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An Overview of Cephalopods Relevant to the SEA 7 Area

For the Department of Trade and Industry

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1. General Introduction

The following review is a component of the information base of the Strategic Environmental Assessment (SEA 7) conducted by the Department of Trade and Industry. Some of the general background material presented here is taken from the previous reports on cephalopods in SEA Areas 2–6 (Pierce *et al.*, 2002, 2003; Stowasser *et al*., 2004; Sacau *et al*., 2005).

The International Council for the Exploration of the Sea (ICES) have, for fisheries management purposes, divided the North Atlantic ocean into fishery areas, divisions and sub-divisions. 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. The SEA 7 Area falls within ICES Fishery Divisions VIa (west of Scotland) and VIb (Rockall Bank). It is by far the largest SEA Area in UK waters, extending from the NW coast of Scotland (4º W) to the mid-Atlantic (24º W) and from Northern Ireland (55º N) to south of the Faroes (60º N) (Figure 1).

Most fishery resources in the NE Atlantic are managed according to European Union (EU) regulations, developed on the basis of scientific advice from ICES. The Common Fisheries Policy (CFP), which controls fishing within the EU zone, came into effect in 1983. It was subject to a limited mid-term review of access arrangements in 1992 and a thorough review in 2002. Under CFP, the UK has declared the area up to 12 nautical miles from the coast to be one within which fishing is restricted to British boats (and, in some areas, vessels from other EC countries with traditional rights) (Territorial Sea Act, 1987). Outside the coastal margin, all EU member countries have equal access to the Exclusive Fishing Zone (EFZ) whereas non-member countries are only allowed to fish if there has been a prior agreement. Fishing in a number of areas around the coastline may also be restricted in order to protect important fish nursery areas or spawning grounds.

A major reform of the CFP in 2002 led to the creation of seven Regional Advisory Councils (RACs) to cover the main areas or fisheries in the EFZ: Baltic Sea, Mediterranean Sea, North Sea, North-western waters, South-western waters, Pelagic stocks and Distant-water fisheries. These were set up in response of the EU and stakeholders' desire for increased participation in the CFP process, and they advise the European Commission (EC) and relevant national governments on fisheries matters in their respective areas. RACs comprise representatives of the fishing sector and other interest groups, while scientists are often invited as experts. Representatives of the EC and member states may attend RAC meetings as observers. The North-western waters RAC (NWWRAC), established in 2005, is organised into four area-based working groups (WGs). One of these, WG 1 (west of Scotland, ICES Areas VIa, VIb) represents areas within SEA 7.

Cephalopods are short-lived molluscs (shellfish), characterised by rapid growth rates, and are important predators and prey in oceanic and neritic environments. They represent arguably the most promising future fishery resource in terms of potential market value, abundance and rapid stock renewal, related to their growth potential and short life cycles (Guerra, 1996). Despite these advantages, it is estimated that the world catch of cephalopods represents only 10 % of exploitable stocks detected (Guerra, 1996). The commercial significance of cephalopods to world fisheries is of relatively recent, but growing, importance (Boyle & Pierce, 1994).

The class Cephalopoda comprises three major divisions, of which two, the Decapoda (squid and cuttlefish) and Octopoda (octopus), are represented in the SEA 7 Area. They range in length from 1.5 cm in pygmy (bobtail) 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. 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.*, 2001). Many species are powerful swimmers and undertake long feeding and spawning migrations, thus influencing prey and predator communities strongly on a seasonal and regional basis. Cephalopods are important elements in marine food webs and interact significantly with commercially exploited finfish species. 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).

Cephalopods play an important role in the NE Atlantic marine ecosystems and are becoming an increasingly important fisheries resource in these waters (Sacau *et al*., 2005). The main commercial species in Scottish waters is the long-finned squid *Loligo forbesi* (Boyle & Pierce, 1994). Since 1995, annual UK landings of loliginid squid have ranged from 1600–3200 t, making the UK the second most important fishery nation for loliginid squid within the ICES region after France (Stowasser *et al.*, 2004). Other species of commercial interest in the SEA 7 Area are squids; *Alloeuthis subulata, Illex coindetii, Loligo vulgaris, Todarodes sagittatus,* and *Todaropsis eblanae*; cuttlefish, *Sepia officinalis,* and the octopus, *Eledone cirrhosa*. Both *T. sagittatus* and *T. eblanae* were part of a substantial fishery off Shetland and Norway in the 1980s (Joy, 1989; Hastie *et al.*, 1994) but are only occasionally landed at present (Stowasser *et al.*, 2004). Large numbers of the oceanic squid *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; Bjorke, 2001) 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, industrial emissions and river discharges (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; Stowasser *et al*., 2005).

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 are expected to occur 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; Bustamante *et al.*, 1998; Koyama *et al.*, 2000; Stowasser *et al*., 2005) and, to a lesser extent, 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 plays an important role in the bioaccumulation of these pollutants in their predators (Koyama *et al.*, 2000).

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

This report focuses mainly on the main species of fishery importance in the SEA 7 Area, the loliginid squid *L. forbesi.* Brief accounts of other commonly occurring cephalopod species of potential importance are also provided.

We review the following topics:

- Important cephalopod species in the SEA 7 Area
- Ecology: trophic interactions
- Cephalopod fisheries and trends
- Sensitivity to environmental contamination

2. Marketable squid species in the NE Atlantic

2.1. *Loligo forbesi* (Veined squid)

The veined squid, *Loligo 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 is the most frequently caught squid species, and 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). At certain times *L. forbesi* is actually targeted, notably on Rockall Bank in summer (Pierce *et al*., 1994a) and in the Moray Firth in autumn (Young *et al*., 2006). In 2005, small-scale directed squid fisheries started in several other localities, including off Skye. *Loligo forbesi* is an annual, semelparous species (Holme, 1974) showing extended breeding seasons with, depending on the area, one, two 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). Early work on *L. forbesi* in the English Channel by Holme (1974) indicated the existence of distinct winter and summer breeding populations of *L. forbesi* in UK waters. However, it seems that since the 1970's, the summer breeding population has declined in Scottish waters and the winter population now dominates and breeds later than was previously the case (Pierce *et al*., 2005).

Animals mature over a range of sizes with males generally growing bigger than females. The two recruitment periods identified for Scottish waters produce distinctive micro-cohorts of two or three different size classes in female and male squid respectively (Collins *et al.*, 1997, 1999). Genetic evidence exists for separate offshore (Rockall bank) and shelf stocks in Scottish waters (Shaw *et al.*, 1999). Both stocks are thus present in the SEA7 area. Mature squid are recorded throughout Scottish waters in winter and eggs of *L. forbesi* have been recorded in trawls off Shetland (Lum-Kong *et al.*, 1992) and are regularly found on creel lines along the Scottish mainland coastline. Although spawning grounds have not yet been documented it has been indicated from the analysis of spatial patterns in fishery data that *L. forbesi* move from the West Coast of Scotland into the North Sea to spawn (Waluda and Pierce, 1998; Pierce *et al.*, 2001). Potential spawning areas have been modelled based on survey and market sample data on squid distribution and size at maturity data (see Stowasser et al., 2005). Although they are short-lived species, fecundity in loliginid squids is surprisingly low, with female *L. forbesi* apparently producing only a few thousand eggs in their lifetime (Boyle *et al.*, 1995).

The main Scottish fishery for *L. 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; Young *et al.*, 2006). 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 SEA 7 Area in all seasons. Pierce *et al*., (1998) presented data from demersal trawl surveys along the west coast of Scotland during November (1990-1994), which showed that highest catches of *L. forbesi* occurred north of Ireland near the Stanton Bank area (~3,200/hr in one haul). Good catches occurred north and west of the Hebrides and in Donegal Bay, whereas catches south and west of Ireland were relatively poor. Recent analysis of long-term trends in abundance points to the possible influence of oceanographic conditions 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; Pierce *et al*., 2005).

2.2. Loligo vulgaris (European squid)

The European squid, *Loligo vulgaris* (Lamarck, 1798), closely related to *L. forbesi*, is another very common loliginid species in the northeastern Atlantic and Mediterranean. Distribution is from the North African coast (20^{o}N) to the northern North Sea (55^{o}N) (Guerra & Rocha, 1994). The ranges of the *L. vulgaris* and *L. forbesi* overlap extensively. However, *L. vulgaris* is less abundant than *L. forbesi* in the northern part of the range and increasingly replaces its congener with decreasing latitude. In the southern part of the range (except for the Azores, where only *L. forbesi* is found), *L. vulgaris* dominates. By contrast, in the SEA 7 Area only *L. forbesi* is common, although small numbers of *L. vulgaris* are occasionally found in catches (Pierce *et al.*, 1994a). The general appearance, life history, ecology, exploitation and market value of *L. vulgaris* and *L. forbesi* are very similar. Although these two species are sometimes caught together, they are relatively difficult to distinguish and consequently are never separated in commercial landings.

2.3. Alloteuthis subulata (European common squid)

The European common squid, *Alloteuthis subulata* (Lamarck, 1798) is often taken in hauls alongside *L. forbesi*. It is considered to be a demersal species, mainly occurring in shallow coastal waters of 20-120 m depth (Roper *et al*., 1984), although it has been taken at depths down to 500 m (Guerra, 1982). *Alloteuthis subulata* is a very small squid (typically <15 cm ML) and there is no market for this species in the UK at present. Consequently, it is normally discarded from trawls if caught. However, large catches of *A. subluta* could be marketed overseas as food ('baby squid') or in the UK as bait for the recreational sea fishing industry (small, 'hook-sized' squid, currently imported frozen, are sought after by anglers and considered to be premium bait). Due to its small size and slim body form, it is likely that most individuals are not retained in commercial trawling gear. There are no landings data for the SEA 7 Area, although some information on abundance is available from trawl surveys. It is often the most common cephalopod encountered during surveys of shallow, coastal waters (Collins *et al*., 1995a; Heij & Baayen, 1999).

In addition to its market potential, *A. subulata* is likely to be an important species in coastal ecosystems since it appears to be abundant and it is the most commonly recorded cephalopod species in stomach contents of demersal fish in UK waters (Hislop *et al.*, 1991; Daly *et al.*, 2001) and is also important in the diet of demersal fish in Spanish waters (Velasco *et al.*, 2001). It also appears to be an important predator of small fish species. Nyegaard (2001) showed that, although *A. subulata* was associated with the distribution of its main prey species, the squid at stations with high prey abundance did not seem to have been more engaged in feeding activity than those at other stations. This could indicate that *A. subulata* feeds in the pelagic zone rather than close to the bottom. Indeed both sandeel and sprat, which are important prey of *Alloteuthis*, undertake vertical migrations, and were found in higher abundances in the pelagic zone than near the bottom during the day in the North Sea (Pedersen, 1999). The demersal co-occurrence of *Alloteuthis* and its prey might thus have been due to other factors.

The only recent studies on the reproductive biology of this species in UK waters were by Rodhouse *et al.* (1988) and Nyegaard (2001) based on samples collected in the English Channel and Irish Sea, respectively. These studies showed that mature animals occur during spring and summer, and juveniles dominate the population in the autumn. Rodhouse *et al.* (1988) found three broods in the English Channel, spawning in spring, summer and autumn. The seasonal migration pattern (if any) is unknown. Nyegaard (2001) found that the spring and autumn distribution of *A. subulata* in the Irish Sea was related to physical factors and local hydrographical features. *Alloteuthis subulata* appear to prefer warm, saline water. Peak abundance was found in association with the warmest part of the Irish Sea in both March and October. Similar observations have been made for both *Loligo forbesi* and *A. subulata* in the North Sea (Waluda & Pierce, 1998; Heij & Baayen, 1999).

2.4. *Todarodes sagittatus* (European flying squid)

The European flying squid *Todarodes sagittatus* (Lamarck, 1798) is a widely distributed bentho-pelagic species. It is found in the Mediterranean and in the north-east Atlantic from the Arctic to around 13°S (Roper *et al*., 1984; Guerra, 1992). It has been recorded from surface waters to estimated depths of 4500 m (Collins *et al.*, 2001) although most specimens have been caught in waters <1000 m deep (Roper *et al.*, 1984). Its presence in coastal waters to the west of Norway, Scotland, Ireland and Portugal is seasonal (Lordan *et al.*, 2001) and thought to be a consequence of extensive geographic migrations from coastal feeding grounds in northern waters to hypothetical deep-water spawning grounds in the mid-Atlantic (Borges & Wallace, 1993). Occurrence and catches of *T. sagittatus* in north European waters (including the SEA 7 Area) seem to be related to influxes of Atlantic water and the fluctuating strength of its current system (Wiborg, 1972; Wiborg & Gj⌀sæter, 1981).

