School of Biological Sciences
University of Aberdeen

Squid fishing in UK waters

A Report to SEAFISH Industry Authority

Title: Squid Fishing in UK Waters

Client: SEAFISH Industry Authority
www.seafish.org

Contact: Mike Montgomerie
SEAFISH Industry Authority
Humber Seafood Institute
Origin Way
Grimsby DN37 9TZ
Tel: 01472 252327
E-mail: m_montgomerie@seafish.co.uk

Manager: Prof. Graham Pierce
University of Aberdeen
School of Biological Sciences
Tillydrone Avenue
Aberdeen AB24 2TZ
Tel: 01224 272648
E-mail: g.j.pierce@abdn.ac.uk

Prepared by: Lee Hastie, Graham Pierce, Cristina Pita, Mafalda Viana, Jennifer Smith & Sansanee Wangvoralak

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Executive summary

During the past decade, total squid landings from the NE Atlantic ranged from 10,000–18,000 t. The bulk of European catches were landed by French, Portuguese, Spanish and UK fleets. *Loligo forbesi* is the most frequently caught species in UK waters, and forms the basis of significant by-catch fisheries, with annual landings as high as 3,500 t. A significant proportion (5–70%) of the total Scottish squid landings are caught in the Moray Firth, where a seasonal, directed fishery operates during summer-autumn. The size of the fleet directly involved in this fishery has ranged from 20–65 vessels in recent years. Many of the fishing crews target squid for several weeks, when large numbers of small squid recruit to the fishery.

Targeted squid-fishing operations were monitored, and fairly clean hauls were reported, with very few species of fish by-caught in large numbers. Only whiting were caught occasionally in large amounts (25% overall). Anecdotal evidence indicates that large numbers of small fish are usually only caught at the start and end of the squid season, when exploratory fishing activity is undertaken. During the peak period of activity, fishermen report that catches are often composed almost entirely of squid, with very little by-catch. It is unlikely that targeted squid fishing significantly impacts stocks of commercial fish species at current levels of effort.

Squid are highly sensitive to environmental conditions and populations are considered to be vulnerable to the effects of climate change. Sea surface temperature (SST) appears to influence recruitment strength and overall distribution. Important changes in cephalopod diversity in the NE Atlantic may occur within the next few decades. Global warming (SST) may result in the continued advance of warm-water species into this region, and the simultaneous retreat of cold-water species to higher latitudes. Another process associated with climate change that may affect cephalopods is the general rise in CO2 concentration that has been observed in recent years.

A market-based study of the Moray Firth squid (*Loligo forbesi*) stock was conducted (2006–2008). Overall patterns of growth, maturation, reproduction and recruitment observed were in general agreement with the findings of previous studies, although a secondary pulse in recruitment, previously reported in Scottish waters, was not evident.

A depletion model, based on monthly catch and effort data (1980–2000) was used to assess the size of the Moray Firth *L. forbesi* stock. Estimates ranged from 0.3 to 5.8 million squid, in seasons 1985–86 and 1990–91, respectively. The Moray Firth *L. forbesi* population exhibits large annual fluctuations. It was also noted that relatively few squid remained at the end of the season (post-exploitation).

During winter, *L. forbesi* abundance in Scottish coastal waters is strongly related to water temperature and salinity, with higher abundance in areas of higher temperature and salinity. Squid appear to prefer intermediate depths throughout the year, but inhabit shallow, coastal waters in summer, consistent with an inshore-offshore migration and summer cohort inshore spawning.

At present, there are no restrictions on the amount of squid caught in UK waters. Given the size of the local fleet and the vessels involved, it seems unlikely that targeted squid fishing seriously impacts the *L. forbesi* population in the Moray Firth. It is possible that squid yield could be increased by delaying fishing by 2–4 weeks, allowing the squid to grow larger prior to capture. However, given that larger squid become more spatially dispersed (and possibly more difficult to catch), it is apparent that more research is required in order to estimate the optimal fishing period and maximise yield. The potentially deleterious effects of bottom-trawling on squid spawning grounds may be more important than direct fishing mortality.

Based on available information, the following management options are suggested for consideration for squid fishing in UK waters: 1) entry dates for directed squid fishing, 2) fleet restrictions (number and size of vessels involved), 3) a by-catch monitoring programme, 4) seabed surveys to assess effects of small-mesh trawling, 5) liaison with stakeholders to prevent or resolve conflicts, and 6) annual surveys of squid spawning grounds in order to determine egg production and stock size.

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1. Introduction

During 2005, there was a marked expansion in directed squid fishing, notably in Scottish inshore waters, with new small-scale directed fisheries appearing in the Inner and Outer Hebrides and on the Aberdeenshire coast, as well as the continuation of established small-scale, seasonal, directed fisheries in the Firth of Forth and Moray Firth. However, this interest now extends all around the UK as fishing on many traditional resources is severely restricted due to the poor state of stocks. Thus, there is a risk of uncontrolled expansion of directed squid fishing and it is in everyone's interests to ensure that the fishery is developed in a sustainable way.

At present, the bulk of landings of squid in UK waters derive from by-catches in the whitefish and prawn bottom trawling fisheries (Pierce *et al.,* 1994). Two long-fin (loliginid) species, *Loligo forbesi* and *Loligo vulgaris*, are the main targets of the directed fisheries, and are also the main squid species landed as by-catch of whitefish and prawn fisheries. While by-catches are mainly of pre-spawning and spawning adults, in late autumn, the directed fisheries have been targeting new recruits, mainly between July and October (Young *et al.,* 2006).

