edwards, R. 1998. All at sea, Oil rigs have created a toxic dilemma that won't go away. New Scientist, 2162.

Finger, J.M. and Smith, J.D., 1987. Molecular association of Cu, Zn, Cd and ^{210}Po in the digestive gland of the squid *Nototodarus gouldi*. Marine Biology 95, 87-91.

Frodello J.P., Romeo M. and Viale D., 2000, Distribution of mercury in the organs and tissues of five toothed- whale species of the Mediterranean. Environmental Pollution 108, 447-452.

FRS, 1998. Environmental monitoring of the seas around Scotland 1994-1997. FRS Marine Laboratory Aberdeen. 47 pp.

Furness, R.W., 1994. An estimate of the quantity of squid consumed by seabirds in the eastern North Atlantic and adjoining seas. Fisheries Research 21, 165-177.

González, A.F., López, A., Guerra, A. and Barriero, A., 1994. Diets of marine mammals on the northwestern Spanish Atlantic coast with special reference to Cephalopoda. Fisheries Research 21, 179-191.

Gray, J. S., Clarke, K. R., Warwick, R. M. & Hobbs, G. 1990. Detection of initial effects of pollution on marine benthos: an example from the Ekofisk and Eldfisk oilfields, North Sea. Marine Ecology Progress Series, 66, 285 - 299.

Guerra, A., 1992. Mollusca, Cephalopoda. In: M.A. Ramos Sánchez et al. (editors), Fauna Ibérica, Madrid: Museo Nacional de Ciencias Naturales, CSIC, 327 pp.

Hanlon, R. T. & Messenger, J. B. 1996. Cephalopod behaviour. Cambridge: Cambridge University Press.

Hastie, L.C., Joy, J.B., Pierce, G.J. and Yau, C., 1994. Reproductive biology of *Todaropsis eblanae* (Cephalopoda: Ommastrephidae) in Scottish waters. Journal of the Marine Biological Association of the United Kingdom 72, 367-382.

Heldal, H. E., Varskog, P. & Føyn, L. 2002. Distribution of selected anthropogenic radionuclides (^{137}Cs, ^{238}Pu, $^{239, 240}$PU and ^{241}Am) in marine sediments with emphasis on the Spitsbergen-Bear Island area. The Science of the Total Environment, 293, 233 - 245.

Heyraud, M., Cherry, R. D., Oschadleus, H.-D., Augustyn, C. J., Cherry, M. I. & Sealy, J. C. 1994. Polonium-210 and Lead-210 in edible molluscs from near the Cap of Good Hope: Sources of variability in Polonium-210 concentrations. Journal of Environmental Radioactivity, 24, 253 - 272.

Hislop, J.R.G., 1997 Database report of the Stomach Sampling Project 1991. ICES Co-operative Research Report 219. International Council for the Exploration of the Sea, Copenhagen.

Hislop, J.R.G., Robb, A.P., Bell, M.A. and Armstrong, D.W., 1991. The diet and food consumption of whiting (*Merlangius merlangus*) in the North Sea). ICES Journal of Marine Science, 48, 139-156.

Hislop, J.R.G., Robb, A.P., Brown, M.A. and Armstrong, D.W., 1983. A preliminary report on the analysis of the whiting stomachs collected during the 1981 North Sea stomach sampling project. International Council for the Exploration of the Sea CM 1983/G: 59.

Holme, N., 1974. The biology of *Loligo forbesi* Steenstrup (Mollusca: Cephalopoda) in the Plymouth area. Journal of the Marine Biological Association of the United Kingdom 54, 481-503

Howard, F.G., 1979. Recent trends in the Scottish fishery for *Loligo forbesi* together with some notes on the biology of the species. International Council for the Exploration of the Sea C.M.1979/K36.

Howard, F.G., Ngoile, M.A. and Mason, J., 1987. *Loligo forbesi*: its present status in Scottish fisheries. International Council for the Exploration of the Sea CM 1987/K:5.

ICES, 1988. Report of the Meeting Co-ordinators in the Stomach Sampling Project 1985 to 1987. International Council for the Exploration of the Sea CM 1988/G:27.

Joy, J.B., 1989. The fishery biology of Ommastrephid squids in the Shetland waters. MSc Thesis, University of Aberdeen.

Joy, J.B., 1990. The fishery biology of *Todarodes sagittatus* in Shetland waters. Journal of Cephalopod Biology 1, 1-19.

Jonsson, E. 1998. Study of european flying squid, Todarodes sagittatus (Lamarck), occurring in deep waters south of Iceland. ICES CM 1998/M:48.

Kershaw, P. J., Woodhead, D. S., Lovett, M. B. & Leonard, K. S. 1995. Plutonium from European reprocessing operations - its behaviour in the marine environment. Appl. Radiat. Isot., 46, 1121 - 1134.

Koyama, J., Nanamori, N. & Segawa, S. 2000. Bioaccumulation of waterborne and dietary cadmium by oval squid, Sepioteuthis lessioniana, and its distribution among organs. Marine Pollution Bulletin, 40, 961 - 967.

Kristensen, T.K., 1983. *Gonatus fabriicii*. In: Boyle PR (ed) Cephalopod Life Cycles, Volume 1. Species Accounts. Academic Press, London, p 159-174.

Kristensen, T.K., 1984. Biology of the squid *Gonatus fabricii* (Lichtenstein, 1818) from West Greenland waters. Meddelelser om Gronland, Bioscience 13, 3-20.

Kunisaki, N., 2000. Nutritional properties of squid and cuttlefish. In: M. Okozumi and T. Fujii (editors), Nutritional and Functional Properties of Squid and Cuttlefish, National Co-operative Association of Squid Producers, Japan, pp. 22-59.

Lick, R. and Piatkowski, U., 1998. Stomach contents of a northern bottlenose whale (*Hyperoodon ampullatus*) stranded at Hiddensee, Baltic Sea. Journal of the Marine Biological Association of the United Kingdom 78, 643-650.

Livingston, H. D. & Povinec, P. P. 2000. Anthropogenic marine radioactivity. Ocean & Coastal Management, 43, 689 - 712.

Lordan, C., Burnell, G.M. and Cross, T.F., 1998. The diet and ecological importance of *Illex coindetii* and *Todaropsis eblanae* (Cephalopoda: Ommastrephidae) in Irish waters. South African Journal of Marine Science 20, 153-163.

Lordan, C., Collins, M.A., Key, L.N. and Browne, E.O., 2001. The biology of the ommastrephid squid, *Todarodes sagittatus*, in the north-east Atlantic. Journal of the Marine Biological Association of the United Kingdom 81, 299-306.

Lum-Long, A., Pierce, G.J. and Yau, C., 1992. Timing of spawning and recruitment in *Loligo forbesi* Steenstrup (Cephalopoda: Loliginidae) in Scottish Waters. Journal of the Marine Biological Association of the United Kingdom 72, 301-311.

MAFF. 1993. Radioactivity in surface and coastal waters of the British Isles, 1992., pp. 1 - 66. Lowestoft: MAFF Direct. Fish. Res.

Martin, J.H. and Flegal, A.R., 1975. High copper concentrations in squid livers in association with elevated levels of silver, cadmium and zinc. Marine Biology 30, 51-55.

Menzie, C.A., 1983. Muddy issues. Oceanus 26, 33-38.