Todarodes sagittatus is generally considered to be an annual species (Rosenberg *et al.*, 1980; Arkhipin *et al.*, 1999), although a 2-year life cycle has also been suggested (Lordan *et al.*, 2001). Breeding seems to be protracted with two peaks occurring, in spring and in autumn (Rosenberg *et al.*, 1980; Wiborg *et al.*, 1983; Wiborg & Beck, 1984; Roper *et al.*, 1984; Lordan *et al.*, 2001). According to Borges & Wallace (1993), there is evidence of at least two *T. sagittatus* populations coexisting in north European waters. In years of abundance, *T. sagittatus* moves inshore during summer and autumn, when it is caught in large numbers (Wiborg & Gj⌀sæter, 1981; Sundet, 1985; Joy, 1989; Lordan *et al.*, 2001). Catches in northern coastal waters are made up mainly of immature female specimens, which suggests that inshore migration is mainly carried out by females, probably for feeding (Wiborg *et al.*, 1982; Sundet, 1985; Joy, 1989; Borges & Wallace, 1993; Boyle *et al.*, 1998).

A significant, directed fishery for *T. sagittatus* has previously been operated by north European countries, notably Norway during 1980–1987. During this period, *T. sagittatus* invaded coastal waters of the Faroes Islands, south-west Iceland and north-west Norway in late summer and autumn, with some squids migrating into the North Sea (Sundet, 1985). Large numbers of *T. sagittatus* were also taken as by-catch by demersal trawlers around Shetland at this time (Joy, 1990). Very large numbers of *T. sagittatus* can be caught in UK waters on occasion, particularly around Shetland and off the west coast of Scotland. However, since there is no current market for this species in Scotland, it is usually discarded by Scottish fishing vessels (Joy, 1989). The directed fishery in Norwegian waters has not operated since 1990 due to a decline in seasonal invasions, although catches of 352 t and 190 t of short-finned squid, presumed to be *T. sagittatus*, were reported in 1995 and 1997 respectively (Anon., 2002).

2.5. *Todaropsis eblanae* (Lesser flying squid)

The lesser flying squid, *Todaropsis eblanae* (Ball, 1841) is a bentho-pelagic 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 (Gonzalez *et al.*, 1994; Arkhipkin & Laptikhovsky, 2000). Within European Atlantic waters there is no evidence of stock differentiation although north Atlantic specimens exhibit genetic differences from Mediterranean specimens (Dillane *et al.*, 2005). It is associated with sandy to muddy bottoms within a temperature range from 9 to 18º C in depths ranging from 20 m to 700 m (but confined to depths less than 200 m in the North Sea) (Guerra, 1992). *T. eblanae* exhibits a so-called “intermittent spawning pattern” (Boletzky, 1975) or “intermittent terminal spawning pattern”. Partial ovulation allows for the presence of oocytes at various stages of development and thus continuous production of ova once spawning has commenced (Rocha *et al*., 1996).

At present, *T. eblanae* is not exploited commercially by the UK fleets and consequently there is little information on this species in the SEA 7 Area. However, reports from adjacent waters (north and south) indicate that it can at times be widespread and abundant in the NE Atlantic. The occurrence of *T. eblanae* in the Irish Sea was reported by Collins *et al*. (1995a). This animal was occasionally caught during research cruises carried out in the spring, summer and autumn of 1992 and 1993. Lordan *et al*. (2001) studied the distribution and abundance of cephalopod species caught during demersal trawls surveys west of Ireland and in the Celtic Sea. The most numerous species in catches was *L. forbesi* followed by *T. eblanae,* which was concentrated close to the shelf break in most years.

However, in 1994 there were also large catches off the south coast of Ireland. It is also reported to be super-abundant in the North Sea in some years, a phenomenon possibly linked to hydrographical anomalies such as high-salinity influxes of Atlantic seawater (Hastie *et al*., 1994).

2.6. ***Illex coindetii*** **(Southern shortfin squid)**

The southern shortfin squid, *Illex coindetii* (Vérany, 1839) is a bentho-pelagic, neritic species found in the Mediterranean and in the NE Atlantic as far north as the Oslo Fjord and the North Sea (~50^{o}N) (Roper *et al.*, 1984). It has been recorded from the surface to 1100 m depth although more commonly in waters of 100–400 m (Guerra, 1992). Spawning occurs throughout the year (Gonzalez *et al.*, 1994). A local trawler by-catch fishery for short-fin squid (*I . coindetii* and *T. eblanae*) has operated in Galacia, NW Spain for ~20 years. The squid are normally landed fresh and auctioned the same day – no distinction is made between the species, both of which are used for human consumption (Gonzalez *et al.*, 1994). No commercial landings of these species have been reported in the SEA 7 Area but they are occasionally recorded in waters west of Scotland during research trawling surveys.

3. Other important cephalopod species

3.1. *Sepia officinalis* (Common cuttlefish)

The common cuttlefish, *Sepia officinalis* has a short life-span, of around two years. The species is abundant in the Eastern Atlantic and in the Mediterranean Sea. From the North Sea southwards, *S. officinalis* occurs in coastal waters and on the continental shelf at depths not greater than 150m (Boletzky, 1983). The spawning season is from early spring to mid summer, followed by mass adult mortality and hatching from mid summer to autumn (Boletzky, 1983; Le Goff & Daguzan, 1991; Dunn, 1999).

Previous studies of the spatial and temporal patterns of abundance of cuttlefish show that there is a regular annual spawning migration from offshore to inshore waters and large inter-annual fluctuations in landings (Boucaud-Camou and Boismery, 1991; Dunn 1999; Denis and Robin, 2001). In early spring, adult cuttlefish aggregate on coastal spawning grounds, mainly along both sides of the English Channel and on the French Atlantic coast. In late autumn, the juveniles migrate from inshore nursery grounds to deeper water in the west part of the English Channel and further west (Irish Sea) and to offshore deep water off the northern part of the French Atlantic coast, where they stay during the winter months. There is no genetic evidence for different populations in these areas, but previous studies suggest that cuttlefish in the Channel are probably a separate stock from those in the Bay of Biscay (Le Goff & Daguzan, 1991; Pawson, 1995, Dunn, 1999). *Sepia officinalis* is less abundant further north, although significant numbers are occasionally taken in the SEA 7 Area, notably in shallow waters off the west coast of Scotland (Anon., 2005).

3.2. *Eledone cirrhosa* (Curled octopus)

The curled octopus, *Eledone cirrhosa* (Lamarck, 1798) is a benthic octopod with a wide distribution over shelf regions of the NE Atlantic from the Mediterranean in the south to the Norwegian Lofoten Islands in the north. Although Collins *et al.* (2001) report 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). In the SEA 7 Area, it appears to be very common in shallow coastal waters west of Scotland. Its life span ranges from 18–24 months, with individuals dying shortly after spawning. Sexual maturity is attained in late summer (from July–September) with spawning following shortly afterwards (Boyle, 1983).

3.3. Sepiolids (Bobtail squids)

On the continental shelf, the Sepiolidae are probably the next most significant cephalopod group. The bobtail squid *Sepiola atlantica* (Orbugny, 1840) is one of at least six sepiolid species present in Scottish waters. There is little information about sepiolids in the SEA 7 Area. As very small, bottom-living species, sepiolids are of no commercial value and tend to be overlooked in catches. However, they may be very abundant – Stephen (1944) cites a record of 256 specimens of *S. atlantica* being taken in a single haul.

3.4. Deep-water species (squids, sepiolids, and octopods)

Oceanic cephalopods found in deeper water, on the shelf edge and beyond are generally less well known, and none are currently marketed. Very large stocks of the potentially marketable Arctic squid *Gonatus fabricii* are found in the deep, cold waters of the NE Atlantic and Arctic (Kristenen, 1983), and it is possible that significant numbers of this species may sometimes occur in British waters. *Gonatus fabricii* is an oceanic species, found at depths of 350-1200 m and is considered to be the most abundant squid in the Arctic and sub-Arctic areas of the North Atlantic (Kristensen, 1983).

Collins *et al.* (2001) reviewed records of deep-water benthic and bentho-pelagic cephalopods in the NE Atlantic, based on specimens collected from commercial and survey vessel trawling. The sepiolids, *Neorossia caroli* (400–1535 m) and *Rossia macrosoma* (205–515 m) were recorded in relatively deep water. Three incirrate octopod genera were also recorded: *Benthoctopus* sp. and *Bathypolypus* sp. were identified at depths of 250–2700 m while *Graneledone verrucosa* was caught at depths of 1785–2095 m. Cirrate octopods dominated the cephalopod catch from the deeper areas: *Opisthoteuthis massyae* (877–1398 m), *O. grimaldii* (2165–2287 m), *Stauroteuthis syrtensis* (1425–3100 m), *Cirroteuthis muelleri* (700–4854 m), *Cirrothauma murrayi* (2430–4850 m) and *Grimpoteuthis* sp. (1775 – 4877 m). In the SEA 7 Area, these species are often caught in benthic trawls at 800–1200 m depth off the west coast of Scotland (Daly *et al.*, 1998).

In 1994, an immature female incirrate octopus, *Haliphron atlanticus* was captured by a bottom trawler near Shetland at a depth of ca. 180 m (Collins *et al.*, 1995). This was the first published record of this species in Scottish waters. This species is rarely caught in nets, but it may be very common and of ecological importance (*Haliphron* sp. Beaks have been identified in whale stomachs from Scottish waters, e.g. in sperm whale stomachs, Santos *et al.*, 1999). *Haliphron atlanticus* is a large, cosmopolitan, gelatinous species that can reach 2 m in length. It is believed to live on the bottom, probably reaching depths 0f 3180 m (Guerra, 1992). Very little is known about deep-water cephalopods. Perhaps images obtained opportunistically by ROVs during future oil-related operations may provide useful data on the distribution of these rarely seen species.

4. Ecology: trophic interactions

4.1. Ecological importance of cephalopods

Cephalopods are regarded as key species in many ecosystems (Amaratunga, 1983; Rodhouse, 1989). They represent an essential link in marine trophic chains and are eaten by many marine top predators, i.e. fish, birds and mammals (Clarke, 1996; Croxall & Prince, 1996; Klages, 1996; Smale, 1996), especially whales (Santos *et al*., 2001). At all life stages after hatching, cephalopods are active voracious carnivores feeding by day or by night on a wide variety of live prey (Nixon, 1987; Boyle 1990; Hanlon & Messenger, 1996) that they detect mainly with their eyes or by touch. The most important source of information needed to determine what cephalopods eat is the analysis of stomach contents although, increasingly, it is possible to make useful inferences about feeding from fatty acid and stable isotope concentrations in squid tissues (see Stowasser *et al.*, 2006). The material present in stomach contents may include scales, bones, otoliths and lenses from fishes, skeletal parts and eggs from crustaceans, the beaks, pens and lenses from cephalopods and the setae and jaws from polychaetes.

4.2. Long-fin squid

The veined squid, *L. forbesi* has been shown to be an opportunistic predator (Pierce *et al*., 1994b; Collins *et al*., 1994), feeding on demersal and pelagic species of fish and crustacea. Its diet has been studied in Scottish waters by several authors (Boyle & Pierce, 1994; Pierce *et al.*, 1994b; Collins & 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. 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). Juvenile European squid, *L. vulgaris* feed mainly on planktonic crustaceans, whereas fish are by far the most important prey type for the adults (Rocha *et al.*, 1994). Ontogenetic shifts from invertebrate- and crustacean-dominated diets in juveniles to fish-dominated diets in adults have in fact been reported in a number of loliginid and ommastrephid squid species (e.g. Pierce *et al.*, 1994a; Lordan *et al.*, 1998).

Nyegaard (2001) showed that fish and crustaceans dominated the diet of European common squid, *A. subulata* in March, which is in line with the findings of Bidder (1950) and Lipinski (1985) for *A. subulata.* As for *L. forbesi* (Collins *et al*., 1994; Pierce *et al*., 1994b), the majority of *A. subulata* stomachs contained remains from only one prey type (Nyegaard, 2001). The dominant fish prey species of *A. subulata* belonged to the family Clupeidae and it is likely that the Clupeidae vertebrae present in stomachs had originated from sprat, as no herring below 8 cm length was caught on the cruise (Nyegaard, 2001). *Alloteuthis subulata* digests its prey rapidly and may have an empty stomach only 4 hours after the initiation of feeding (Bidder, 1950). The occurrence of stomachs with food present thus reflects relatively recent feeding activity. The lack of any apparent trend in the proportion of empty stomachs during the day indicates that feeding proceeded throughout daylight hours, with a possible trend towards less feeding activity for the females towards the end of the day. Feeding might have taken place also at night.