In southern Europe, targeted squid fisheries are mainly based in coastal waters, prosecuted from small boats operating jigs. Although official statistics on landings from directed artisanal fisheries are unreliable, since much of the catch is thought to bypass official monitoring programmes, studies in Galicia (NW Spain) in the 1990s suggested that more than half of the squid landed come from the directed artisanal fishery (Guerra *et al.,* 1994). A similar balance between directed and by-catch fisheries may be achievable in the UK.

There is a requirement to develop best practice, put in place monitoring procedures, and help to develop an appropriate assessment and management strategy for the target fishery on squid. It is important to note that it is likely to be difficult to regulate by-catches of squid by demersal trawlers that target whitefish and prawns. Certainly, there would be little or no merit in restricting such landings (e.g. with quotas) since squid are easily damaged and, once in the net, would not survive being discarded. Thus, in devising management measures for the directed fishery, allowance must be made for the effects of the by-catch fishery.

Loligo forbesi is primarily a winter breeding species and is the only squid species normally present in Scottish squid landings. Its congener, *Loligo vulgaris* is also a winter breeder in southern Europe but it is less clear when it normally breeds in UK waters. Both *Loligo* species occur in the English Channel, where their breeding cycles are out of phase - and there may also be summer breeders (as well as winter breeders) present. Part of the monitoring work will be directed at establishing the timing of the breeding cycle in both species. Even in Scottish waters, where the breeding cycle is well-documented, there is evidence that the timing of the life-cycle varies from year to year (e.g. related to temperatures) and that there are occasional influxes of an offshore stock into coastal waters, so that continued monitoring would be useful.

A number of other squid species are present in UK waters and are potentially marketable. Thus catches of all squid species will be monitored during the proposed trials. At present, very small squid (>5 cm mantle length [ML]) are usually discarded. However, foreign demand is high and if large catches of small squid were regularly caught, they could be marketed overseas (although Spain and Portugal observe a 10 cm minimum landing size [MLS]). Furthermore, there is also a potentially lucrative local market for these due to the high demand from recreational fishermen. Small ‘hook-size’ squid are considered to be premium bait and anglers will pay >£6-8 per kilo for frozen ‘baby squids’ that are currently imported. There are estimated to be over one million sea anglers in the UK. Some boat crews have set up private arrangements to supply small squid to anglers, but with the increased catches and gear trials to be set up, there may be scope to organise a bait marketing exercise through one of the major distributors.

When a fishery is developing it is crucial to determine the levels of fishing effort that will be sustainable and hence prevent excessive capacity building. The chokka squid (*Loligo reynaudii*) fishery in the Eastern Cape (South Africa) has been regulated by limiting the number of fishing permits issued, invoking an annual closed season and by closing areas to commercial fishing. The effects of some of those measures and the estimation of appropriate levels of fishing have been determined by simulation approach, based on a biomass dynamic (production) model (Roel & Butterworth 2000, Glazer & Butterworth 2006) and this approach could be adapted for the UK directed fisheries. The simulation framework was able to quantify the biological risk associated with a range of effort levels. Acceptable risk levels were agreed with stakeholders and measures to limit effort were then implemented on that basis.

Formal stock assessment, which will be attempted if data availability allows it, will be based on the approach used in the Falkland Islands squid fishery, namely application of so-called "depletion" methods. The basic idea is that once squid migrate into the fishing area, the rate at which they are removed by the fishery can be monitored, eventually allowing an estimate of the original stock size to be made. In the Falklands, this has been combined with licensing and the option of early closure of the fishery if stock size falls too low. There are difficulties with this approach, since it is not presently clear how many "stocks" exist in UK waters (even if genetic studies suggest that there is a single coastal stock of *Loligo forbesi* along Europe's Atlantic coastline, in practice there may be discrete units characterised by particular migration patterns). Furthermore, there may be several pulses of migration, both into and out of fishing areas, which must be taken into account. However, provided that a reasonably good monitoring coverage of a fishery can be achieved, stocks and migration pulses can be identified retrospectively and both initial local stock size and the level of escapement estimated.

The relationship between landings of young squid from the directed fishery in July to September, and subsequent by-catch landings of older squid, and the effect of both on the next year's fishery, must also be established. Access to historical data will assist with this, as will use of official landings records for the by-catch fishery during the study years. Nevertheless, this work will need to continue beyond the end of the present study, since it may take several years before effects of the directed fishery become clear.

Another issue is the need to minimise by-catches of quota species and other non-target species in squid catches, potentially a problem when small mesh nets are used. Of course, development of a viable fishery based on jigging would probably eliminate almost all by-catches of other species. Concern has been expressed that the Moray Firth squid fishery is depleting food supplies for the resident bottlenose dolphin population. While dietary studies suggest little direct predation of squid by these dolphins, it is important to establish the ecological role of squid, especially as prey for exploited fish species (or indeed as predators on young fish).

It is important to keep in mind that individual *Loligo* live around one year, breed once and then die. They may be more resilient to overfishing than many fish but, on the other hand, if one year's spawners are all lost, there will not be a next generation. Thus, another issue is the protection of spawners. To some extent this is more a problem for the by-catch fishery but targeted fishing on new recruits could disrupt summer spawners and could potentially take out so many recruits that the spawning stock was reduced.

It is generally thought that loliginid squid, which are known to attach egg strings to rocks (and to creel lines), need hard substrate for spawning. Thus it is possible that many spawning beds are, in effect, protected, as they cannot be trawled. However, this cannot be assumed to be the case: for example, spawning squid are also associated with gravely substrate. Also, it is not clear how many potential spawning areas are actually used; certainly it will be necessary to record all observations of egg strings in catches and to be prepared to protect spawning grounds that are identified.