Miramand, P. and Bentley, D., 1992. Concentration and distribution of heavy metals in tissues of two cephalopods, *Eledone cirrhosa* and *Sepia officinalis* from the French coast of the English Channel. Marine Biology 114, 407-414.

Neff, J.M., Rabalais, N.N. and Boesch, D.F., 1987. Offshore oil and gas development activities potentially causing long-term environmental effects. In: D.F. Boesch and N.N. Rabalais (editors), Long-term Environmental Effects of Offshore Oil and Gas Development Long, Elsevier Applied Science, London and New York, pp. 149-173.

Nesis, K.N., 1987. Cephalopods of the world: squid, cuttlefishes, octopuses, and allies. English-language edition. TFH Publications, Neptune City, New Jersey.

Nixon, M. 1987. Cephalopod diets. In: Cephalopod life cycles. Comparative Reviews (Ed. by Boyle, P. R.), pp. 201-220. London, Orlando: Academic Press.

Nyegaard, M., 2001. What does it for a squid? An analysis of reproductive behaviour, demography, diet and spatial distribution of the European common squid (*Alloteuthis subulata*) in the Irish Sea. Unpublished MSc thesis, University of Tromsø.

OLF. 2000. Physical, chemical and biological characterisation of offshore drill cuttings piles. Version 2. Norwegian Oil Industry Association.

Olsgard, F. & Gray, J. S. 1995. A comprehensive analysis of the effects of offshore oil and gas exploration and production on the benthic communities of the Norwegian continental shelf. Marine Ecology Progress Series, 122, 277 - 306.

Pedersen, J. 1999. Diet comparison between pelagic and demersal whiting in the North Sea. Journal of Fish Biology, 55, 1096 - 1113.

Pierce, G.J. and Santos, M.B., 1996. Trophic interactions of squid *Loligo forbesi* in Scottish waters. In: S.P.R. Greenstreet and M.L. Tasker (editors), Aquatic Predators and their Prey, Fishing News Books, Cambridge, pp. 58-64.

Pierce, G.J. and Santos, M.B., 2003. Diet of harbour seals (*Phoca vitulina*) in Mull and Skye (Inner Hebrides, W. Scotland, UK). Journal of the Marine Biological Association of the United Kingdom.

Pierce, G.J., Bailey, N., Stratoudakis, Y. and Newton, A., 1998. Distribution and abundance of the fished population of *Loligo forbesi* in Scottish waters: analysis of research cruise data. ICES Journal of Marine Science 55, 14-33.

Pierce, G.J., Boyle, P.R. and Thompson, P.M., 1990. Diet selection by seals. In: M. Barnes and R.N. Gibson (editors), Trophic Relations in the Marine Environment, Proceedings of the 24th European Marine Biology Symposium, Aberdeen University Press, Aberdeen, pp. 222-238.

Pierce, G.J., Boyle, P.R., Hastie, L.C. and Key, L.N., 1994a. The life history of *Loligo forbesi* (Cephalopoda: Loliginidae) in Scottish waters. Fisheries Research 21, 17-41.

Pierce, G.J., Boyle, P.R., Hastie, L.C. and Santos, M.B., 1994c. Diets of squid *Loligo forbesi* in the northeast Atlantic. Fisheries Research 21, 149-163.

Pierce, G.J., Boyle, P.R., Hastie, L.C. and Shanks, A.M., 1994d. Distribution and abundance of the fished population of *Loligo forbesi* in UK waters: analysis of fishery data. Fisheries Research 21, 193-216.

Pierce, G.J., Hastie, L.C., Guerra, A., Thorpe, R,S., Howard, F.G. and Boyle P.R., 1994b. Morphometric variation in *Loligo forbesi* and *Loligo vulgaris*: regional, seasonal, sex, maturity and worker differences. Fisheries Research 21, 127-148.

Pierce, G.J., Wang, J., Zheng, X., Bellido, J.M., Boyle, P.R., Denis, V. and Robin, J.-P., 2001. A cephalopod fishery GIS for the Northeast Atlantic: development and application. International Journal of Geographical Information Science 15, 763-784.

Pierce, G.J., Young, I.A.G. and Wang, J., 2002. An overview of cephalopods relevant to the SEA 2 and SEA 3 areas. Report No TR_009_Rev1. Department of Trade and Industry (available at http://www.offshore-sea.org.uk).

Rasero, M., González, A.F., Castro, B.G. and Guerra, A., 1996. Predatory relationships of two sympatric squid, *Todaropsis eblanae* and *Illex coindetii* (Cephalopoda: Ommastrephidae) in Galician waters. Journal of the Marine Biological Association of the United Kingdom 76, 73-87.

Ridgway, J., Breward, N., Langston, W. J., Lister, R., Rees, J. G. & Rowlatt, S. M. 2003. Distinguishing between natural and anthropogenic sources of metals entering the Irish Sea. Applied Geochemistry, 18, 283 - 309.

Roberts, P. D. & Jones, D. G. 1993. BGS Seabed gamma Spectrometer NW Hutton Platform Survey.: Bristish Geological Society.

Rocca, E., 1969. Copper distribution in *Octopus vulgaris* Lam. hepatopancreas. Comparative Biochemistry and Physiology 28, 67-82.

Rodhouse, P. G. & Nigmatullin, C. M. 1996. Role as consumers. Philosophical Transactions of the Royal Society of London, 351, 1003 - 1022.

Roper, C.F.E., Sweeney, M.J. and Nauen, C.E., 1984. Cephalopods of the world. An annotated and illustrated catalogue of species of interest to fisheries. Memoirs of the National Museum, Victoria 44, 49-63.

Ryan, T. P., Dowdall, A. M., Long, S., Smith, V., Pollard, D. & Cunningham, J. D. 1999. Plutonium and Americium in fish, shellfish and seaweed in the Irish environment and their contribution to dose. Journal of Environmental Radioactivity, 44, 349 - 369.

Santos, M.B. and Pierce, G.J., 2003. Diet of harbour porpoise (*Phocoena phocoena*) in the NE Atlantic: a review. Oceanography and Marine Biology Annual Review 41.

Santos, M.B., Clarke, M.R. and Pierce, G.J., 2001a. Assessing the importance of cephalopods in the diets of marine mammals and other top predators: problems and solutions. Fisheries Research 52, 121-139.

Santos, M.B., Pierce G.J., Smeenk, C., Addink, M.J., Kinze, C.C., Tougaard, S. and Herman, J., 2001d. Stomach contents of northern bottlenose whales *Hyperoodon ampullatus* stranded in the North Sea. Journal of the Marine Biological Association of the United Kingdom 81, 143-150.

Santos, M.B., Pierce, G.J., Boyle P.R., Reid, R.J., Ross, H.M., Patterson, I.A.P., Kinze, C.C., Tougaard, S., Lick, R., Piatkowski, U. and Hernández-García, V., 1999. Stomach contents of sperm whales (*Physeter macrocephalus*) stranded in the North Sea 1990-1996. Marine Ecology Progress Series 183, 281-294.

Santos, M.B., Pierce, G.J., Garcia Hartmann, M., Smeenk, C., Addink, M.J., Kuiken, T., Reid, R.J., Patterson, I.A.P., Lordan, C., Rogan, E. and Mente, E., 2002. Additional notes on stomach contents of sperm whales *Physeter macrocephalus* stranded in the NE Atlantic. Journal of the Marine Biological Association of the United Kingdom 82, 501-507.