Nyegaard (2001) found the proportion of empty stomachs, in both spring and autumn, was generally high (79-86%) in *A. subulata*, which is not uncommon among wild caught squid

(Amaratunga, 1983). However, in comparison, an overall analysis of *L. forbesi* from the Irish Sea revealed that 48% had food in the stomach (Collins *et al*., 1994), while values varied between 46% and 82% for *L. forbesi* from the NE Atlantic (Pierce *et al*., 1994b). This discrepancy might be due to *A. subulata* feeding predominantly at night, or reflect a comparatively lower energy requirement for growth in the smaller *A. subulata*. In comparison to this small and delicate species, *L. forbesi* reaches larger maximum mantle lengths (410-900 mm) and is more robust in body structure.

4.3. Short-fin squid

The lesser flying squid, *T. eblanae* is also considered a generalist predator, feeding on the most abundant available prey. As with other cephalopod species the dominant prey is dependent on availability, relative squid size and season. Nevertheless, the species is primarily piscivorous with crustaceans and cephalopod prey being present to a lesser extent. The most important prey are 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. The diet of the European flying squid, *T. sagittatus* is composed of mainly fish but also crustaceans and cephalopods. In northern waters, this squid feeds primarily on small herring (*Clupea harengus*) and cod (*Gadus morhua*) (Joy, 1990; Piatowski *et al.*, 1998). Opportunistic cannibalism, with larger individuals preying on smaller members of their own species, appears to be a common feature of loliginid and ommastrephid squid species (Collins & Pierce, 1996; Piatkowski *et al.*, 1998).

4.4. Cuttlefish and octopods

The cuttlefish, *S. officinalis* is an opportunistic predator mainly feeding on crustaceans, bony fish and molluscs as well as polychaete and nematode species (Najai & Ktari, 1979; Guerra, 1985; Hanlon & Messenger, 1996). With increasing size cuttlefish also exhibit cannibalistic behaviour (Nixon, 1987). The octopus, *E. cirrhosa* is benthic and feeds mainly on crustaceans and molluscs, with crustaceans predominating (Boyle, 1983). They are known to take large Crustacea trapped in creels, including lobster (*Homarus gammarus*), edible crab (*Cancer pagurus*) and Norway lobster (*Nephrops norvegicus*) (Boyle, 1983).

5. Fisheries and trends in abundances

5.1. Cephalopod fisheries

Data on cephalopod landings from the ICES area are compiled by the ICES Working Group on Cephalopod Fisheries and Life History (WGCEPH, Table 1). The SEA 7 Area corresponds approximately to ICES Divisions VIa, and VIb, which are fished by Scottish, other UK (English/Welsh/Northern Irish), Irish, French and Spanish fleets. Data for these fleets are collected separately and compiled by the respective national fisheries laboratories. General patterns in landings for ICES Divisions VIa and VIb can be inferred from data presented in the WGCEPH report 2005 (Anon., 2005). Common squid (i.e. long-finned squid, loliginids): *L. forbesi, L. vulgaris, A. subulata*) is the most important cephalopod fishery resource in these areas, with the Scottish fleet alone typically landing around 200-300 tonnes annually since 2000.

Significant landings of short-finned squid (*I. coindetii, T. eblanae, T. sagittatus*) from ICES Divisions VIa and VIb were also reported during the 1990's, mainly by Spain (25-50 tonnes annually). However, very little has been reported from these areas since 2000 (Anon., 2005).

Only Spain reported small annual landings of cuttlefish (mainly *S. officinalis*) from ICES Divisions VIa and VIb (<20 tonnes) pre-2000 (although the Scottish fleet landed 5 tonnes in 2001). Octopus landings (mainly *E. cirrhosa*) of c. 30 tonnes per annum were reported by Spain pre-1999 (Anon., 2005). Since 2001, reported landings of cuttlefish and octopods from ICES Divisions VIa and VIb have been negligible. 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 demersal trawling, landings per unit effort (LPUE) can be used as an index of species abundance (see Pierce *et al.*, 1994a) and such data were available on a monthly, by ICES rectangle, basis (pre-1998 only for Scotland, these are no longer available due to changes in the recording of fishing effort).

5.2. Long-fin squid

In general, most squid catches in the UK, as in most northern European countries, are a by-catch of demersal trawl and seine net fisheries (Boyle & Pierce, 1994a). There is, however, increased interest in directed fishing in Scotland, with trawlers in the Moray Firth and Firth of Forth targeting squid in the autumn. Landings of loliginid squid (Mainly *L. forbesi*) in ICES Divisions VIa and VIb, by the UK fleet (landing into the UK and abroad), ranged from 217 – 484 tonnes in the years 2000 and 2003, respectively with corresponding values of £275,000 – £910,000 (Scottish Sea Fisheries Statistics, 2004) (Table 2, Figure 3). Taking into account combined fishery data from the SEA 7 Area, squid landings from this area represent a significant proportion of the total caught in UK waters (Figure 4). Although large catches of loliginid squid are reported by a number of European fleets, significant proportions caught in the SEA Area 7 are only apparent for the Irish and Scottish fleets (Figure 5).

Approximately 453 tonnes of loliginid squid was landed in Scotland from catches in the SEA 7 Area in 2003, around 20 % of the total that year (Figure 5). Within the SEA 7 Area, the majority of squid landed are caught in ICES Division VIa (west of Scotland). The proportion of squid caught in ICES Division VIb (mainly Rockall Bank) has ranged from 2–23% over recent years (Table 2, Figure 4). As Figure 6 shows, the squid fishery in Scottish waters is cyclical occurring mainly in Autumn-Winter. The spatial distribution of landed catches of loliginid squid from the SEA 7 Area is illustrated in Figures 7–8.

5.3. Short-fin squid

Landings of short-fin squid (Ommastrephids, mainly *I. coindetii*, *T. sagittatus*, *T. eblanae*) caught in the SEA Area 7 by the Spanish fleet peaked at 177 tonnes in 1998. Since then, however Spanish boats have landed <20 tonnes per annum from the SEA 7 Area. During this period, the only other significant landings of short-fin squid (probably *T. eblanae*) from SEA Area 7 were 13 tonnes and 32 tonnes reported by the UK and Irish fleets, respectively in 2003. Apart from these, landings of short-fin squid from the SEA 7 Area since 1998 have been negligible (Table 1).

5.4. Cuttlefish and octopods

The Spanish fleet landed 16 tonnes of cuttlefish (mainly *S. officinalis*) from the SEA 7 Area in 1998. French and Scottish boats also reported small catches, of 5 tonnes in 1999 and 2001, respectively. Apart from these, landings of cuttlefish from the SEA 7 Area since 1998 have been negligible (Table 1).

The Spanish fleet landed 42 tonnes of octopods (mainly *E. cirrhosa*) from the SEA 7 Area in 1998. However, landings from this area have been negligible since 1998. The English fleet has reported small catches of 0-3 tonnes of octopods per annum from the SEA 7 Area since 1998 (Table 1). The spatial distribution of landed catches of octopods from the SEA 7 Area is illustrated in Figure 9.

6. Sensitivity to environmental contamination

6.1. Heavy metal contamination

Heavy metals, including arsenic, barium, cadmium, chromium, copper, iron, mercury, nickel, lead and zinc reach the marine environment via rivers and certain marine operations, such as the exploitation of offshore resources and disposal of dredged materials. Highest concentrations of trace metals are found near freshwater outlets, with much lower levels in the open sea. Metallic contaminants are incorporated in the body of top marine predators via the food chain (Stowasser *et al*., 2005). Consequently, diet is the first factor controlling the metal intake (Aguilar *et al*., 1999). Transfer of trace elements from prey to predator greatly depends on the bioavailability of the metal, which is determined by the detoxification processes in prey species. Metals located in the cytosolic fraction are readily available to higher trophic levels, whereas those bound to the insoluble subcellular fraction have a lower potential for transfer (Wallace & Lopez, 1997). Consequently, the different physico-chemical forms of metals in preys appear to be a key factor that might control the metal bioaccumulation in top marine predators. The most recent survey of mercury levels in cephalopods from the Northeast Atlantic indicated higher levels of mercury in demersal cephalopods than in pelagic species (Bustamante *et al*., 2006)

As trace elements, certain metals (e.g. copper, selenium, zinc) are 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 bio-accumulate to harmful levels in the tissue.

6.2. Oil and gas production

At present, offshore oil and gas production is a major environmental issue in other waters around the UK (Pierce *et al*., 2002; Stowasser *et al*., 2004; Sacau *et al*., 2005), but not in the SEA 7 Area. The main risks of oil pollution in this area are currently from accidental spills, bunkering operations, fishing vessel casualties and tanker source spillages (Acops, 1999). However, during the past 20 years there has been considerable interest in the potential of the SEA 7 Area for oil production. Important sedimentary basins are found to the west of Shetland and around St. Kilda. The UK continental shelf area is divided into quadrants for the purposes of licensing hydrocarbon exploration and production. Each block measures 1° by 1° (except where the coastline or a neighbouring country's continental shelf intervene) and each is given a unique number and divided into 30 blocks of average 90 square miles in size. At present, the SEA 7 Area contains c. 36 of the 110 UK licensed blocks (including 12 with licensed acreage). More than 100 exploration wells had been drilled in the UK sector of the Atlantic margin before BP discovered the Foinaven and Schiehallion oilfields to the west of Shetland in 1992/1993 (Table 3). A wide variety of wastes are produced during oil and gas production. Based on the current level of interest from oil companies, it is possible that significant oil fields may be discovered in the SEA 7 Area and exploited in future. Therefore, the possible effects of oil and gas production on cephalopods in this area should be considered. These are discussed in detail in previous SEA Area reports (Pierce *et al*., 2002; Stowasser *et al*., 2004; Sacau *et al*., 2005).

6. 3. Radionuclide contamination

Radionuclides discharged by the nuclear industry may also have a contaminating effect on marine biota. The main contribution to anthropogenic marine radioactivity is 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 UK waters, including the SEA 7 Area, 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). Many radionuclides exhibit 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 km in the North Atlantic (Kershaw *et al.*, 1995). Although recent years have seen the improvement of waste treatments, Sellafield is still a major source 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 readily accumulate in seafood (STOA, 2001, Aarkrog, 2003).

6.4. Sensitivity of cephalopods to heavy metals

Cephalopods represent an important link in marine food webs, being consumed by many top predators such as marine mammals, birds and fish (e.g. Clarke, 1996, Croxall & Prince, 1996, Smale, 1996, Santos *et al.*, 2001a, Stowasser *et al*., 2005). Studies on trace metal contents in cephalopod tissues indicated significant bioaccumulation in the digestive gland (hepatopancreas) (Martin & Flegal, 1975, Schipp & Hevert, 1978, Miramand & Bentley, 1992, Caurant & Amiard-Triquet, 1995, Bustamante *et al.*, 1998a,b, 2002, 2006; Stowasser *et al*., 2005). The availability of trace metals in cephalopods indicates their importance as vectors of contaminant transfer in the food chain.

Like many other molluscs, cephalopods rapidly accumulate high levels of cadmium, copper mercury and zinc and other trace metals (Martin & Flegal, 1975, Finger & Smith, 1987; Stowasser *et al*., 2005). 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 100 times higher than those of 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; Stowasser *et al*., 2005). Even in areas like the Faroer and Kerguelen islands, which are relatively isolated from human activity, high cadmium concentrations were found in both cephalopods and their marine mammal predators (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). During a recent study funded by the Department of Trade and Industry, Stowasser *et al*. (2005) found cadmium and mercury levels in squid to be highly variable between- and within-species (Table 4). Spatial and temporal variations of the concentrations of these metals in the tissues of *Loligo forbesi* were also observed, with the highest levels recorded in the SEA 7 Area (west of Scotland) during March (Table 5) although these may be confounded by seasonal migrations (Stowasser *et al*., 2005).

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 6. 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.

6.5. Sensitivity of cephalopods to radionuclides

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 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 7). 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).

6.6. 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.