We also hope to be able to collect some useful information on habitat preferences and fine-scale movements of squid. This will assist not only with improving our understanding of the species but also with identifying the best fishing areas. Squid are known to migrate offshore as they grow bigger and to later migrate inshore to spawn: details of migration routes have been mapped in squids elsewhere in the world but most information for UK squid s still anecdotal. It is likely that young squid form feeding aggregations and where they feed probably depends on the tidal cycle, the light-dark cycle, salinity and turbidity (among other things). Studies on *Loligo reynaudii*, a related South African species, suggest that they avoid turbid waters. However, we don't know the details of where they live or what affects when and where they move. This kind of information will be helpful in deciding where and when to fish for squid in the future.

Finally, we can also make some first steps towards management of directed squid fisheries. Throughout Europe there is presently little control of squid fishing and it may be necessary to look to fisheries elsewhere in the world for examples of management measures that work. Squid are not fish and approaches designed for fish may not work for squid. At present, we have a unique opportunity to design an appropriate management regime before the directed fishery expands too far.

SEAFISH commissioned the University of Aberdeen to undertake work to assess the status of the UK squid fisheries and of the fished stocks over a two-year period (2006-2008). Focus was placed on monthly market samples of squid caught locally and on vessels targeting young squid in the Moray Firth during summer-autumn. The following report describes the work carried out and the main findings of the study.

1.1. Project objectives

In collaboration with SEAFISH, the initial project objectives were as follows:

1) To assist in identification of best practice for gear choice and deployment.

2) To monitor by-catch and discards.

3) To carry out a review of the possible wider environmental effects on squid.

4) To make attempts at stock assessment.

5) To improve knowledge of distribution, movements and the life-cycle of squid – both at local and wider scales.

6) To build up a description of the directed squid fishery and provide a prelimnary assessment of its socio-economic importance.

7) To assist in development of recommendations for management of the directed squid fishery and communication of results to the industry and to the wider public.

2. Squid fisheries of the world (short review)

As traditionally exploited fin fish stocks continue to decline in many parts of the world, there has been much interest in the development of cephalopod fisheries during the past 20 years. The large natural populations, shoaling behaviour and high-quality proteins of many species make cephalopods very suitable for commercial exploitation. There is some evidence that cephalopod populations have increased in a number of areas where fin fish stocks have declined as a result of over-fishing (Caddy & Rodhouse, 1998). Although very little is known about squid populations, for example, global consumption estimates suggest that the amount of squid consumed annually by whales and other marine predators may, in terms of mass, exceed the world commercial catch of all marine species combined (Voss, 1973; Clarke, 1983).

2.1. Harvested species

The global squid catch has increased substantially in recent years. The main exploited species are listed in Table 1. These comprise 8 short-fin squid (ommastrephid) and 3 long-fin (loliginid) squid species. In 2002, 25% of the 2.18 million tonnes of the reported world squid catch was not identified to species (FAO, 2002). This is largely due to the large number of artisanal and small-scale inshore fisheries, and also the fact that large quantities of squid are caught in the tropical and subtropical regions, where species diversity is high and poorly understood (Rodhouse, 2005).

Three ommastrephid squid species; *Dosidicus gigas*, *Illex argentinus* and *Todarodes pacificus*, together account for >60% of the world squid catch and the total identified ommastrephids account for ~70%. The total identified loliginids account for 10–15% of the world squid catch. The most important loliginid squid species in the world catch during the past 20 yr has been *Loligo gahi*, representing ~1% of the world squid catch. Squid catches that have not been identified as either ommastrephid or loliginid are categorised as ‘not elsewhere included’ (NEI) and currently account for 15–20% of the world squid catch.

Table 1. Summary of the world squid catch in 2002 (FAO, 2003; in Rodhouse, 2003).

Species	Family	Common name	Nominal Catch (t)	% of world cephalopod catch
Loligo gahi	Loliginidae	Patagonian squid	24976	0.8
Loligo pealei	Loliginidae	Long-fin squid	16684	0.5
Loligo vulgaris (reynaudi)	Loliginidae	Cape Hope squid	7406	0.2
Common squids nei	Loliginidae	Various	225958	7.5
Ommastrephes bartrami	Ommastrephidae	Neon flying squid	22483	0.7
Illex illecebrosus	Ommastrephidae	Northern short-fin squid	5525	0.2
Illex argentinus	Ommastrephidae	Argentine short-fin squid	511087	16.1
Illex coindetii	Ommastrephidae	Broadtail short-fin squid	527	<0.1
Dosidicus gigas	Ommastrephidae	Jumbo flying squid	406356	12.8
Todarodes sagittatus	Ommastrephidae	European flying squid	5197	0.2
Todarodes pacificus	Ommastrephidae	Japanese flying squid	504438	15.9
Notodarus sloani	Ommastrephidae	Wellington flying squid	62234	1.9
Squids NEI	Various	Various	311450	9.8
Total squids	N/A	N/A	2189206	75.8
Total cephalopods	N/A	N/A	3173272	100.0

2.2. Fishing methods

2.2.1. Jigging

Short-fin (ommastrephid) squid are typically caught by mechanised jigging. Jigs are essentially lures armed with barbless hooks. Mechanised jigs are fished in series on lines using special automated jigging machines (Suzuki, 1990). Jigging operations are usually carried out at night using powerful incandescent, metal halide lamps. These are suspended above the deck of the jigger (vessel) on cables. Small inshore jiggers may use only a single lamp whilst >150 (2kW) lamps may be operated on a large industrial, distant-water vessel. Mostly white light is emitted, but the arrays are often interspersed with small numbers of green lamps in order to create optimal light conditions for jigging (Inada & Ogura, 1988). Jigs are also used successfully in some of the smaller long-fin (loliginid) squid fisheries (Porteiro & Martins, 1994).