Santos, M.B., Pierce, G.J., Herman, J., López, A., Guerra, A., Mente, E. and Clarke, M.R., 2001b. Feeding ecology of Cuvier's beaked whale (*Ziphius cavirostris*): a review with new information on the diet of this species. Journal of the Marine Biological Association of the United Kingdom 81, 687-694.

Santos, M.B., Pierce, G.J., Learmonth, J.A., Reid, R.J., Ross, H.M., Patterson, I.A.P., Reid D.G. & Beare, D., 2004. Variability in the diet of harbor porpoises (Phocoena phocoena) in Scottish waters 1992-2003. Marine Mammal Science 20, 1-27.

Santos, M.B., Pierce, G.J., Reid, R.J., Patterson, I.A.P., Ross, H.M. and Mente, E. 2001c. Stomach contents of bottlenose dolphins (*Tursiops truncatus*) in Scottish waters. Journal of the Marine Biological Association of the United Kingdom 81, 873-878.

Santos, M.B., Pierce, G.J., Ross, H.M., Reid, R.J. and Wilson, B., 1994. Diets of small cetaceans from the Scottish coast. ICES Council Meeting Papers. International Council for the Exploration of the Sea CM 1994/N:11.

Santos, M.B., Pierce, G.J., Wijnsma, G., Ross, H.M. and Reid, R.J., 1995. Diets of small cetaceans stranded in Scotland 1993-1995. International Council for the Exploration of the Sea CM 1995/N:6.

Schipp, R. and Hevert, F., 1978. Distribution of copper and iron in some central organs of *Sepia officinalis* (Cephalopoda). A comparative study by flameless atomic absorption and electron microscopy. Marine Biology 47, 391-399.

Scottish Sea Fisheries Statistics, 1996. The Scottish Office. Agriculture, Environment and Fisheries Department.

Scottish Sea Fisheries Statistics, 1997. The Scottish Office. Agriculture, Environment and Fisheries Department.

Scottish Sea Fisheries Statistics, 1998. Scottish Executive. Rural Affairs Department.

Scottish Sea Fisheries Statistics, 1999. Scottish Executive Rural Affairs Department.

Scottish Sea Fisheries Statistics, 2000. Scottish Executive Rural Affairs Department.

Scottish Sea Fisheries Statistics, 2001. Scottish Executive Rural Affairs Department.

Scottish Sea Fisheries Statistics, 2002. Scottish Executive Rural Affairs Department.

Shaw, P.W., Pierce, G.J. and Boyle, P.R., 1999. Subtle population structuring within a highly vagile marine invertebrate, the veined squid *Loligo forbesi*, demonstrated with microsatellite DNA markers. Molecular Ecology 8, 407-417.

Sheahan, D., Rycroft, R., Allen, Y., Kenny, A., Mason, C. & Irish, R., 2001. Contaminant Status of the Morth Sea. SEA2 Technical Report TR_004. Department of Trade and Industry (available at http://www.offshore-sea.org.uk).

Smale, M.J., 1996. Cephalopods as prey. IV. Fishes. Philosophical Transactions of the Royal Society London Series B 351, 1067-1081.

Stephen, A.C., 1944. The cephalopoda of Scottish and adjacent waters. Transactions of the Royal Society of Edinburgh 61, 247-270.

STOA. 2001. Possible toxic effects from the nuclear processing plants at Sellafield (UK) and Cap de La Hague (France). Luxembourg: European Parliament.

Storelli, M.M. and Marcotrigiano G.O., 1999. Cadmium and total mercury in some cephalopods from the South Adriatic Sea (Italy). Food Additives and Contaminants 16, 261-265.

Stowasser, G., 1997. On the feeding ecology of decapod cephalopods. Diplomarbeit. Christian-Albrecht-Universitaet Kiel. pp.67.

Sundet, J.H., 1985. A short review on the biology and fishery of the squid *Todarodes sagittatus*. International Council for the Exploration of the Sea C.M.1985/K:44.

Tanaka, T., Hayashi, Y. and Ishizawa, M., 1983. Subcellular distribution and binding of heavy metals in the untreated liver of the squid; comparison with data from the livers of cadmium and silver exposed rats. Experienta 39, 746-748.

Tollit, D.J. and Thompson, P.M., 1996. Seasonal and between-year variations in the diet of harbour seals in the Moray Firth, Scotland. Canadian Journal of Zoology 74, 1110-1121.

UKAEA. 2001. Radioactive waste discharges from UKAEA establishments during 2001 and associated monitoring results., pp. 1- 86. Harwell: United Kingdon Atomic Energy Authority.

Velasco, F., Olaso, I. and Sánchez, F., 2001. The role of cephalopods as forage for the demersal fish community in the southern Bay of Biscay. Fisheries Research 52, 65-77.

Voss G.L., 1973. Cephalopod resources of the world. FAO Fisheries circular No. 149, 75 pp.

Waluda, C.M. and Pierce, G.J., 1998. Temporal and spatial patterns in the distribution of squid *Loligo* spp. in United Kingdom waters. South African Journal of Marine Science 20, 323-336.

Watson, W. S., Sumner, D. J., Baker, J. R., Kennedy, S., Reid, R. & Robinson, I. 1999. Radionuclides in seals and porpoises in the coastal waters around the UK. The Science of the Total Environment, 234, 1 - 13.

Wiborg, K.F. and Gjosæter, J., 1981. Squid *Todarodes sagittatus* (Lamarck) distribution and biology in northern waters, April 1980 - April 1981. International Council for the Exploration of the Sea C.M. 1981/K:14.

Wiborg, K.F., 1979. *Gonatus fabricii* (Lichtenstein), en mulig fiskeriressurs i Norskehavet. Fisken og Havet 1979, 33-46.

Wiborg, K.F., Gjøsæter, J. and Beck, I.M., 1982b. The squid *Gonatus fabricii* (Lichtenstein). Investigations in the Norwegian Sea and western Barents Sea 1978-1981. International Council for the Exploration of the Sea, CM 1982/K:31

Wiborg, K.F., Gjosaeter, J., Beck, I.M. and Fossum, P., 1982a. Squid *Todarodes sagittatus* (Lamarck) distribution and biology in northern waters, April 1981 - April 1982. International Council for the Exploration of the Sea C.M./K:30.

Zuur, A. & Pierce, G. J. 2004. Common trends in northeast Atlantic squid time series. Journal of Sea Research, In Press.

Table 1. Total annual cephalopod landings (in tonnes) in whole ICES area by the UK fleet in relation to total landings from the ICES area. This table is based on a more extensive tabulation in Anon. (2003). Data for 2002 were provisional (P).