6.7. Other conservation issues

The only other serious impact involving cephalopod species in the SEA 7 Area would be the physical disturbance of spawning grounds due to displacement of bottom sediments. Loliginid squid aggregate to spawn – during a recent study, Stowasser *et al*. (2005) compared the distributions of mature adult *L. forbesi* during spawning with suitable physical habitat conditions for spawning. Based on these, extensive areas of seabed within the SEA 7 Area, and elsewhere in UK waters, were identified as potentially suitable spawning habitat for *L. forbesi* (Figure 10). However, at present, it is unclear how many of these areas are actually used by squid . Since *L. forbesi* is an annual species (Boyle *et al.*, 1995), serious failure to reproduce and recruit in one year may endanger the survival of the population. In the SEA 7 Area, spawning could occur over an extended area and the *L.*

forbesi population is probably less dependent on any single spawning site so that localised disturbance would not affect breeding success of the whole population. However, occasional targeted fishing for squid could reflect a high concentration of spawning activity under pressure.

In the north-eastern part of the SEA 7 Area and off the west coast of Scotland 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* 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. Quantifying the effects of human activity on the marine ecosystem is problematic since no pristine "baseline" marine habitats exist and historical data are sparse - and may still be impacted by historical activities (Frid *et al*., 2000).

7. Conclusions

- Cephalopod species of economic and/or ecological importance in the SEA 7 Area are the long-finned squid species *Loligo forbesi* and *Alloteuthis subulata*.
- The most important commercial species in the SEA 7 Area is *L. forbesi*, which is landed as by-catch of the UK demersal trawl fishery (485 tonnes, generating £910,000 (first sale value) in 2003). Genetic evidence indicates that two distinct stocks (inshore and offshore) are present in the area.
- Specimens of *A. subulata* frequently occur in hauls alongside *L. forbesi*. Even though it is of no commercial value this species has an important ecological role in the coastal food webs since it is the most commonly recorded cephalopod species in stomach contents of demersal fish in UK waters.
- Top marine predators feeding on cephalopods are naturally exposed to very high concentrations of metallic contaminants. Trace elements in cephalopods also raise potential public health concerns due to their consumption by humans.
- Drilling operations, oil spills and extensive demersal fisheries may have an effect on the propagation of cephalopod stocks should they occur in spawning areas.

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9. References

ACOPS, 1998. *Long-term analysis of oil spill statistics for the waters around the British Isles*. Report submitted to the Coastguard Agency by the Advisory Committee on the Protection of the Sea.

Aguilar, A., Borrell, A., and Pastor, T., 1999. Biological factors affecting variability of persistent pollutant levels in cetaceans. *In*: Aguilar and Donovan eds., Chemical pollutants and cetaceans, Reijnders, *J. Cetacean Res. Manage*, Special Issue, **1**: 83-116.

Amaratunga, T., 1983. The role of cephalopods in the marine ecosystem. In I. F. Caddy, *Advances in assessment of world cephalopod resources*. *FAO Fisheries Technical Papers,* **231**, 379-415.

Anonymous, 2005. Report of the Working Group on Cephalopod Fisheries and Life History (WGCEPH). International Council for the Exploration of the Sea CM 2005/05.

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.

Arkhipkin, A. I., Laptikhovsky, V. V. & Golub, A., 1999. Population structure and growth of the squid *Todarodes sagittatus* (Cephalopoda: Ommastrephidae) in north-west African waters. *Journal of the Marine Biological Association of the United Kingdom* 79: 467-477.

Barghigiani, C., Dulivo, A., Zamboni, R. & Lampugnani, L., 1993. Interaction between selenium and cadmium in Eledone cirrhosa of the Northern Tyrrhenian Sea. *Marine Pollution Bulletin*, **26**, (4), 212 - 216.

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.

Bidder, A., 1950. The digestive mechanism of the European squids *Loligo vulgaris*, *Loligo forbesi*, *Alloteuthis media*, and *Alloteuthis subulata*. *Quarterly Journal of Microscopical Science*, **91**, 1-43.

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

BNFL, 1997. Annual report on radioactive discharges and monitoring of the environment 1996. BNFL, Risley, UK.

Boletzky, S.v., 1975. The reproductive cycle of Sepiolidae (Mollusca, Cephalopoda). *Pubblicazioni della Stazione Zoológica di Napoli*, **39** (Suppl.), 84-95.

Boletzky, S.V., 1983. *Sepia officinalis*. In Cephalopod life cycles Vol.1. Ed. by Boyle, P.R. Academic Press, London.

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, R. and T. Kubodera (editors), *Recent Advances in Cephalopod Fisheries Biology*. Tokai University Press, Tokyo, pp. 25-36.

Boucaud-Camou, E. and Boismery, J., 1991. The migration of the cuttlefish *Sepia officinalis* L. in the English Channel. In: E. Boucaud-Camou (Editor), "The cuttlefish", Act. 1st International Symposium on the Cuttlefish Sepia Caen, June 1-3 1989, Centre de publications de l'Université de Caen, pp. 179-189.

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.

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

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.

Bustamante, P., Lahaye, V., Durnez, C., Churlaud, C. & Caurant, F. 2006. Total and organic Hg concentrations in cephalopods from the North Eastern Atlantic waters: Influence of geographical origin and feeding ecology. *Science of the Total Environment*, **368**, 585-596.

Bustamante P., Teyssié J-L., Fowler S.W., Cotret O., Danis B., Miramand P., and Warnau M., 2002. Biokinetics of zinc and cadmium accumulation and depuration at different stages in the life cycle of the cuttlefish *Sepia officinalis*. *Marine Ecology Progress Series*, **231**, 167-177.

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.

CEFAS, 1998. Monitoring surveillance of non-radioactive contaminants in the aquatic environment and activities regulating the disposal of wastes at sea, 1995 and 1996. CEFAS, Lowestoft. *Science Series Aquatic Environment Monitoring Reports*, No. 51.

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

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 Journal of Marine Science*, **51**, 337-344.

Collins, M. A., Burnell, G. M. & Rodhouse, P. G., 1995b. Reproductive strategies of male and female *Loligo forbesi* (Cephalopoda: Loliginidae). *Journal of the Marine Biological Association of the United Kingdom* **75**, 621-634.

Collins, M. A., Burnell, G. M., and Rodhouse, P. G., 1995a. Distribution and demography of *Loligo forbesi* in the Irish Sea. *Biology and Environment: Proceedings of the Royal Irish Academy*, **95B**, 49-57.

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., 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.

Cook, G. T., MacKenzie, A. B., McDonald, P., Jones, S. R., 1997. Remobilization of Sellafield-derived radionuclides and transport from the North-east Irish Sea. *J. Environ. Radioactivity*, **35**, 227-241.

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.

Crumpton, C.A. and Goodwin, M.J., 1995. Chapter 9.7 Water Quality and Effluent Discharges. In: Coasts and seas of the United Kingdom. Region 12 Wales: Margam to Little Orme. J.H. Barne, C.F. Robson, S.S. Kaznowska and J.P. Doody. eds. Peterborough, Joint Nature Conservation Committee. 213-217.

Crumpton, C.A., Goodwin, M.J. and Holt, T.J., 1996. Chapter 9.6 Water Quality and Effluent Discharges. In: Coasts and seas of the United Kingdom. Region 13 Northern Irish Sea: Colwyn Bay to Stranraer, including the Isle of Man. ed. by J.H. Barne, C.F. Robson, S.S. Kaznowska, J.P. Doody & N.C. Davidson. Peterborough, Joint Nature Conservation Committee. 245-252.

Crumpton, C.A. and Goodwin, M.J., 1996. Chapter 9.6 Water Quality and Effluent Discharges. In: Coasts and seas of the United Kingdom. Region 11 The Western Approaches: Falmouth Bay to Kenfig, J.H. Barne, C.F. Robson, S.S. Kaznowska, J.P. Doody, N.C. Davidson and A.L. Buck., eds. Peterborough, Joint Nature Conservation Committee. 231-236.

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., Boyle, P.R. & Collins, M.A., 1998. Reproductive status of *Opisthoteuthis* sp. Over an annual cycle. *South African Journal of Marine Science,* **20**, 187-192.

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.

Decleir, W., Vlaeminck, A., Geladi, P. and Van Grieken, R., 1978. Determination of protein-bound copper and zinc in some organs of the cuttlefish *Sepia officinalis* L. *Comparative Biochemistry and Physiology*, **60B**, 347-350.

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

Denis, V. and Robin, J.-P., 2001. Present status of French Atlantic fishery for cuttlefish (*Sepia officinalis*). Fisheries Research 182, 1-12.

Dillane, E., Galvin, P., Coughlan, J., Lipinski, M., Cross, T.F., 2005. Genetic variation in the lesser flying squid *Todaropsis eblanae* (Cephalopoda, Ommastrephidae) in east Atlantic and Mediterranean waters. *Marine Ecology-Progress Series*, **292**, 225-232.

Ducrotoy, J. P., Elliot, M. And De Jorge, V. N., 2000. The North Sea. *Marine Pollution Bulletin*, **41**, 5-23.

Dunn, M.R., 1999. Aspects of the stock dynamics and exploitation of cuttlefish, *Sepia officinalis* (Linnaeus, 1758), in the English Channel. Fisheries Research 40, 277-293.

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.

Frid, C. L. J., and Clarck, R. A., 2000. Long-term changes in North Sea benthos: discerning the role of fisheries. In *Effects of Fishing on non-target species and habitats: biological, conservation and socio-economic issues*, eds. M. J. Kaiser and S. J. De Groot, pp. 198-216, Blackwell Science Ltd.

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.

Froesch, D. and Packard, A., 1979. Octopus chromatophores accumulate nickel. *Experientia*, **35**, 828-829.

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

Ghiretti-Magaldi, A., Giuditta, A. and Ghiretti, F., 1958. Pathways of terminal respiration in marine invertebrates. I. The respiratory system in cephalopods. *Journal of Cellular and Comparative Physiology*, **52**, 389-429.

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.

Guary J.-C.,Fowler S. W. ,and Beasley T. M., 1982. Routes of plutonium uptake and their relation to biomagnification in starfish. *Marine Pollution Bulletin*, **13**, 99-102.

Guerra, A., 1982. Cephalopods collected in the Gulfo de Cadiz 81 cruise to Southwest Spain. *Resultados Cientificos*, **10**, 17-50.

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

Guerra, A., 1996. Explotación mundial de cefalópodos. In: II Jornadas Internacionales sobre Utilización de Cefalópodos: Aspectos Científicos y tecnológicos. Madrid, Spain: Instituto del Frío.

Guerra, A. & Rocha, F., 1994. The life history of *Loligo forbesi* (Cephalopoda: Loliginidae) in Galacian waters (NW Spain). *Fisheries Research* **21**, 43-69.

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*, **74**, 367-382.

Heij, De, A. & Baayen, R.P., 1999. Seasonal distribution of the cephalopod *Alloteuthis subulata* in the central and southern North Sea. *Basteria*. **63**, p.129.

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., 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.

Holme, N. A., 1974. The biology of *Loligo forbesi* Steenstrup (Mollusca: Cephalopoda) in the Plymouth area. *J. Mar. Biol. Assoc. UK* **54**, 481-503.

Hunt, G. J., Kershaw, P. J., 1990. Remobilisation of artificial radionuclides from the sediment of the Irish Sea. *J. Radiological protection*, **10**, 147-151.

Joy, J.B., 1989. The Fishery Biology of Ommastrephid squids in Shetland waters. M.Sc Thesis, University of Aberdeen.

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

Kennedy, V. H., Horrill, A.D. and Livens, F.R., 1988. Radioactivity and wildlife. Institute of Terrestrial Ecology NCC/NERC contract HF 3-08-21 (10). TFS Project T07006GL. Merlewood Research Station.

Kershaw, P. J., Pentreath, R. J., Woodhead, D. S. and Hunt, G. J., 1992. A review of radioactivity in the Irish Sea. A report prepared for the Marine Pollution Monitoring Management Group. *Aquatic Environment Monitoring Report* Number **32**, MAFF, Lowestoft.

Kershaw, P. J., Denoon, D. C. and Woodhead, D. S., 1999. ´Observations on the redistribution of plutonium and americium in the Irish Sea sediments, 1978 to 1996: concentrations and inventories´. *J. Environ. Radioactivity*, **44**, 191-221.

Klages, N. T. W., 1996. Cephalopods as a prey. II. Seals. *Philosophical Transactions of the Royal Society London Series*, **351**, 1045-1052.