2.2.2. Trawling

Long-fin (loliginid) squid are typically caught by demersal trawling. The trawls are used during hours of daylight, when the squid are concentrated near the seabed. A number of trawl gear types are used for squid fishing. These include: conventional otter trawls, which are used to fish on the bottom over rough ground; pelagic trawls, which can be used to fish just off the seabed; and specially designed squid trawls, which tend to have small mesh cod ends and higher head ropes than those normally used to catch fish (Boyle & Pierce, 1994).

2.2.3. Other methods

In some of the smaller loliginid squid fisheries around the world, a variety of fishing techniques are used. These include hand-figs, small nets and special traps (Chotiyaputa, 1993). In the Gulf of Thailand, lights are used to lure squid (*Loligo duvauceli*) into stick-held cast nets (Supongpan *et al.,* 1992). In European waters, substantial numbers of loliginid squid are also taken by seine net (Boyle & Pierce, 1994).

3. Squid fishing in UK waters

3.1. General

A number of north-east Atlantic squid species are highly valued for consumption, and substantial catches of these are taken each year. During the past decade, total squid landings (all species) from the north-east Atlantic ranged from ~10,000–18,000 t (Anon., 2008). Several species are exploited, although for (FAO) fisheries statistics records, they are conveniently grouped into three broad categories: long-fin (loliginid) squid, short-fin (ommastrephid) squid, and squid "not elsewhere included" (NEI). The main species caught and marketed in Europe are *Loligo forbesi*, *L. vulgaris*, and various ommastrephid spp. The bulk of European catches are landed by the French, Portuguese, Spanish and UK fleets. These four nations, in fact, account for >95% of the total north-east Atlantic squid catch. Total landings of long-fin squid from the north-east Atlantic (ICES areas) ranged from ~8,000–11,000 t per annum during the past decade (Anon., 2008).

3.2. Long-fin squid

Loligo forbesi is the most frequently caught squid species in UK waters, and forms the basis of significant by-catch fisheries (Pierce *et al.,* 1994b), with annual landings as high as 3500 t (Collins *et al.,* 1997a). Based on historical fishery data (Figure 1), this species appears to exhibit cyclical population trends, with marked abundances every decade. At certain times *L. forbesi* is targeted, notably on Rockall Bank in summer during the 1980s (Pierce *et al.,* 1994a) and in the Moray Firth in autumn (Young *et al.,* 2006). There is also some directed squid fishing, including jig fishing (as described by Hamabe *et al.,* 1982), off the south coast of England, although it is not clear which species of *Loligo* is targeted. On the Spanish and Portuguese Atlantic coasts, inshore jigging catches mainly *Loligo vulgaris*, which is thought to generally occur closer inshore than *L. forbesi*, although it is also the case that *L. forbesi* is increasingly rare to the south; see Chen *et al.,* (2006). Recently, squid fishing has attracted considerable attention in Scotland and in 2005 small-scale directed squid fisheries were reported in several localities, including the Firth of Forth, off Aberdeen, and off the islands of Skye and Lewis.

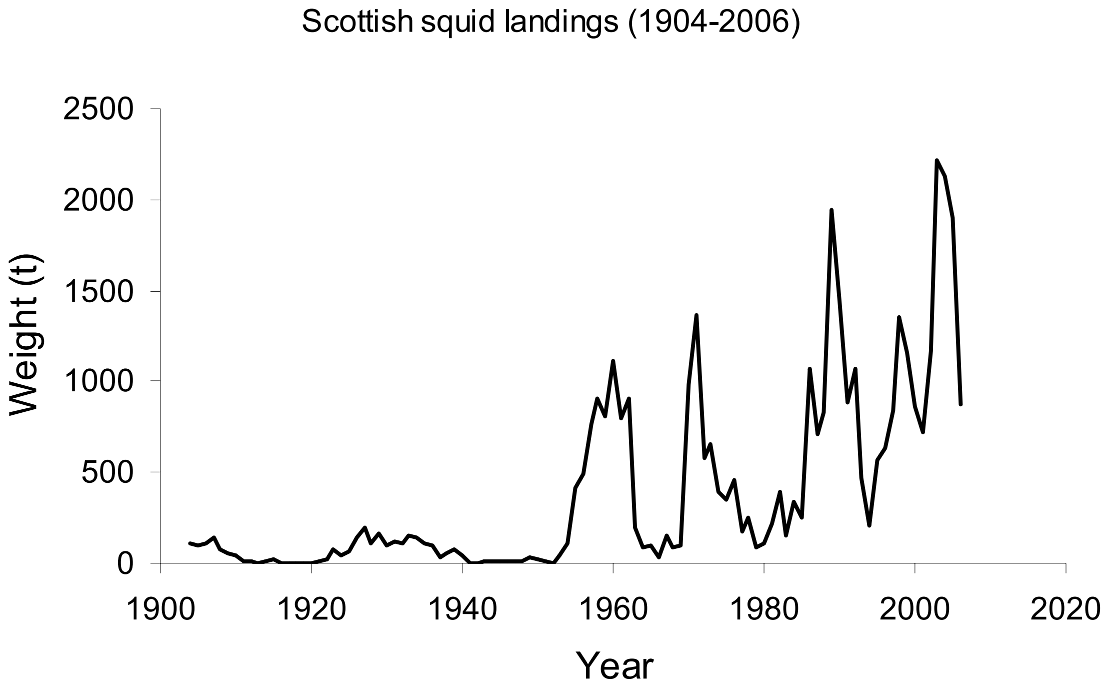

Figure 1. Scottish squid (*Loligo forbesi*) landings during period 1904–2006 (Scottish Sea Fisheries Database).