Category and country	1996	1997	1998	1999	2000	2001	2002P
(a) Cuttlefish (Sepiidae)							
Channel Islands	11	8	20	22	26	8	15
England, Wales & N. Ireland	4607	2202	2760	2259	3035	2699	3451
Total	19736	16652	20275	20725	26080	19560	22915
(b) Common Squid (Loliginidae)							
Channel Islands	1	6	5	11	9	1	10
England, Wales & N. Ireland	2464	2005	1466	1261	776	852	983
Isle of Man	3	2	2	2	+	1	+
Scotland	799	1001	1572	1350	980	808	1338
Total	9632	11519	11245	11115	9944	9184	11191
(c) Short-finned Squid (Ommastrephidae)							
England, Wales & N. Ireland	13	26	293	204	187	200	170
Total	4219	6145	5841	7719	5677	4381	2709
(d) Octopods (Octopodidae)							
Channel Islands	0	0	0	+	+	+	+
England, Wales & N. Ireland	221	140	87	33	115	146	174
Scotland	8	8	23	19	20	16	2
Total	17658	15801	13043	15743	16779	11804	12890

Table 2. Landings of squid in Scotland, by fishing area for recent years. (Scottish Sea Fisheries Statistics, 1996-2002)

Landings by area	1996	1997	1998	1999	2000	2001	2002
Weight in tonnes							
Total for Scotland	637	823	1355	1199	852	696	1165
IVa	293	453	844	712	543	348	687
IVb	14	62	211	137	92	121	232
Value in £,000							
Total for Scotland	970	1523	2189	1395	1130	1291	1968
IVa	458	850	1252	810	680	559	1148
IVb	33	137	392	184	145	244	338

Table 3. Concentration ranges of trace metals in drilling fluids and in typical marine sediments (concentrations in mg/kg dry weight, ppm) (Reproduced from Neff et al., 1987).

Metal	Concentration in marine sediments (ppm)	Concentration in drilling fluids (ppm)
Barium	60-8100	720-449000
Chromium	10-200	0.1-5960
Cadmium	0.3-1	0.16-54.4
Copper	8-700	0.05-307
Iron	20000-60000	0.002-27000
Mercury	0.05-3	0.017-10.4
Lead	6-200	0.4-4226
Zinc	5-4000	0.06-12270
Nickel	2-10	3.8-19.9
Arsenic	2-20	1.8-2.3
Vanadium	10-500	14-28
Aluminium	10000-90000	10800
Manganese	100-10000	290-400

Table 4. Mean concentrations of trace metals in squid and whiting, and median values recorded in piscivorous (porpoise, minke whale) and teuthophagous (Risso's dolphin, sperm whale) marine mammals in Scottish waters (mg/kg wet weight) (FRS, 1998). Limits set by the Food Standard Committee (FSC) are shown for comparison.

	Cadmium	Copper	Lead	Zinc	Mercury	Arsenic
Squid	0.030	7.12	0.02	11.0	0.03	7.91
Whiting	0.001	0.14	<0.01	3.75	0.04	4.27
Risso's dolphin	5.00-8.73	4.18-9.09	0.10-0.89	26.7-46.2	1.47-5.22	-
Sperm whale	17.0	5.00	0.73	48.3	22.7	-
Porpoise	0.016	11.5	0.11	48.5	1.02	-
Minke whale	0.13	3.93	<0.07	87.4	1.84	-
FSC	0.02	20	2	50	0.5	-

Table 5: Radioactivity concentrations in samples of fish and shellfish at Sellafield and estimated collective doses from consumption of fish and shellfish in the UK between 1990 and 1997. Most of the collective dose estimated is due to radiocaesium in fish. Other radionuclides contributing in small proportions are ^{90}Sr, ^{14}C, ^{99}Tc. Liquid discharges from Sellafield are the main source of collective dose in the UK. The recommended dose per person per year is set at 1mSv.
Sources: DEFRA, e-Digest of Environmental statistics, published August 2003.

	Collective dose rate (man-SV per year)	Average dose per person (μSv per person per year)	Cod ^{137}Cs conc. Sellafield coastal waters (Bq kg^{-1})	Cod ^{137}Cs conc. Sellafield offshore waters (Bq kg^{-1})	Plaice ^{137}Cs conc. Sellafield offshore waters (Bq kg^{-1})	Whiting ^{137}Cs conc. Sellafield offshorel waters (Bq kg^{-1})
1990	10	0.20	0.8	0.5	0.2	0.6
1991	8	0.14	0.9	0.7	0.2	0.3
1992	5	0.09	0.25	---	---	0.34
1993	4	0.07	0.37	0.17	0.04	0.19
1994	5	0.09	0.27	---	0.15	---
1995	3	0.05	0.11	---	0.08	---
1996	4	0.07	0.06	---	0.07	0.05
1997	4	0.07	< 0.23	< 0.17	< 0.07	< 0.16