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 fabricii. In Boyle, P.R. (editor). *Cephalopod Life Cycles, Volume 1. Species Accounts.* Academic Press, London, pp. 159-174.

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.

Le Goff, R. and Daguzan, J., 1991. Growth and life cycles of the cuttlefish *Sepia officinalis* L. (Mollusca: Cephalopoda) in south Brittany (France). Bulletin of Marine Science 49, 341-348.

Lipinski, M. R., 1985. Laboratory survival of *Alloteuthis subulata* (Cephalopoda: Loliginidae) from the Plymouth area. *Journal of the Marine Biological Association of the United Kingdom*, **65**, 845 - 855.

Lordan, C., Collins, M. A., Burnell, G., and Cross, T. F., 1995. The significance of cephalopods in Irish fisheries. *International Council for the Exploration of the Sea Council Meeting*, K: **13**, 1-13.

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*s, **20**, 153-163.

Lordan, C., Collins, M.A., Key, L.N. & 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.

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

Massy, A. L., 1909. The Cephalopoda Dibranchiata of the coasts of Ireland. Fisheries Ireland Sci. Inevst., 1, 1-39.

Massy, A. L., 1928. The Cephalopoda of the Irish coast. *Proceedings of the Royal Irish Academy*, **38B**, 25-37.

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.

Miramand, P. and Guary, J. C., 1980. High concentrations of some heavy metals in tissues of the Mediterranean octopus. *Bulletin of Environmental and Contamination Toxicology*, **24**, 783-788.

Morris, K., Butterworth, J. C., Livens, F. R., 2000. Evidence for the remobilization of Sellafield waste radionuclides in an intertidal salt marsh, West Cumbria, UK. *Estuarine Coastal and Shelf Science*, **51**, 613-625.

Najai, S. & Ktari, M. H., 1979. Etude du régime alimentaire de la seiche commune *Sepia officinalis* Linné, 1758 (Mollusque, Céphalopode) du golfe de Tunis. *Bull. Inst. natn. scient. techn. Océanogr. Pêche Salammbô*, **6**, 53 - 61.

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. MSc thesis, University of Tromsø.

OSPAR 2000. Quality Status Report 2000, Region III- Celtic Seas. OSPAR Commission London, 136 p.

Parrett, A., 1998. Pollution Impacts on North Sea Fish Stocks. (1998). European Commission, Directorate General XIV - Fisheries. Ref: 96-083.

Pawson, M.G., 1995. Biogeographical identification of English Channel fish and shellfish stocks. MAFF Fisheries Research technical Report. 99. CEFAS. Lowestoft.

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

Piatkowoski, U., Hernandez-Garcia, V. & Clarke, M.R., 1998. On the biology of the European flying squid *Todarodes sagittatus* (Lamarck, 1798) (Cephalopoda, Ommastrephidae) in the central eastern Atlantic. *South African Journal of Marine Science* 20: 375-383.

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

Pierce, G. J., Boyle, P. R., Hastie, L. C. and Santos, M. B., 1994b. 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., 1994a. 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., 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).

Pierce, G.J., Santos, M. B., Mente, E., Wang, J., Stowasser, G. and Boyle P. R., 2003. *An Overview of Cephalopods Relevant to the SEA 4 Area*. Department of Trade and Industry Report (available at http://www.offshore-sea.org.uk).

Pierce, G.J., Zuur, A.F., Smith, J.M., Santo, B.M. Bailey, N., Chen, C. & Boyle, P.R., 2005. Interannual variation in life-cycle characteristics of the veined squid (*Loligo forbesi*) in Scottish (UK) waters. *Aquatic Living Resources* **18**, 327-340.

Poole, A.J., Denoon, D. C. and Woodhead, D. S., 1997. ´The distribution and inventory of ^{137}Cs in sub-tidal sediments of the Irish Sea´. *Radioprotection-Colloques*, **32**, 263-270.

Raimundo, J., Caetano, M., and Vale, C., 2004**.** Geographical variation and partition of metals in tissues of *Octopus vulgaris* along the Portuguese coast. *Science of the Total Environment* **325**, 71-81.

Renzoni, A., Bacci, E. and Falciai, L., 1973. Mercury concentration in the water, sediments and fauna of an area of the Tyrrhenian coast. *Revue Internationale d´Océanographie Médicale*, **31-32**, 17-45.

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.

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

Rocha, F., González, A. F., Rasero, M.,Guerra, A., Castro, B. G. & Cortez , T., 1996. An overview on the reproductive strategies in Cephalopoda. *ICES Working Group on Cephalopod Fisheries and Life Histor*y. 17-19 April 1996, Lisbon, Portugal, 6 pp.

Rocha, F., Castro, B.G., Gil, M.S. & Guerra, A., 1994. The diets of *Loligo vulgaris* and *Loligo forbesi* (Cephalopoda: Loliginidae) in northwestern Spanish Atlantic waters. *Sarsia* **79**, 119-126.

Rodhouse, P. G., Swinfen, R.C. and Murray, A. W. A., 1988. Life cycle, demography and reproductive investment in the myopsid squid *Alloteuthis subulata*. *Marine Ecology*, **45**, 245-253.

Rodhouse, P. G., 1989. Antartic cephalopods-a living marine resource? *Ambio*, **18**, 56-59.

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.

Rosenberg, A.A., Wiborg, K.F. & Bech, I.M., 1980. Growth of *Todarodes sagittatus* L. (Cephalopoda: Ommastrephidae) from the Northeast Atlantic, based on counts of statolith growth rings. *Sarsia* **66**, 53-57.

Sacau, M., Pierce, G.J., Stowasser, G., Wang, J. & Santos, M.B., 2005. *An Overview of Cephalopods Relevant to the SEA 6 Area*. Department of Trade and Industry Report (available at http://www.offshore-sea.org.uk).

Santos, M.B., Clarke, M.R. and Pierce, G. J., 2001. 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., Boyle P.R., Reid, R.J., Ross, H.M., Patterson, I.A.P., Kinze, C.C., Tougaard, S., Lick, R., Piatkowski, U. & 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.

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

Seixas, S., Bustamante, P. & Pierce, G. J., 2005. Accumulation of mercury in the tissues of the common octopus *Octopus vulgaris* (L.) in two localities on the Portuguese coast. *Science of the Total Environment* **340**, 113-22.

Sheahan, D., Rycroft, R., Allen, Y., Kenny, A., Mason, C. & Irish, R., 2001. Contaminant Status of the North 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.

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.

Scottish Sea Fisheries Statistics, 2003. Scottish Executive Rural Affairs Department.

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.

Stowasser, G., Pierce G., J., Wang, J., and Santos, M. B. 2004. *An Overview of Cephalopods Relevant to the SEA 5 Area*. Department of Trade and Industry Report (available at http://www.offshore-sea.org.uk).

Stowasser, G., Bustamante, P., MacLeod, C.D., Wang, J. & Pierce, G.J., 2005. *Spawning Areas and Selected Metal Concentrations in Squid (Loligo forbesi) in UK Waters, with Notes on Metal Concentrations in other Squid Species*. Department of Trade and Industry Report.

Stowasser, G., Pierce, G.J., Moffat, C.F., Collins, M.A. & Forsythe, J.W., 2006. Experimental study on the effect of diet on fatty acid and stable isotope profiles of the squid *Lolliguncula brevis*. *Journal of Experimental Marine Biology and Ecology*, **333**, 97-114.

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.

Ueda, T., Nakahara, M., Ishii, T., Suzuki, Y. And Suzuki, H., 1979. Amounts of trace elements in marine cephalopods. *Journal of Radiation Research*, **20**, 338-342.

Ueda T.,Nakahara M., Nakamura R., Suzuki Y., and Shimizu C., 1985.Accumulation of ^{65}Zn by Octopus *Octopus vulgaris .J. Radiat. Res.*, **26**: 313-320.

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.

Wallace, W. G., and Lopez, G. R., 1997. Bioavailability of biologically sequestered cadmium and the implications for metal detoxification. *Mar. Ecol. Prog. Ser*., **147**, 149-157.

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.

Wiborg, K.F., 1972. The squid *Todarodes sagittatus* (Lamarck). Norwegian investigations in the Norwegian Sea and North Atlantic waters 1970-1972. International Council for the Exploration of the Sea C.M. 1972/K:25.

Wiborg, K.F. & Gj∅sæter, 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. & Beck, I.M., 1984. The squid *Todarodes sagittatus* (Lamarck) investigations in the Norwegian coastal and bank waters, July 1983-January 1984, and west of the British Isles, March-April 1984. International Council for the Exploration of the Sea C.M. 1984/K: 20.

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

Yamada, H., Takayanagi, K., Tateishi, M., Tagata, H. and Ikeda, K., 1997. Organotin compounds and polychlorinated biphenyls of livers in squid collected from coastal waters and open ocean. *Environmental Pollution*, **96**, 217-226.

Young, I.A.G., Pierce, G.J., Stowasser, G., Santos, M.B., Wang, J., Boyle, P.R., Shaw, P.W., Bailey, N., Tuck, I. & Collins, M.A., 2006. The Moray Firth directed squid fishery. *Fisheries Research* **78**, 39-43.

Table 1. Total annual cephalopod landings (in tonnes) from catches in ICES Divisions VIa and VIb, by national fleets. Also shown are total landings for each category in the whole ICES area. This table is based on a more extensive tabulation in ICES WGCEPH Report 2005 (Anon., 2005). Data for 2004 were provisional (P).

Category and country	1998	1999	2000	2001	2002	2003	2004P
(a) Cuttlefish (Sepiidae)							
England, Wales & Northern	+	0	0			0.2	
France	0	5.3	0.6	0.4	0.2	0	
Scotland				4.8			
Spain	16	0	1	0	0	0	
Total (whole ICES area)	20275	20210	23754	18034	22614	19492	8886
(b) Common Squid (Loliginidae)							
England, Wales & N. Ireland	21	4	2	3.1	4	17	14
France	136	95	51	8.4	28	23	5.8
Ireland	101	108	41	0	0	37	
Scotland	312	347	215	226	255	453	344
Spain	56	10	3	0	5	9.6	1.6
Total (whole ICES area)	11245	11049	10253	8234	9939	7527	5177
(c) Short-finned Squid (Ommastrephidae)							
England, Wales & N. Ireland	3	5	+	0.6	1.1	13	1
France		2.7	0.4	0.1	0.2	0	
Ireland	+	0	+			32	
Spain	177	3	+	0	11	0	0.3
Total (whole ICES area)	5841	7693	5607	4260	2571	1348	10802
(d) Octopods (Octopodidae)							
Belgium	1	+	+				
England, Wales & N. Ireland	2	0	+			2.1	2
Ireland	0	1	1				
Scotland	0	+	0				
Spain	42	0	+			0	0
Total (whole ICES area)	13043	15718	16500	11461	12831	12191	13083

Table 2. Landings of squid from ICES Divisions VIa and VIb, by the UK Fleet landing into the UK and abroad for recent years. (DEFRA, UK Sea Fisheries Statistics, 1998-2004).

Landings by ICES Division	1998	1999	2000	2001	2002	2003	2004
Weight in tonnes							
Division Via	292	338	212	194	199	382	325
Division Vib	43	19	5	35	60	102	24
Total (VIa + VIb)	335	357	217	229	259	484	349
Value in £,000							
Division Via	552	394	265	379	346	725	706
Division Vib	113	21	10	109	155	185	62
Totals (VIa + Vib)	665	415	275	488	501	910	768

Table 3. Crude oil production west of Shetland ('000 tonnes per year).
Source: www.databydesign.co.uk

Oilfield	Pre - 1999	2000	2001	2002	2003	2004	Cumulative total
Foinaven	8205	4588	4419	5358	4085	3521	30177
Schiehallion	5282	5073	4780	5061	5161	4795	30152

Table 4. Average concentrations of cadmium (Cd) and mercury (Hg) in cephalopod (squid) tissues. Concentrations are expressed in µg/g wet weight (Reproduced from Stowasser *et al.*, 2005).