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; Pierce *et al.,* 1994c; Young *et al.,* 2006). In the English Channel, Holme (1974) noted the presence of both summer and winter breeding populations of this species.

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 *RV Scotia* confirm the wide distribution while also highlighting its patchy nature. Research trawling surveys record squid in UK waters in all seasons. Pierce *et al.* (1998) presented data from demersal trawl surveys along the west coast of Scotland during November (1980–1994), 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. Data collected from research cruises carried out in 2004 showed highest catch numbers from waters to the west of the Isle of Man.

Recent analysis of long-term trends in abundance points to the possible influence of oceanographic conditions on abundance of *L. forbesi* in Scottish waters (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).

Loligo vulgaris is also landed mainly as a by-catch of multi-species demersal and pelagic trawl fisheries in the north-eastern Atlantic and Mediterranean. Total landings of this species are estimated to be ~5000 t per year (Guerra, 1992; WGCEPH, 2008). In UK waters, the English Channel and off the northwest coast of Spain, it is usually landed in mixed catches with *L. forbesi*. In these areas where the two species overlap, the landing statistics refer to *Loligo* spp. (Robin & Boucaud-Camou, 1993). Therefore, the overall catch of *L. vulgaris* in UK waters is currently unknown, although it is believed to be significant. Further south, *L. vulgaris* is an important secondary target species in the Saharan Bank trawl fishery (Raya *et al.,* 1999) and it is also targeted by a number of small, inshore, directed hand-jig fisheries operating from the coasts of Spain and Portugal (Guerra *et al.,* 1994). Landings from the small-scale fisheries are poorly reported, but in NW Spain they may be of a similar order of magnitude to the trawl by-catch landings. In Greek and Portuguese waters, spawning aggregations of *L. vulgaris* are also targeted using beach seines, gill nets and trammel nets.

3.3. Short-fin squid

Total landings of short-fin squid (f. Ommastrephidae) from the north-east Atlantic (ICES areas) ranged from ~3000–10,000 t per annum during the past decade (Anon., 2008). Landings have generally been sporadic, although, in particular, landings from Spain and Portugal have been fairly consistent, at >1000 t per annum. However, very large catches (>4000 t) were landed by the Danish and Norwegian fleets in 2004.

Ommastrephid squid stocks from the north-east Atlantic are harvested throughout the year by Spanish and other European fleets. In the north-east Atlantic and Mediterranean, ommastrephid squid are usually taken as by-catch during demersal and pelagic trawling operations and in gill and trammel nets, in depths of 100–400 m (Mangold & Boletzky, 1987; Ragonese & Jereb, 1992; González *et al.,* 1994; González & Guerra, 1996). Different species (predominantly *Illex coindetii* and *Todaropsis eblanae*, occasionally *Ommastrephes bartramii* and *Todarodes sagittatus*) are often landed together as mixed ‘short-fin’ squid.

Consequently, landings data for individual ommastrephid species are often unavailable. Nevertheless, ommastrephid squid stocks are now regarded to be a high value fishery resource (Jereb & Ragonese, 1995). During the past decade, the total ommastrephid catch in European waters has ranged from 3,000–7,000 t annually, with UK fleets accounting for 0–300 t per annum (Anon., 2008).

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 Faroe 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 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., 2005).

At present, *I. coindetii*, *O. bartramii* and *T. eblanae* are not exploited commercially by UK fleets and consequently there is little information available on their abundance in UK waters, although they are caught and landed in Spain by Spanish trawlers. Reports from adjacent waters indicate that they can at times be widespread and abundant in the northeastern Atlantic and may represent a significant potential fishery resource. The North Atlantic stock of *O. bartramii* is estimated to be ~2.5 million t (Nigmatullin *et al.,* 1991) – this species is already exploited commercially in the Pacific (Bower & Ichii, 2005). The occurrence of *T. eblanae* in the Irish Sea was reported by Collins *et al.,* (1995). 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 influxes of warm high-salinity Atlantic seawater (Hastie *et al.,* 1994).

3.4. Other squid species

Aside from loliginids and ommastrephids, a number of other squid species in UK waters may have some fishery potential. *Gonatus fabricii*, for example, is considered to be the most abundant squid of Arctic and subarctic waters (Nesis, 1965; Kristensen, 1984). Spawning concentrations of *G. fabricii* may be a valuable, exploitable resource, based on the large catches of sub-adults frequently taken by mid-water trawlers operating in the Norwegian Sea (Wiborg *et al.,* 1984; Bjørke & Gjøsæter, 2004). Using a fishery production model, Bjørke & Gjøsæter (1998) estimated the spawning stock biomass of *G. fabricii* in the Norwegian Sea to be ca. five million t. Bjørke (2001) estimated the annual consumption of *G. fabricii* by sperm whales alone to be ca. 385,000 t. Santos *et al.,* (1999) estimated the consumption of *Gonatus* spp. in Norwegian waters to be 400,000–520,000 t. In Greenland, Inuit fishermen use *G. fabricii* as bait in local cod and shellfish fisheries. It is also frequently taken as by-catch in shrimp trawls. A high lipid content of the digestive gland (>60%) makes this species potentially suitable for industrial use (Kristensen, 1984). Although there are no British records of large spawning aggregations of *G. fabricii* or *G. steenstrupi*, juvenile gonatids are relatively common in UK waters, based on the numbers found in plankton samples (Collins *et al.,* 2001).