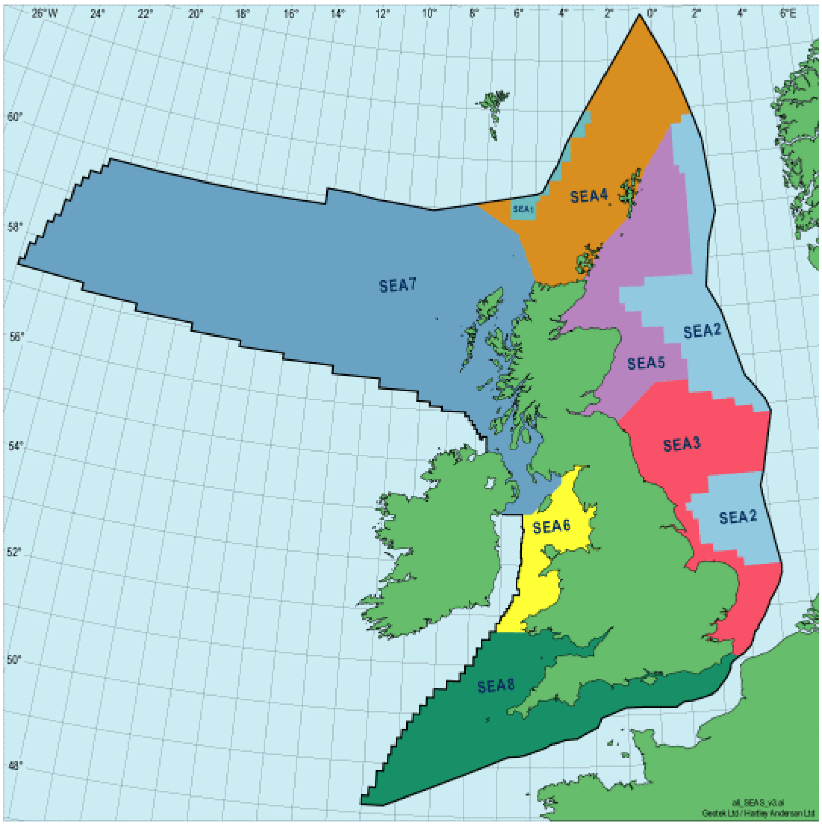


Figure 1. Maps showing the SEA areas and detail of the SEA5 area

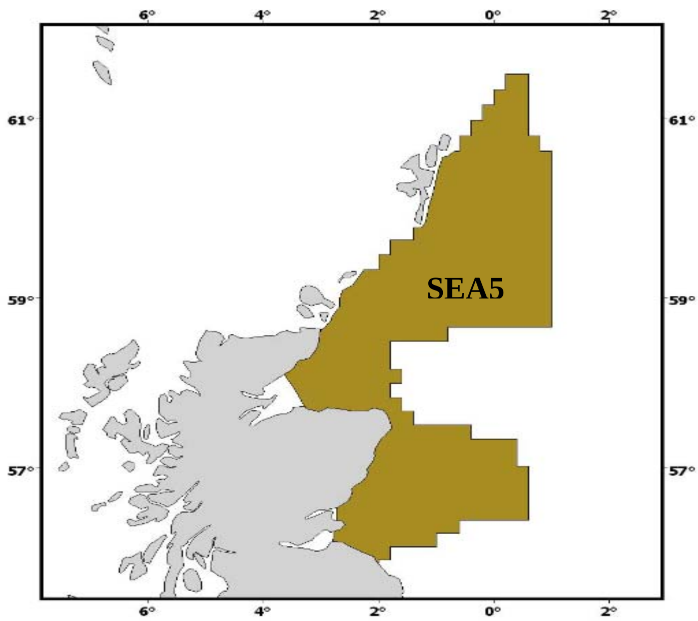
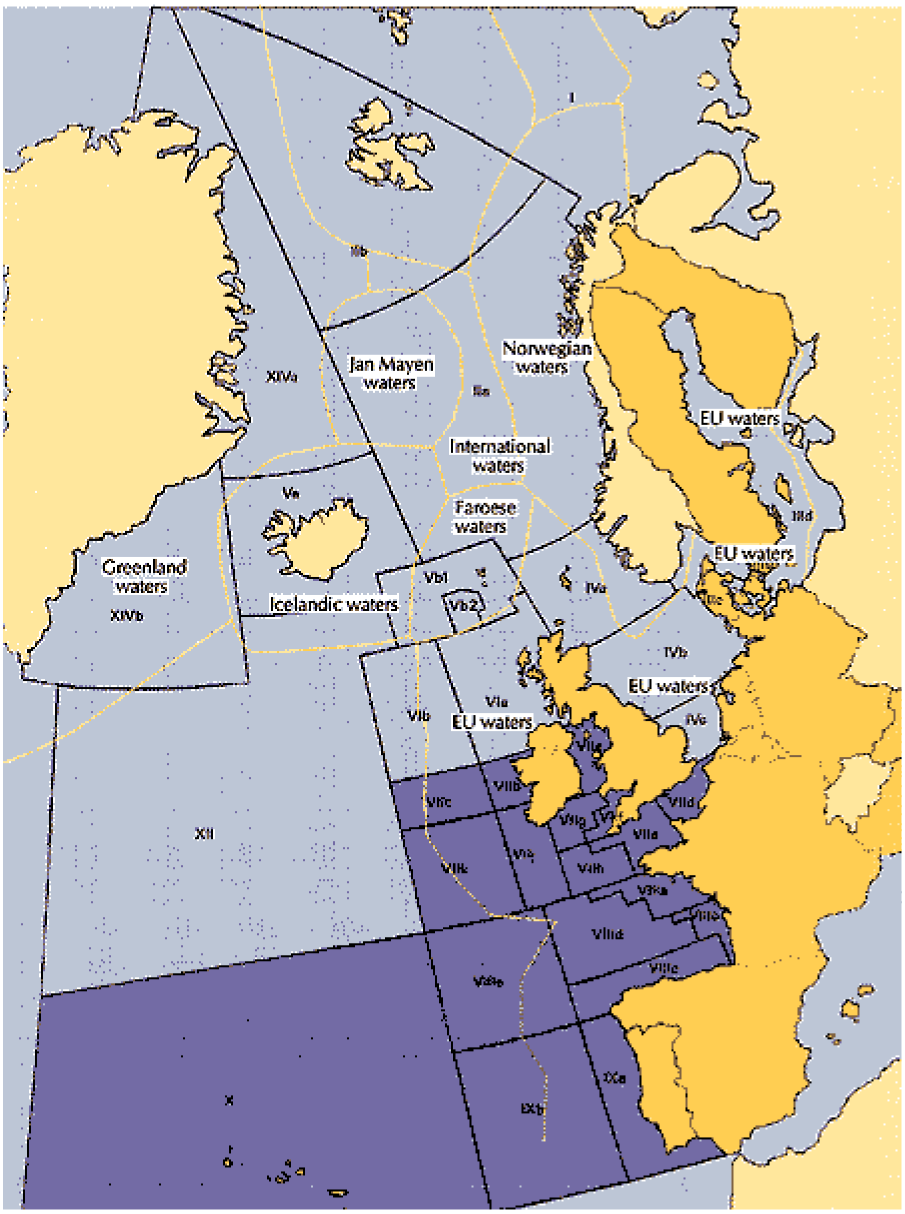


Figure 2. Map showing ICES fishery areas and divisions



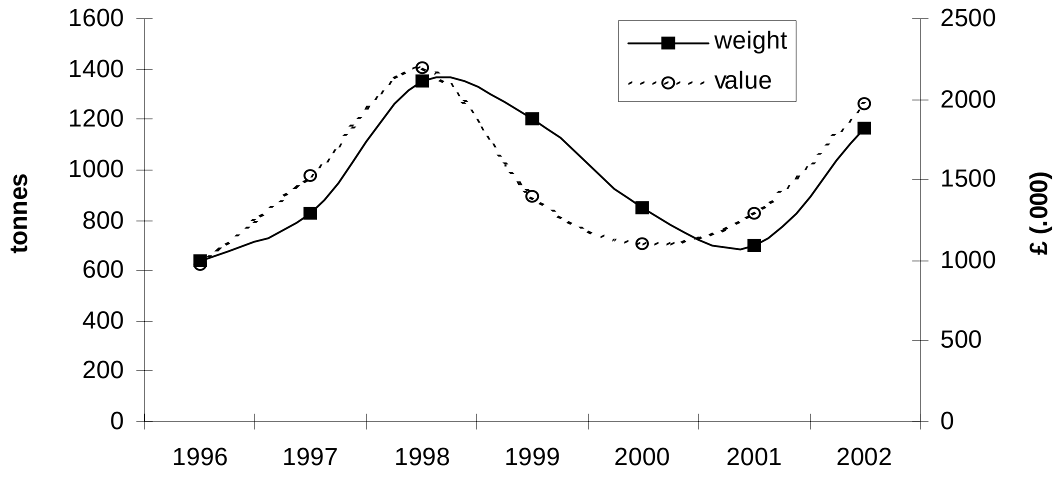


Figure 3. Total squid landings into Scotland between 1996 and 2002 (Scottish Sea Fisheries Statistics, 2002)

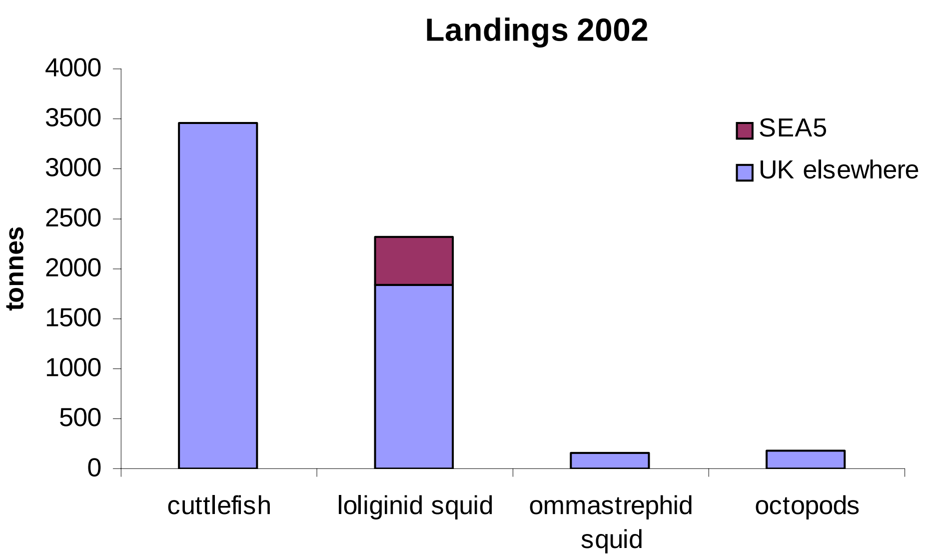


Figure 4. Landings of cephalopods in 2002, by commercial category by UK-registered fishing boats landing in the UK: landings from the SEA 5 area are distinguished from those taken elsewhere.