Species and tissues	*n*	Size range (mm)	Cd (µg/g wwt)	Hg (µg/g wwt)
Loliginidae:				
Loligo forbesi	***171***	***129 ± 78***		
Digestive gland	105		2.238 ± 2.299	0.065 ± 0.052
Muscle	101		0.021 ± 0.033	0.035 ± 0.019
Gonads	47		0.028 ± 0.036	0.034 ± 0.022
Gills	78		0.055 ± 0.066	0.029 ± 0.019
Remaining tissue	77		0.110 ± 0.121	0.028 ± 0.015
Alloteuthis sp.	***74***	***67 ± 15***		
Digestive gland	5		2.274 ± 0.618	0.017 ± 0.002
Muscle	20		0.159 ± 0.033	0.017 ± 0.005
Ommastrephidae:				
Todaropsis eblanae	***25***	***100 ± 41***		
Digestive gland	23		8.405 ± 8.638	0.042 ± 0.031
Muscle	23		0.256 ± 0.311	0.035 ± 0.035
Gonads	4		0.431 ± 0.211	0.039 ± 0.026
Gills	6		1.226 ± 1.099	0.041 ± 0.030
Remaining tissue	6		0.238 ± 0.218	0.029 ± 0.022
Todarodes sagittatus	***12***	***343 ± 100***		
Digestive gland	11		27.886 ± 27.710	0.110 ± 0.066
Muscle	12		0.068 ± 0.065	0.080 ± 0.054
Gonads	6		0.211 ± 0.289	0.061 ± 0.026
Gills	7		1.683 ± 1.634	0.047 ± 0.036
Remaining tissue	7		0.305 ± 0.356	0.064 ± 0.034

Table 5. Concentrations of cadmium (Cd) and mercury (Hg) in tissues of *Loligo forbesi* by area and month (Reproduced from Stowasser *et al.*, 2005).

	Hg (µg/g wwt)		Cd (µg/g wwt)	
Moray Firth				
Digestive gland	0.063 ± 0.024	0.022 ± 0.005	2.930 ± 1.022	4.074 ± 0.909
Muscle	0.026 ± 0.005	0.021 ± 0.002	0.010 ± 0.006	0.020 ± 0.015
Gills	0.028 ± 0.007	0.014 ± 0.003	0.020 ± 0.018	0.051 ± 0.048
Gonads	0.021 ± 0.007	0.013 ± 0.003	0.016 ± 0.019	0.006 ± 0.002
Scottish west coast				
Digestive gland	0.107 ± 0.076	0.049 ± 0.032	5.510 ± 4.598	2.535 ± 0.964
Muscle	0.060 ± 0.024	0.025 ± 0.009	0.029 ± 0.025	0.018 ± 0.030
Gills	0.059 ± 0.023	0.023 ± 0.011	0.120 ± 0.092	0.028 ± 0.022
Gonads	0.056 ± 0.010	0.024 ± 0.009	0.080 ± 0.038	0.014 ± 0.015
Irish west coast				
Digestive gland	0.100 ± 0.080	0.024 ± 0.012	4.726 ± 0.656	7.827 ± 0.944
Muscle	0.060 ± 0.012	0.021 ± 0.015	0.014 ± 0.008	0.030 ± 0.028
Gills	0.048 ± 0.016	0.016 ± 0.011	0.026 ± 0.011	0.180 ± 0.095
Gonads	*nd*	*nd*	*nd*	*nd*

nd = no data available

Table 6. 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 7. 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. Source: DEFRA, e-Digest of Environmental statistics, published August 2003.

Year	Collective dose rate[2] (man-Sv[3] per year)	Average dose per person (µSv[4] per person per year)
1990	10	0.20
1991	8	0.14
1992	5	0.09
1993	4	0.07
1994	5	0.09
1995	3	0.05
1996	4	0.07
1997	4	0.07

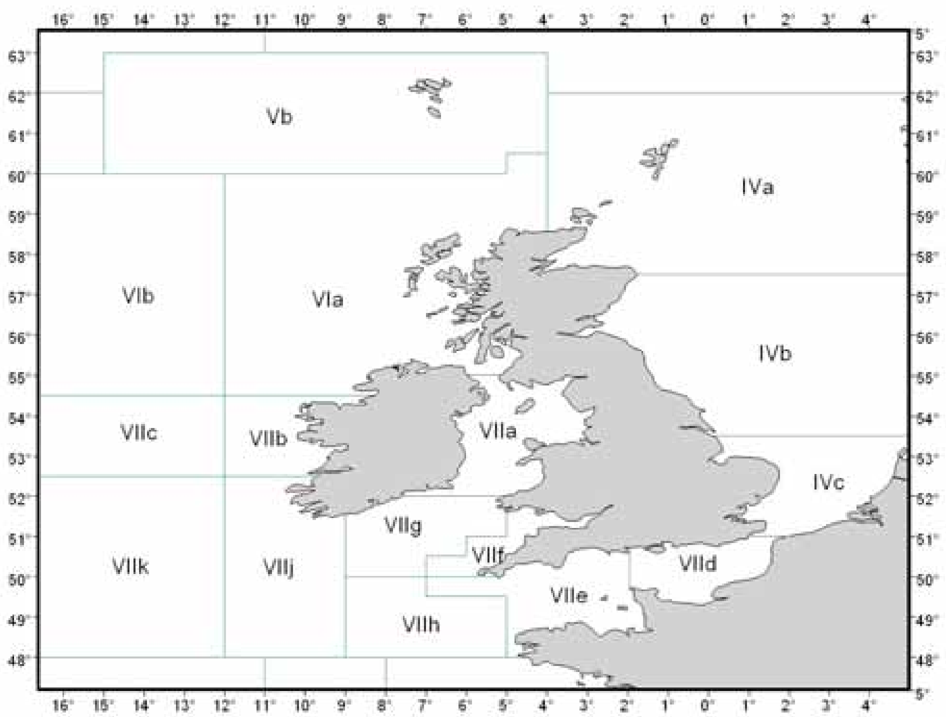


Figure 1. ICES fishing divisions situated around the British Isles.

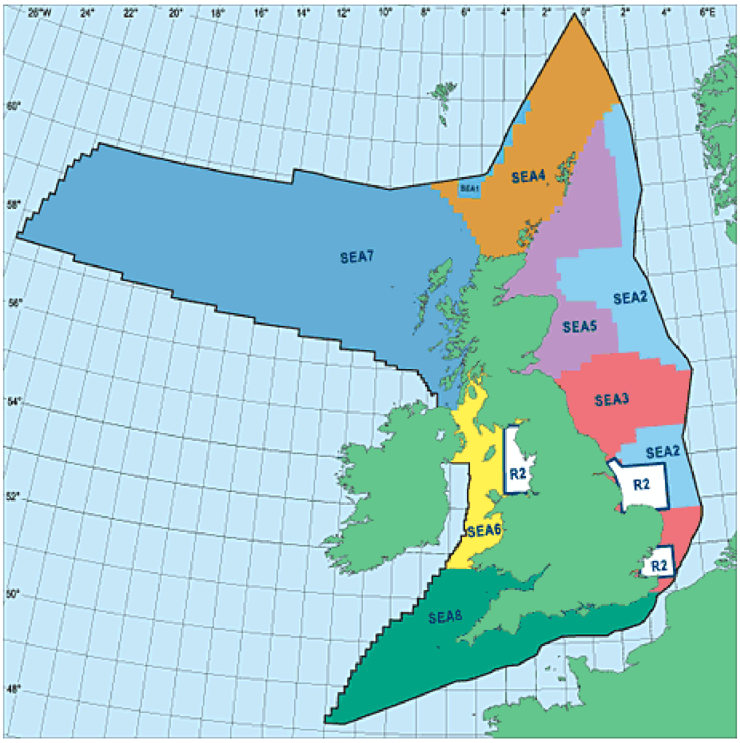


Figure 2. Maps showing the SEA Areas (SEA 7 Area in purple).

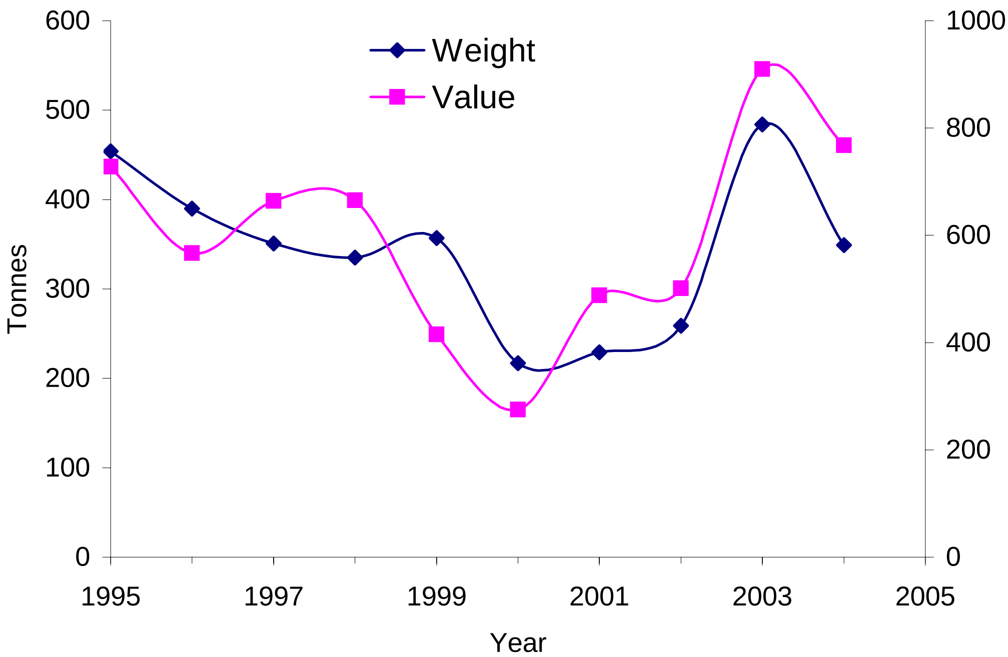


Figure 3. Total squid landings from the SEA 7 Area (ICES Divisions VIa and VIb) by the UK fleets between 1995 and 2004 (Source: DEFRA, UK Sea Fisheries Statistics).

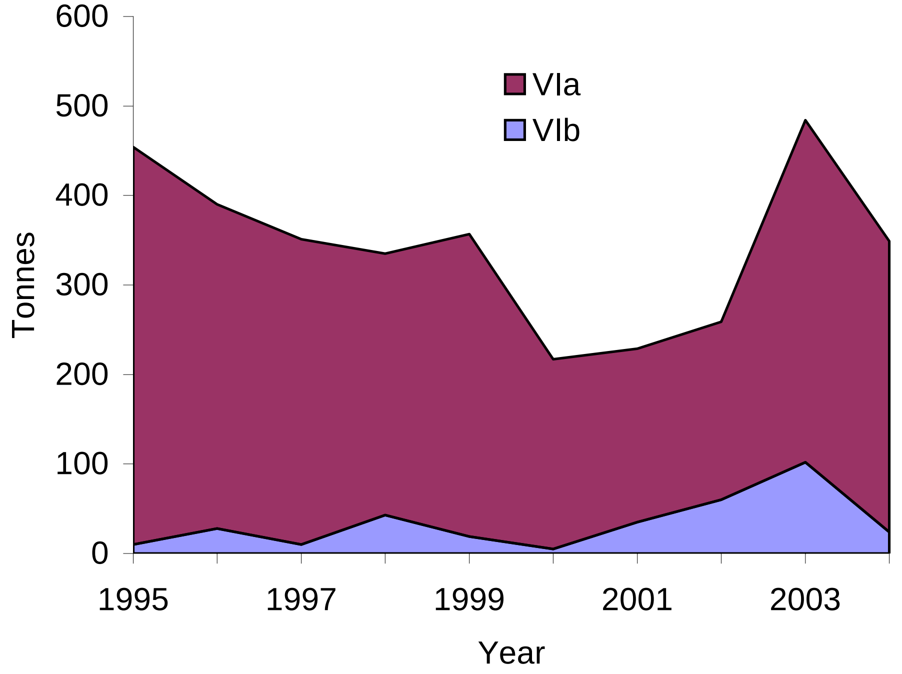


Figure 4. Total squid landings from the SEA 7 Area by ICES Division (VIa and VIb) by the UK fleets between 1995 and 2004 (Source: DEFRA, UK Sea Fisheries Statistics).