3.5. The Moray Firth squid fishery

A significant proportion (5–70%) of the total Scottish squid landings are caught annually in the Moray Firth (Pierce *et al.,* 1994) (Figure 2), a shallow, coastal body of water in the northern North Sea (ICES Area IVa). The Moray Firth is an important, historical fishing area off north-east Scotland, where demersal fish species such as haddock, cod, whiting, plaice, and lemon sole have been exploited during the past 200 years (Young *et al.,* 2006). It is also an important over-wintering area for pelagic species such as herring (Hopkins, 1986). In 2006, >1200 people based around the Moray Firth were directly employed (regularly or partly) in commercial fishing operations, based in the fishing districts of Fraserburgh, Buckie and Wick, respectively. Significant numbers of local, inshore fishing vessels operate in the Moray Firth. In 2006, 230 vessels <10 m and 185 vessels ≥10 m were registered in the three fishing districts.

The most important, commercially-exploited shellfish species in the Moray Firth is the Norway Lobster, *Nephrops norvegicus*, which supports a local, bottom trawl "prawn" fishery (Hopkins, 1986). *Nephrops* has traditionally accounted for ~35% of all landings into Moray Firth ports, followed by mackerel (23%) (Table 2). During the past 30 years, however, substantial catches of squid (*Loligo forbesi*) from the Moray Firth have also been landed (Young *et al.,* 2006; Campbell & Murray, 2007).

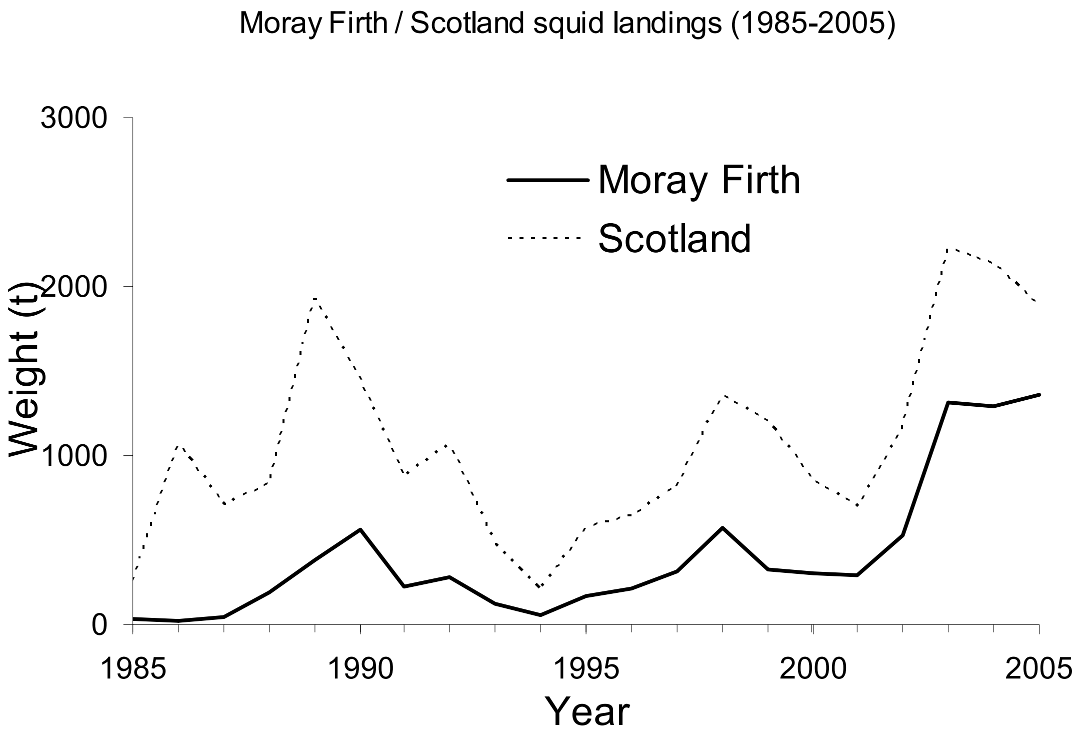

Figure 2. Moray Firth and total Scottish squid (*Loligo forbesi*) landings during period 1985–2005 (Scottish Sea Fisheries Database).

Most squid caught in Scottish coastal waters are landed as by-catch of targeted whitefish species (Pierce *et al.,* 1994). In the Moray Firth, however, large numbers of young squid, too small to be retained in the mesh of standard whitefish trawls, are taken at certain times, and this area appears to be specially favoured by new recruits of the year (Young *et al.,* 2006).

Table 2. Socio-economic classification of the fishing sector in the Moray Firth and Scotland (2007).

	Moray Firth	**Scotland**
Employment (No.)	1 249	5 424
Vessels (No.)	385	2 191
Vessels (Tonnage – t)	44 543	116 587
Vessels (Power – kW)	129 386	401 402
≤ 10m vessels (% in total No.)	55%	68%
Landings ('000 ton)	33.7	311.1
Landings (£ million)	61.8	348.3
Species (% in total catch)	Nephrops (35%) Mackerel (23%)	Mackerel (31%) Herring (15%)
Species (% in total value)	Nephrops (61%)	Nephrops (30%) Mackerel (18%)
Fishing Method (% in total catch)	Bottom trawl (45%) Mid-water trawl (21%)	Bottom trawl (24%) Mid-water trawl (45%)
Squid		
Landings (ton)	602,1	1 217,8
Landings ('000 £)	1 638,7	3 337,8
Fishing Method (% in total catch)	Bottom trawl (80%)	Bottom trawl (81%)

Source: Scottish Executive - Scottish Sea Fisheries Statistics 2007.

A seasonal (summer-autumn), directed, demersal trawl fishery for squid currently operates in the Moray Firth, with most activity occurring between July and November (Young *et al.,* 2006). The number of vessels directly involved in this fishery has ranged from 20–65 vessels in recent years, based at four main ports: Nairn, Burghead, Buckie and Fraserburgh (Young *et al.,* 2006). The fleet usually comprises variable numbers of small vessels (<10 m length, ~100 hp, 1–2 crew) and large vessels (>10 m length, 200–500 hp, 3–5 crew). In certain years, a few large, twin-rig trawlers (~30 m length, ~1500 hp, >5 crew) may also enter the fishery (Young *et al.,* 2006). Many of the fishing crews target squid for several weeks, when large numbers of small squid recruit to the fishery. When squid catches fall, they switch back to different bottom gears to target *Nephrops* during the rest of the year.