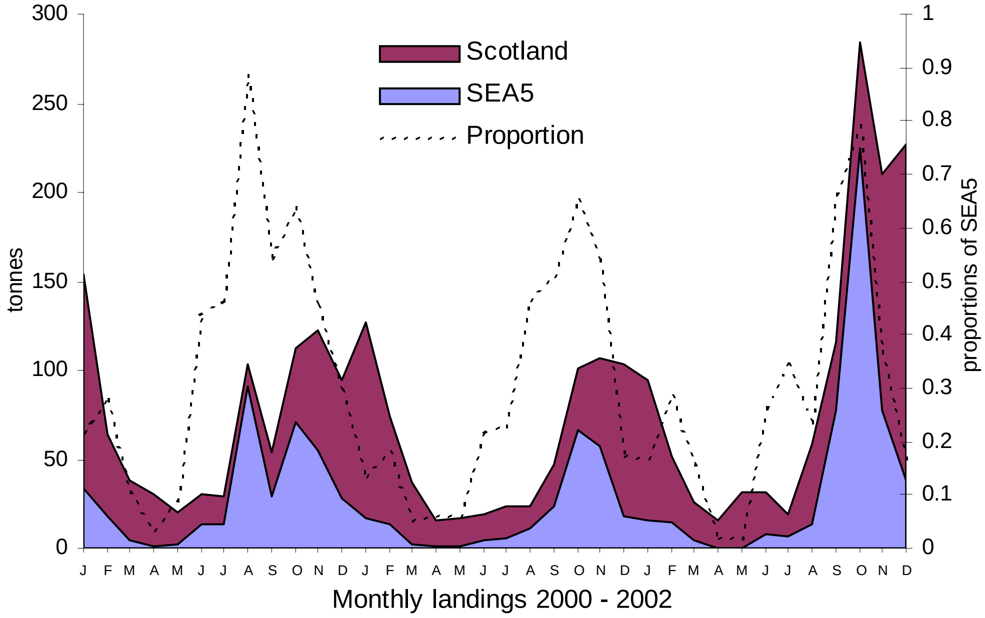


Figure 5. Month-to-month trends in landings of loliginid squid in Scotland and for the SEA 5 area. The dotted line shows the proportion of Scottish landings arising from catches in the SEA 5 area.

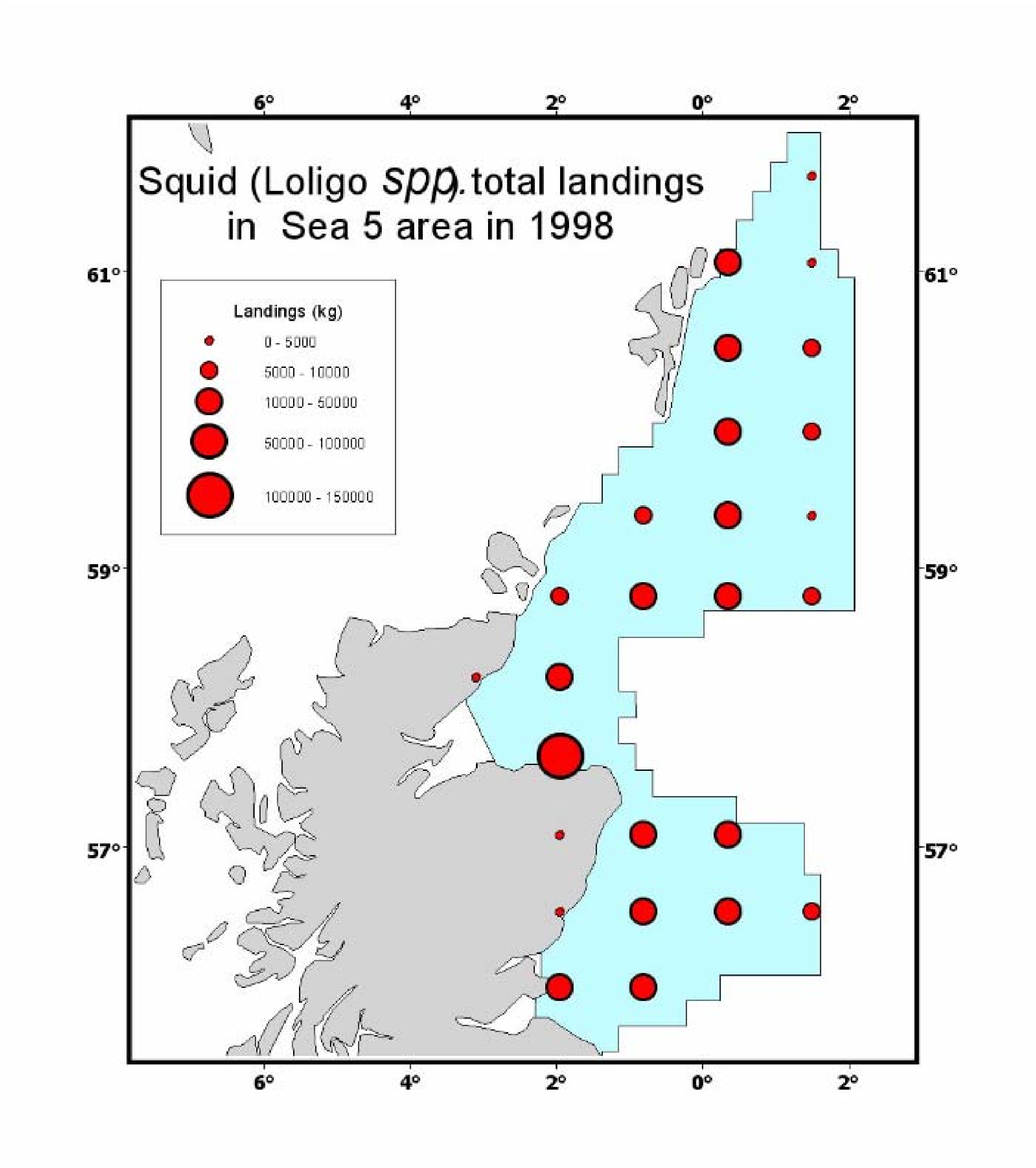

Squid (Loligo spp). total landings
in Sea 5 area in 1998
Landings (kg)
0 - 5000
5000 - 10000
10000 - 50000
50000 - 100000
100000 - 150000
6°
4°
2°
0°
2°
61°
59°
57°