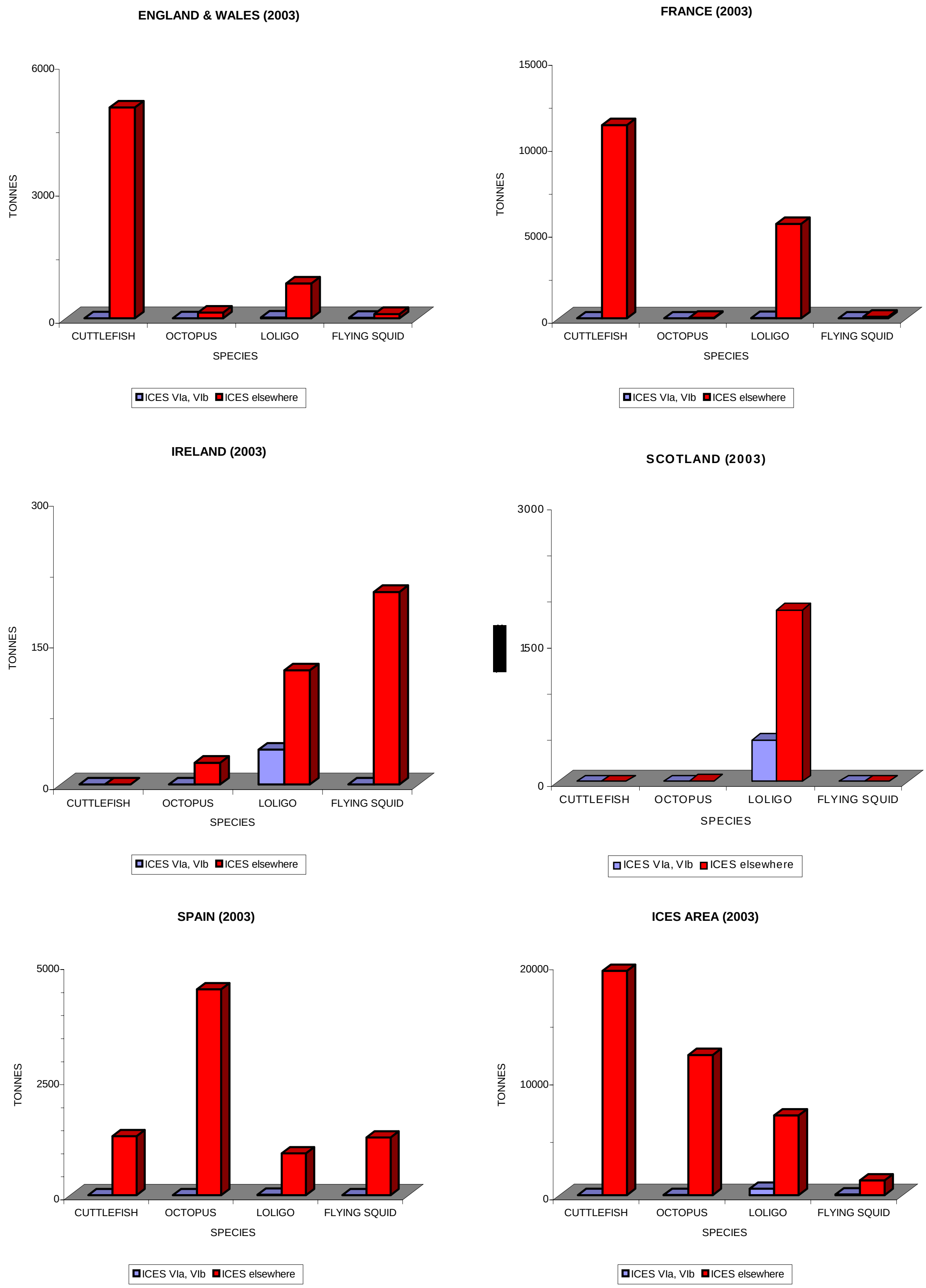


Figure 5. National cephalopod landings in 2003, by fleets fishing. Given are total landings of cephalopods caught in the SEA 7 Area (ICES Divisions VIa and VIb) and other waters (other than ICES Divisions VIa and VIb).

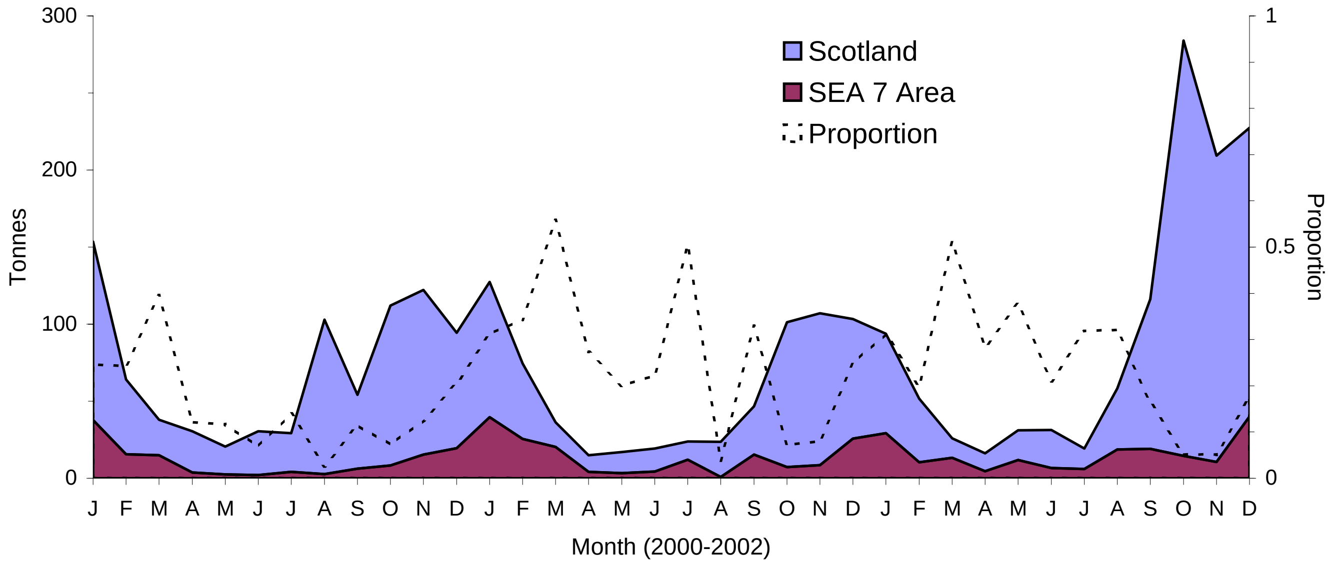


Figure 6. Monthly landings of long-fin (loliginid) squid into Scotland. The broken line shows the proportion of landings arising from catches in the SEA 7 Area.

* Scottish Fishery data

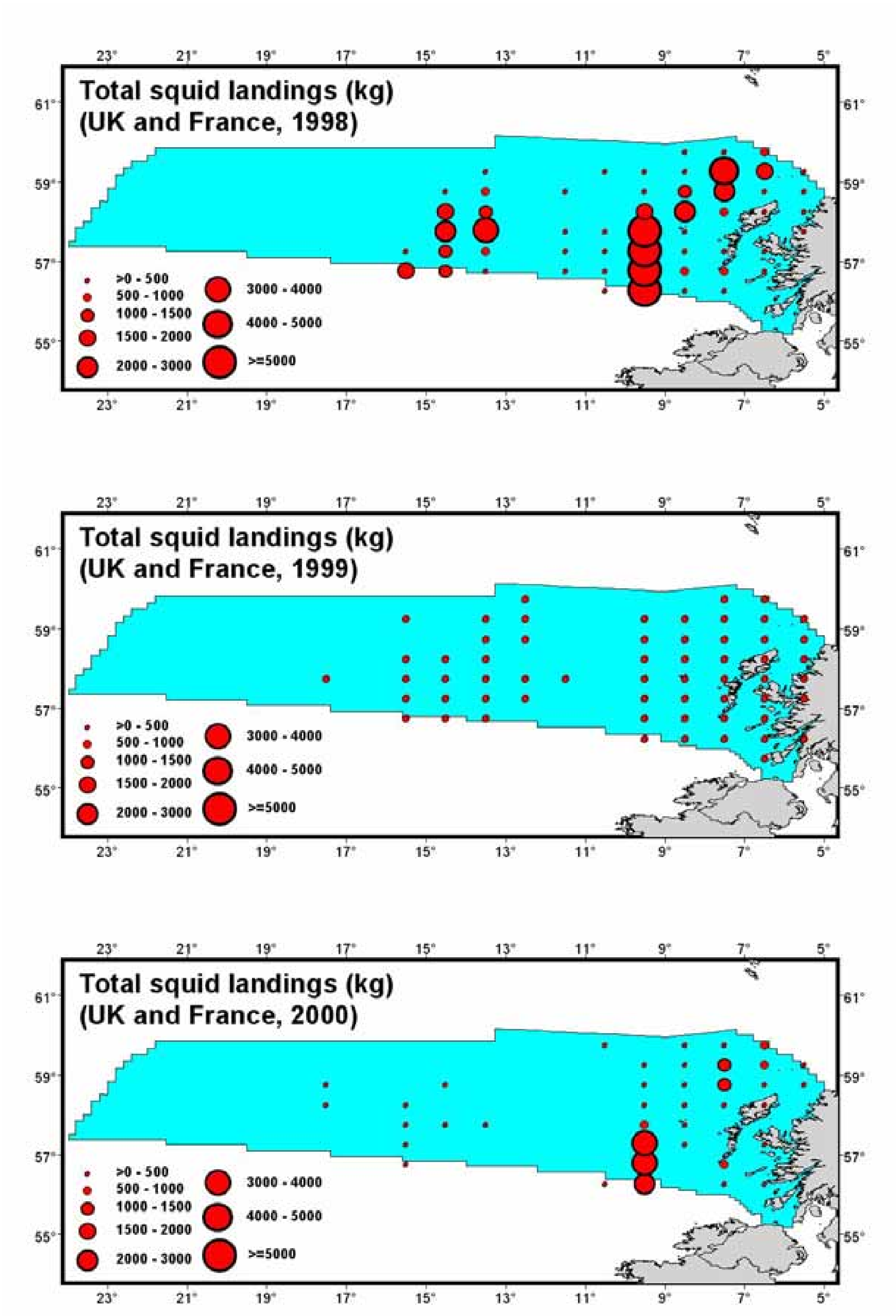


Figure 7. Total squid landings (mainly *Loligo forbesi*) from the SEA 7 Area (1998-2000).