Targeted squid fishing in the Moray Firth varies considerably from year to year, but generally begins in July/August/September and lasts for 8–10 weeks, with a peak in catches occurring in September/October (Young *et al.,* 2006). Most of the vessels targeting squid in this area are locally-based. However, during years of exceptional abundance and large squid catches (e.g. 2004), substantial numbers of vessels from the Scottish west coast and the Firth of Forth may also participate in this fishery.

The directed fishery in 2006 failed to yield the landings of the previous seasons (see Figure 3). Across Scotland, total landings (directed and by-catch) decreased by over 50% from the previous year (Table 3), with total market revenue decreasing by over GBP £1,900,000 (Table 4). Scottish Fisheries Protection Agency (SFPA) officers in Buckie reported large (> 10 m) vessels arriving and changing to squid gear in early August, but also reported the presence of unfavourable weather. A combination of strong tides and easterly gales occurred in September, and the Buckie fishery failed to materialize, with the exception of a few small vessels (< 10 m) fishing off Burghead. It was hypothesized that the environmental conditions had contributed to the low catch, as approximately 18 years ago when similar weather conditions were present over a prolonged period, squid and lobster were observed washed up along the shoreline in the area.

Squid landings in the Moray Firth in 2007 were higher than those of the previous fishing season, but failed to reach the quantity landed during the years immediately prior to the 2006 fishery decline (e.g., 2003-2005 landings). Across Scotland, substantial total landings in 2007 occurred only during the month of September (see Figure 3).

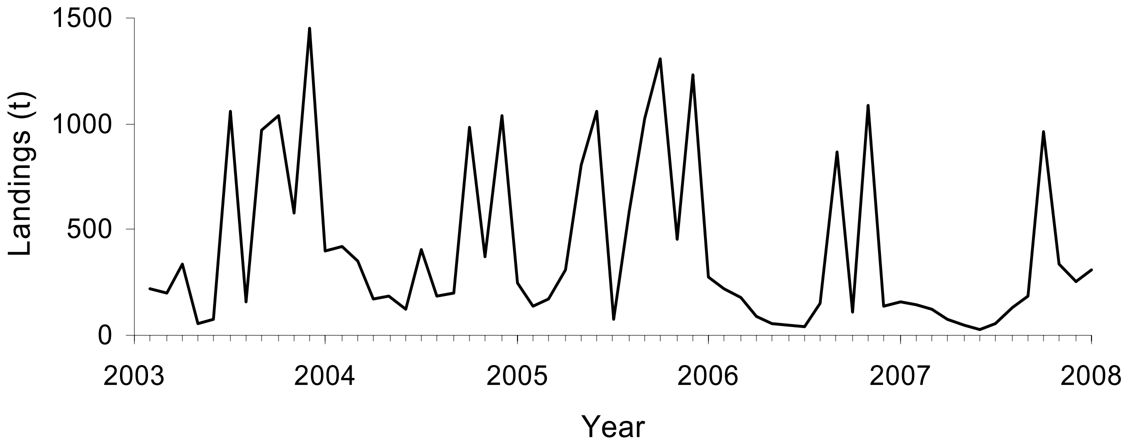

Figure 3. Monthly combined squid landings for all Scottish ports from 2003-2007 (source: Scottish Executive Sea Fisheries Statistics).

Table 3. Yearly Landings of Squid (in Tonnes) at Scottish Ports.

Port	2002	2003	2004	2005	2006	2007
Eyemouth	184	256	671	74	41	78
Pittenweem	NA	NA	67	NA	20	112
Aberdeen	58	76	219	189	53	35
Peterhead	98	153	275	125	141	157
Fraserburgh	285	632	1480	571	283	372
Buckie	158	534	1276	735	80	220
Wick	104	125	NA	69	38	46
Shetland	66	52	81	55	136	104
Lochinver	51	150	135	NA	NA	NA
Kinlochverbie	53	124	321	33	47	34
Ullapool	38	44	93	NA	NA	NA
Portree	41	21	NA	NA	NA	NA
TOTAL	1136	2167	4618	1851	839	1158

Source: Scottish Executive – Scottish Sea Fisheries Statistics

Table 4. Value (in (£'000) of Yearly Squid Landings at Scottish Ports.

Port	2002	2003	2004	2005	2006	2007
Eyemouth	249	688	671	182	102	210
Pittenweem	NA	NA	67	NA	72	324
Aberdeen	104	157	219	371	174	119
Peterhead	171	303	275	273	317	432
Fraserburgh	479	1432	1480	1272	722	1023
Buckie	249	1150	1276	1574	199	594
Wick	197	272	NA	178	82	105
Shetland	105	103	81	142	407	323
Lochinver	108	285	135	NA	NA	NA
Kinlochverbie	70	197	321	64	78	64
Ullapool	74	99	93	NA	NA	NA
Portree	102	55	NA	NA	NA	NA
TOTAL	1908	4741	4618	4056	2153	3194

Source: Scottish Executive – Scottish Sea Fisheries Statistics

4. By-catch and discards programme

4.1. Background

With declining North Sea fish stocks under increasing pressure, there is an interest in the amount and nature of discarding that is associated with targeted squid fishing. There is a need to minimise by-catches of quota species and other non-target species in squid catches, potentially a problem when small mesh nets are used. Unfortunately, very few studies have been undertaken and there is a dearth of information available on the species that are caught and discarded during squid-fishing operations. In 2005, some discard monitoring was carried out by Fisheries Research Services (FRS) in Aberdeen (Campbell & McLay, 2006). Four monthly samples of fish by-catch (August to November) were recorded. The August sample was processed at sea by an on-board observer, and the other samples were provided by the squid fishermen and processed in the laboratory. All of the non-squid catch in August was discarded. Discard rates were reported for three important whitefish (gadoid) species, including cod (<1%), haddock and whiting (0.5–8.4%). However, the results were not considered to be indicative, since insufficient data were obtained for the reliable estimation of numbers and ages of fish caught and discarded (Campbell & McLay, 2006).