Fig.: 6

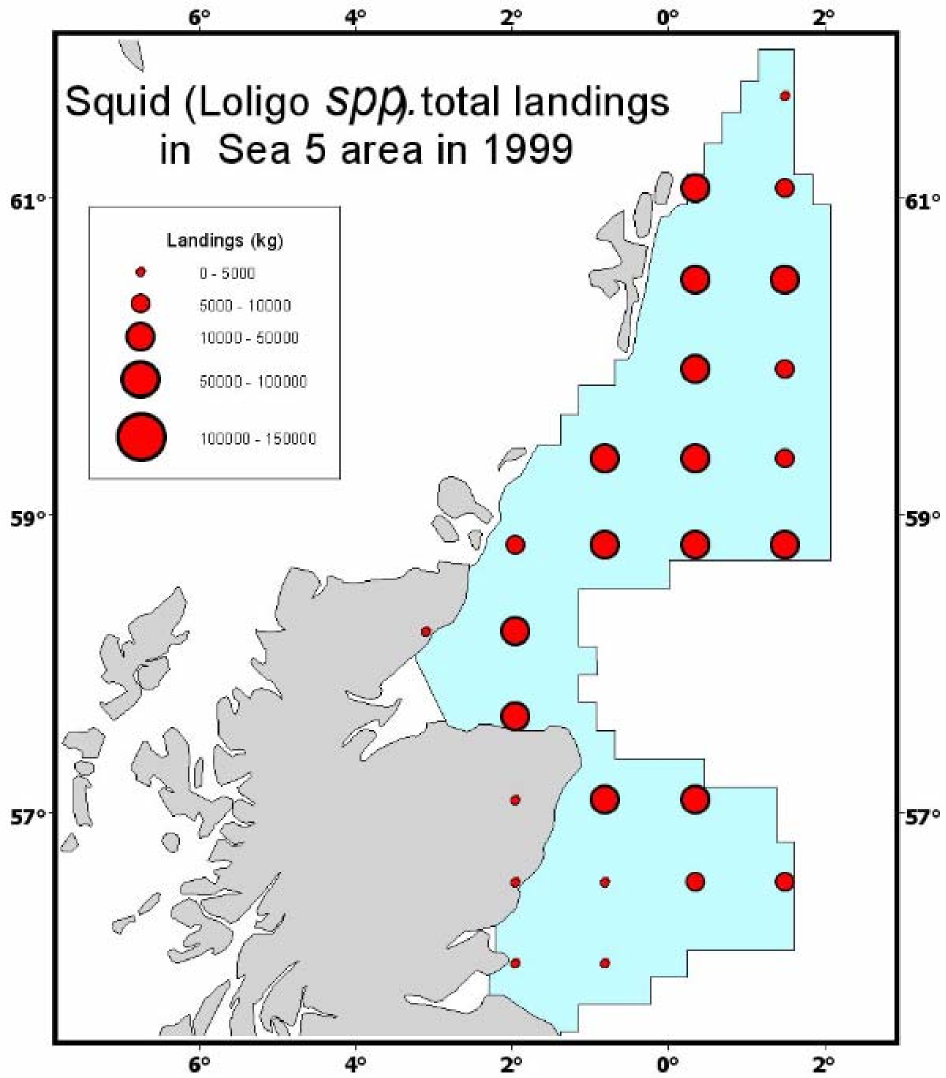

Squid (Loligo spp). total landings
in Sea 5 area in 1999
Landings (kg)
0 - 5000
5000 - 10000
10000 - 50000
50000 - 100000
100000 - 150000
6°
4°
2°
0°
2°
61°
59°
57°

Fig.7

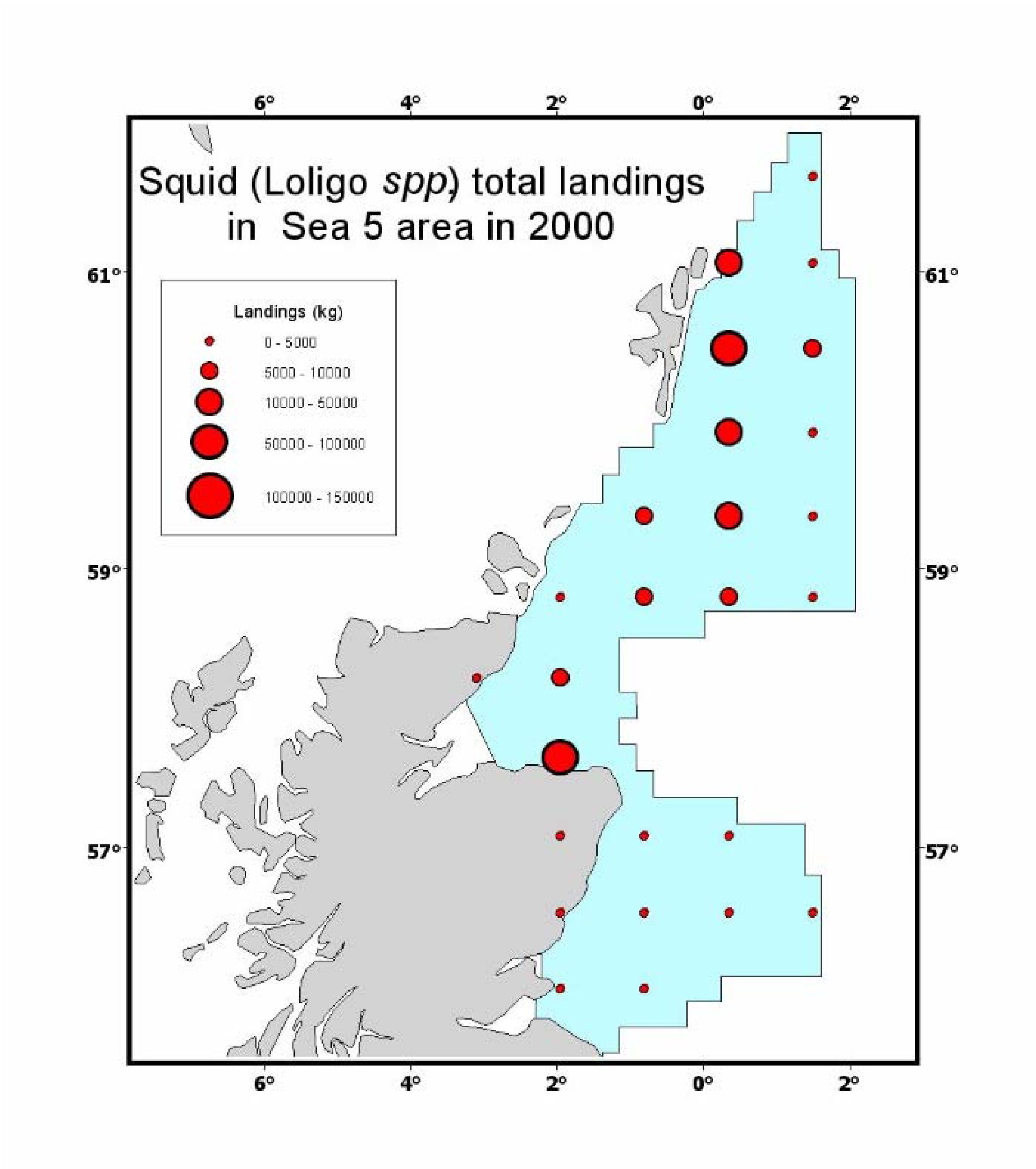

Squid (Loligo spp) total landings
in Sea 5 area in 2000
Landings (kg)
0 - 5000
5000 - 10000
10000 - 50000
50000 - 100000
100000 - 150000
6°
4°
2°
0°
2°
61°
59°
57°