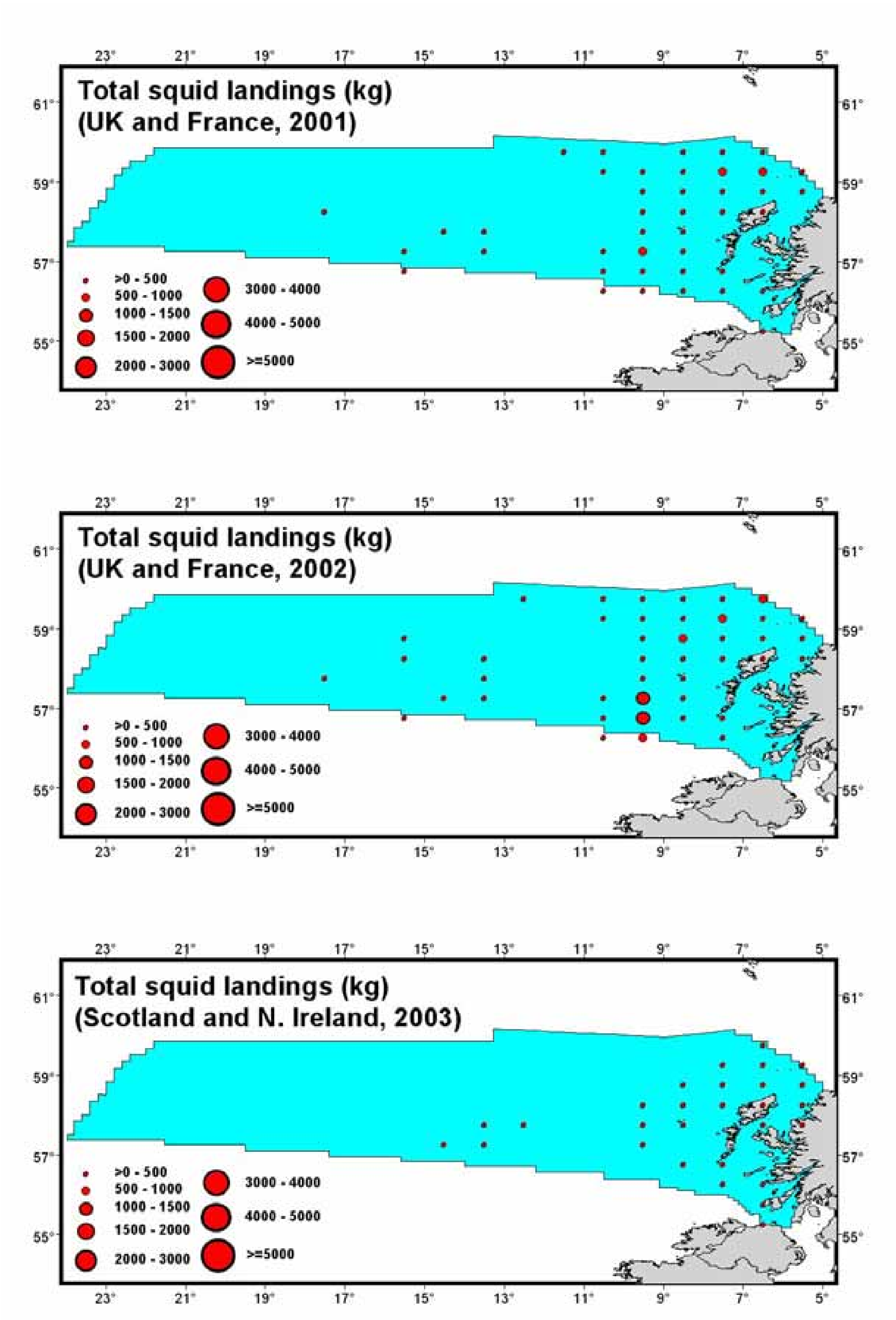
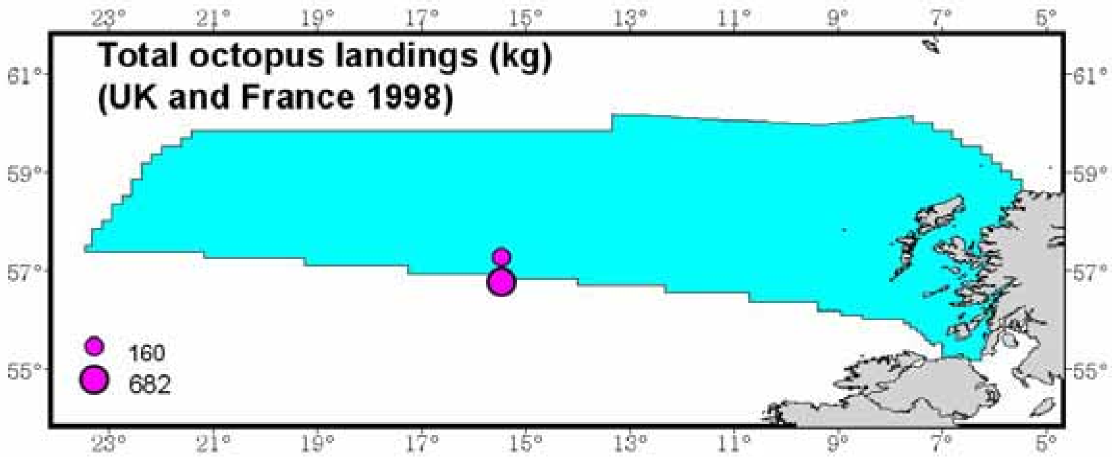


Figure 8. Total squid landings (mainly *Loligo forbesi*) from the SEA 7Area (2001-2003).



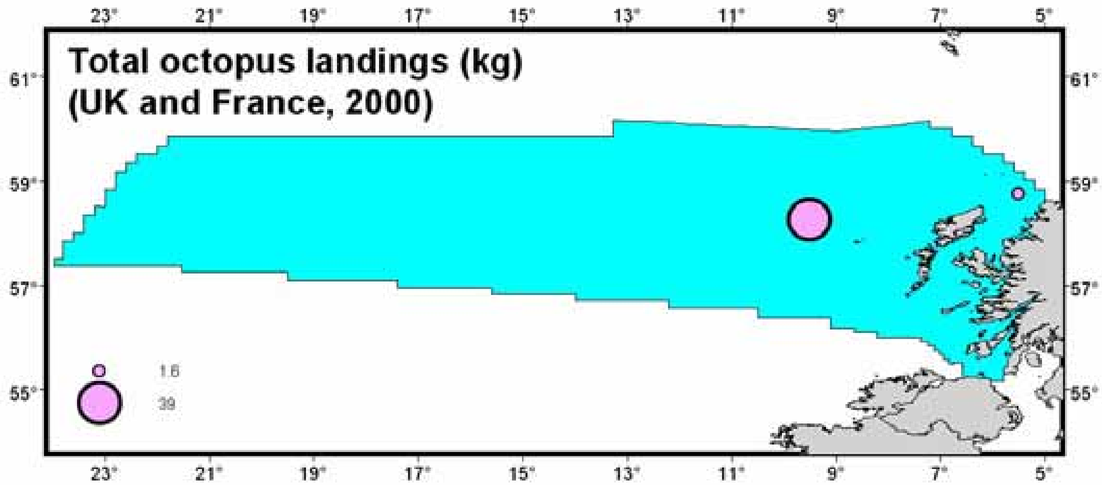


Figure 9. Total octopod (mainly *Eledone cirrhosa*) from the SEA Area 7 (1998-2000).

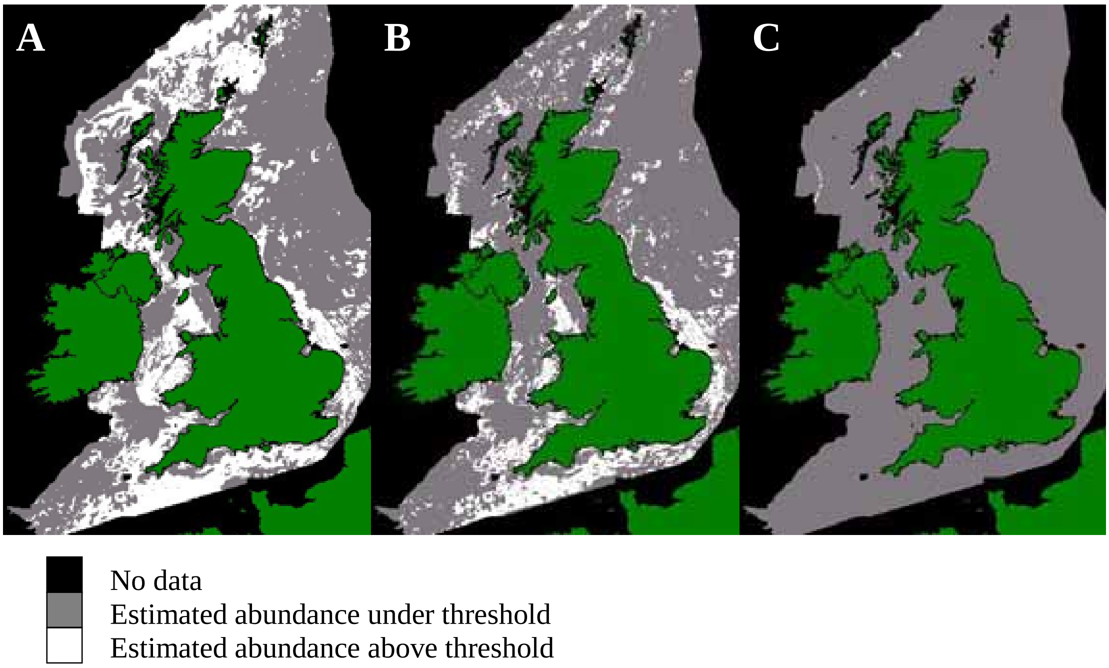


Figure 10. Potential spawning areas of *L. forbesi* in UK waters, based on aggregations of mature adults in suitable physical habitats during spawning season (November-December). Abundance thresholds: A: 5 squid.hr^{-1} fishing, B: 30 squid.hr^{-1} fishing, C: 60 squid.hr^{-1} fishing (Stowasser *et al*., 2005).

An Overview of Cephalopods relevant to the SEA 7 Area.

The class Cephalopoda comprises three major divisions, of which two: Decapoda (squids and cuttlefish) and Octopoda (octopods) are represented in the SEA 7 Area. They are highly developed, but short-lived molluscs with rapid growth rates. They are important elements in marine food webs and interact significantly with marine mammals, seabirds and commercially exploited finfish species. They also represent a promising future fishery resource in terms of market value, abundance and growth potential. At present, only an estimated 10% of exploitable stocks are utilised worldwide. There are six marketable squid species that occur in the SEA 7 Area. These belong to the long-fin (loliginid) and short-fin (Ommastrephid) squids – the two most important exploited families of decpods. In the SEA 7 Area, only one species, *Loligo forbesi* is commercially exploited on a regular basis, although there are significant landings of other species on occasion. The closely related *Loligo vulgaris* sometimes appears in catches and the small *Alloteuthis subulata* is thought to be naturally abundant and an important food item in the marine ecosystem.

There are other important species represented in the SEA 7 Area. These include cuttlefish, octopods, sepiolids and a number of deep-water species. Most of these are marketable and may be ecologically important. Large fisheries for some of these species, particularly octopods and cuttlefish operate in European waters further south, but they are not currently exploited in the SEA 7 Area.

Ecological importance

Cephalopods are very important in marine ecosystems for a number of reasons:

1. *Food* – cephalopods are important prey for many species of fish, seabird and marine mammal.

2. *Predators* – cephalopods are also important predators of small fish.

3. *Bio-accumulators* – cephalopods are a significant route for heavy metal and organic contaminant bioaccumulation in the food web.

4. *Ecological status* – cephalopods have a very similar ecological role to fish and are though to have actually replaced a number of over-exploited fish stocks around the world.

5. *Indicator species* – cephalopods are considered to be potential indicator species on the basis of their characteristic rapid response to environmental change.

Economic status

On a global basis, cephalopods are of high economic importance – landings >3.5 million tonnes were reported by FAO in 2003. There are a number of large cephalopods fisheries around the world. A number of species are exploited by European fleets, although in northern waters, these are mostly non-targeted or by-catch fisheries. During the last decade, UK landings of *Loligo forbesi* from the SEA 7 Area have fluctuated between 200 and 500 tonnes, with a first sale value of £200,000 to £900,000. >95% of UK landings from this area are landed by the Scottish fleet. Within the SEA 7 Area, the majority of squid landed are caught in ICES Division Via (west of Scotland). The proportion caught in VIb (Rockall Bank) has ranged from 2-24% in recent years.

Cephalopods from the SEA 7Area are landed and marketed by a number of European fleets, including the Belgian, English, French and Spanish fleets. However, only the Scottish and Irish fleets regularly catch a significant proportion of their overall *Loligo forbesi* catch (ca. 20%) in the SEA 7 Area. For other countries it is typically <5%. Monthly data show the Scottish squid fishery to be cyclical, with most catches landed between August and March. There is some annual variation.

Conservation issues

Environmental factors associated with human activity that may impact cephalopods in the SEA 7 Area can be placed into four main categories:

1. *Heavy metals* – reach the marine environment via rivers and certain marine operations. Diet is the main factor controlling uptake. They tend to bio-accumulate in tissues due to slow excretion rates. As trace elements, certain metals (e.g. copper, selenium, zinc) are essential for metabolism but toxic in high doses. Others (e.g. cadmium, mercury) play no biological role. Molluscs tend to rapidly accumulate certain metals. In cephalopods, high levels of cadmium, mercury, zinc and copper are found in the digestive gland (liver). These are fed upon by larger animals and consequently metals are concentrated at the top of the food chain. A recent study of mercury and cadmium in squid tissues found that levels were highly variable and influenced by species, geographic area, body size and season. Levels of cadmium in squid were thirty times higher than those in whiting and mammal species (e.g. Risso's dolphin, sperm whale) feeding on squid had much higher levels than those feeding on fish (e.g. porpoise, minke whale).

2. *Oil and gas production* – a large variety of wastes are produced during oil and gas production. At present there are no major oilfields in the SEA 7 Area, although there is considerable interest west of the Hebrides and around St Kilda and large areas are already under licence. At present, the nearest producing oilfields are Foinaven and Schiehallion (west of Shetland) and there is also some activity in the Irish Sea.

3. *Radionuclides* – the main souce of radionuclides in the SEA 7 Area is from the Sellafield plant in Cumbria. Levels of plutonium and caesium decrease from source and are not very high in the open sea. However, there is some evidence of bioaccumulation of caesium by marine mammals feeding on cephalopods.

4. *Other issues* – physical disturbance and degradation of squid spawning grounds associated with extensive fishing activity and other large-scale seabed operations could potentially impact cephalopods in the SEA 7 Area.

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