Fig.8

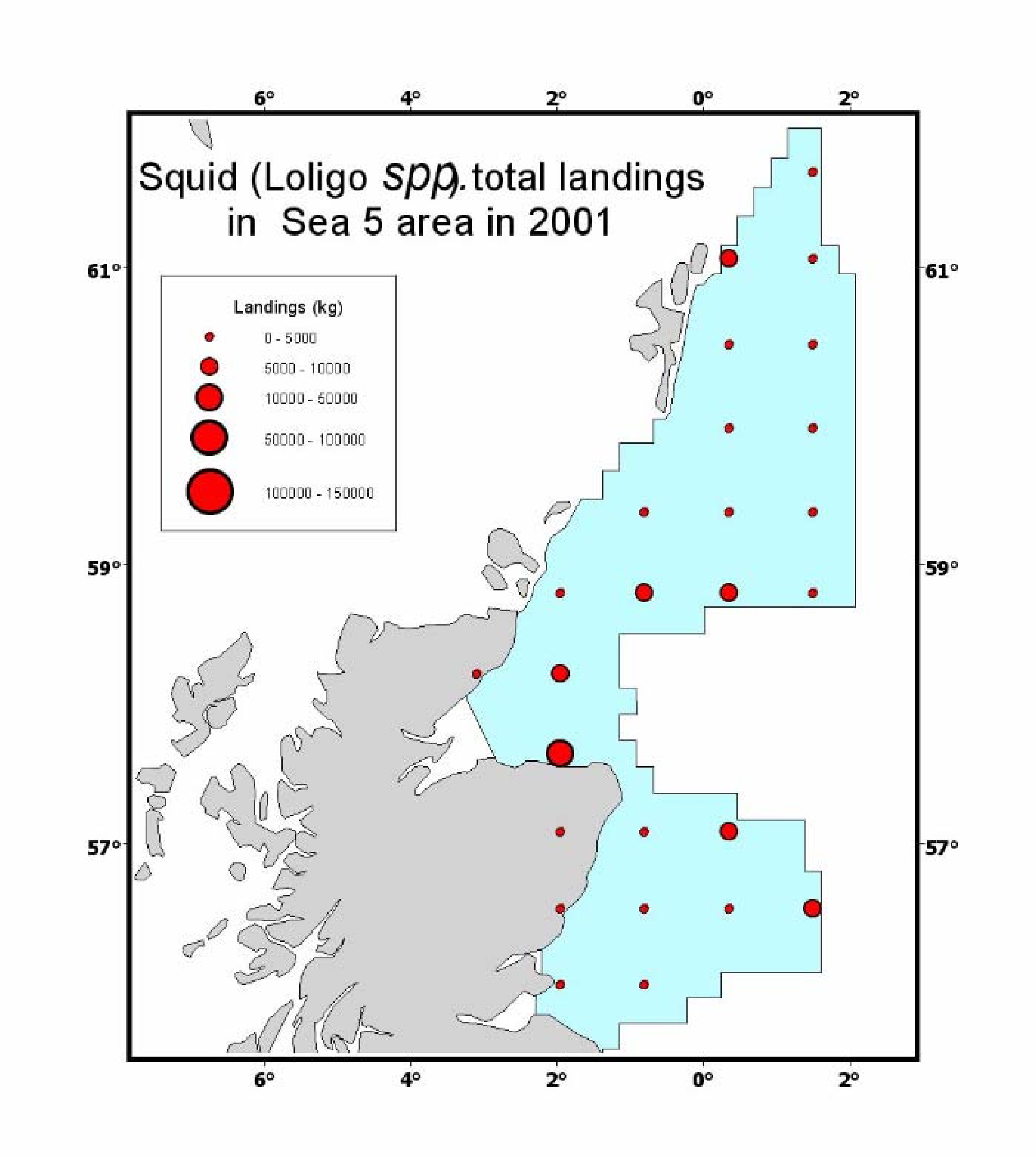

Squid (Loligo spp). total landings
in Sea 5 area in 2001
Landings (kg)
0 - 5000
5000 - 10000
10000 - 50000
50000 - 100000
100000 - 150000
6°
4°
2°
0°
2°
61°
59°
57°

Fig. 9

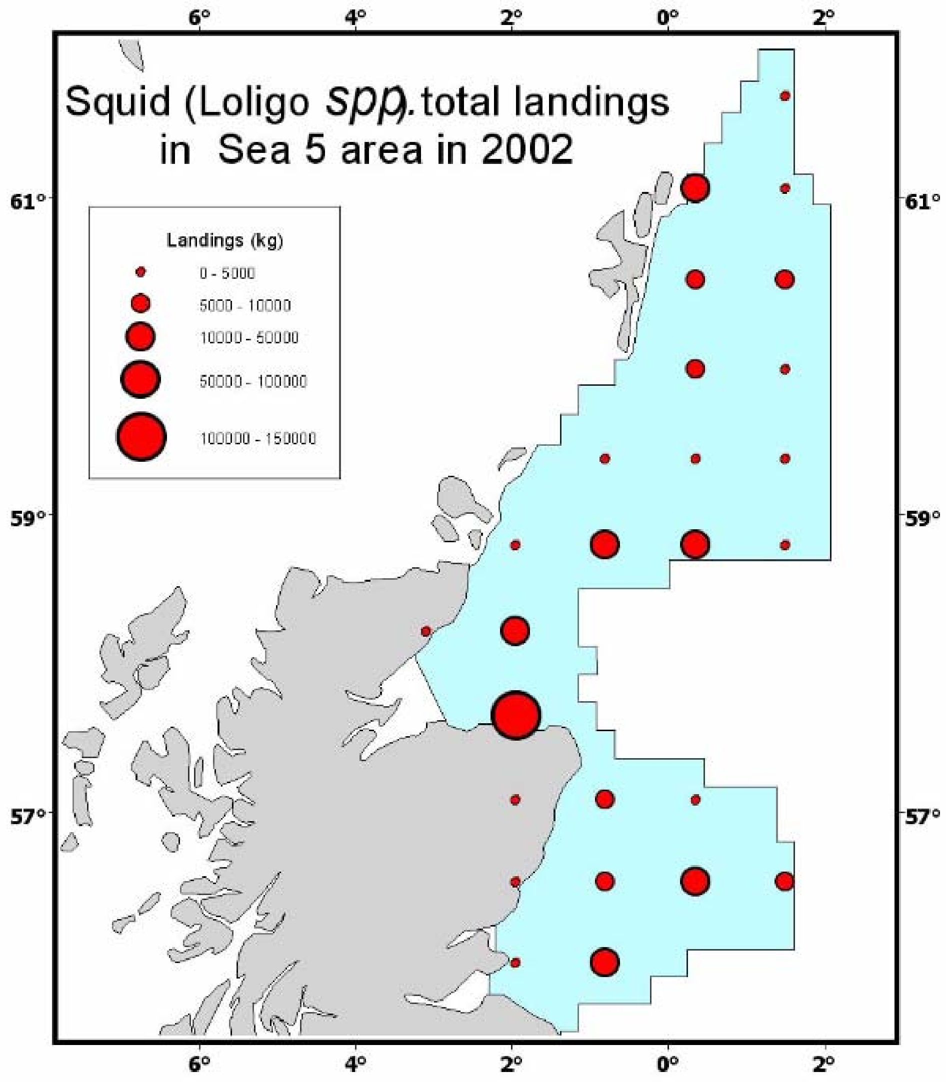

Squid (Loligo spp). total landings
in Sea 5 area in 2002
Landings (kg)
0 - 5000
5000 - 10000
10000 - 50000
50000 - 100000
100000 - 150000
6°
4°
2°
0°
2°
61°
59°
57°

Fig. 10