Given the increasing commercial importance of squid in Scottish waters, and the continued decline of traditionally exploited fin-fish stocks, there is an urgent requirement for more information about the character and magnitude of discarding associated with targeted squid-fishing. The following section provides additional squid by-catch information obtained from squid-fishing trips in the Firth of Forth and Moray Firth undertaken during the period 2007–2008.

4.2. Methodology

In 2007 and 2008, a number of targeted squid-fishing trips in the Firth of Forth and the Moray Firth, aboard small fishing vessels (demersal trawlers), were made by SEAFISH observers. The main intention of the exercise was to monitor discards (Table 5). Environmental information and biological data were collected onboard during fishing operations. Summaries (haul logs) are provided in the appendix (Tables A1–A4).

Table 5. Discard monitoring trips in Firth of Forth and Moray Firth (2007).

Date	Vessel	Area Fished[1]	ICES division	Mesh (mm)	No. tows	Catch (kg) squid	Bycatch[2]
15/08/07	Osprey	MF	IVa	40	5	117	17
04/09/07	Winanway	FF	IVb	40	8	44	102
05/09/07	Tamaralyn	FF	IVb	40	5	114	80
12/09/07	Crusader	FF	IVb	40	5	189	97
13/09/07	Crusader	FF	IVb	40	5	42	62

1. MF = Moray Firth, FF = Firth of Forth.
2. Fish only - does not include shellfish (crabs, prawns, lobsters) discarded.

4.3. Results

A summary of the catches and by-catches observed during directed squid-fishing is provided in Table 5. Squid (*Loligo forbesi*) catches ranged from 0–38 kg per tow (≈ 0–20 kg per hour), and from 42–188 kg per (day) trip and, as expected, dominated the catches (30–87% of the total catch by weight). A total of 24 fish and three shellfish species were recorded in the by-catches (Table 6). The main fish species by-caught were whiting, haddock, dab and flounder. The main shellfish species caught was velvet swimming crab, although catches were sporadic. All of the non-squid species caught were discarded.

Relatively large numbers of small whiting were caught, resulting in discard rates of 17–56% (overall catch weight, per day). Whiting was by far the main by-catch species, constituting >25% of total catches by weight and appearing in 18/25 hauls (i.e. prevalence >70%) (Table 6). Haddock, dab, flounder, plaice and mackerel were also occasionally caught in large numbers (0–11% discarded). Prawn and swimming crab by-catches were sometimes substantial (not accurately quantified).

A size-frequency profile of the squid caught is provided in Figure 4. The distribution is unimodal, centred on modal class 6–7 cm ML. Size-frequency profiles of the main fin-fish species by-caught are provided in Figures 5–14. Multi-modal size distributions were observed in the whiting, dab and flounder samples (Figures 4, 7 and 8, respectively).

Table 6. Recorded fish and shellfish species by-caught and discarded during directed squid-fishing operations (pooled data, 2007).

	Species	Prevalence /25 tows(%)	Proportion of catch wt (%)
Fish			
	Whiting (*Merlangius merlangus*)	18 (72)	25.7
	Haddock (*Melanogrammus agelefinus*)	7 (28)	2.8
	Dab (*Limanda limanda*)	12(48)	3.3
	Flounder (*Platichthys flesus*)	9 (36)	2.0
	Plaice (*Pleuronectes platessa*)	7 (28)	0.3
	Mackerel (*Scomber scombrus*)	14 (56)	4.8
	Sandeel (*Ammodytes marinus*)	5 (20)	0.3
	Sprat (*Sprattus sprattus*)	3 (12)	0.4
	Gurnard (*Trigla lucerna*)	10 (40)	0.2
	Scad (*Trachurus trachurus*)	8 (32)	0.4
	Bib (*Trispoterus luscus*)	2 (8)	<0.1
	Megrim (*Lepidorhombus whiffiagonis*)	1 (4)	<0.1
	Scorpion (*Myxoceohalus scorpius*)	3 (12)	<0.1
	Sole (*Solea solea*)	2 (8)	<0.1
	Weaver (*Trachinus draco*)	2 (8)	<0.1
	Dragonet (*Callionymus lyra*)	2 (8)	<0.1
	Pipefish (*Syngnathus acus*)	3 (12)	<0.1
	Monkfish (*Lophius piscatorius*)	1 (4)	<0.1
	Herring (*Clupea harengus*)	1 (4)	<0.1
	Butterfish (*Pholis gunnellus*)	1 (4)	<0.1
	Cod (*Gadus morhua*)	3 (12)	<0.1
	John Dory (*Zeus faber*)	2 (8)	<0.1
	Coley (*Pollachius virens*)	1 (4)	<0.1
	Cuckoo Ray (*Raja naevus*)	1 (4)	<0.1
Shellfish			
	Velvet crab (*Necora puber*)	6 (24)	ND
	Prawn (*Nephrops norvegicus*)	1 (4)	ND
	Lobster (*Homarus gammarus*)	3 (12)	ND

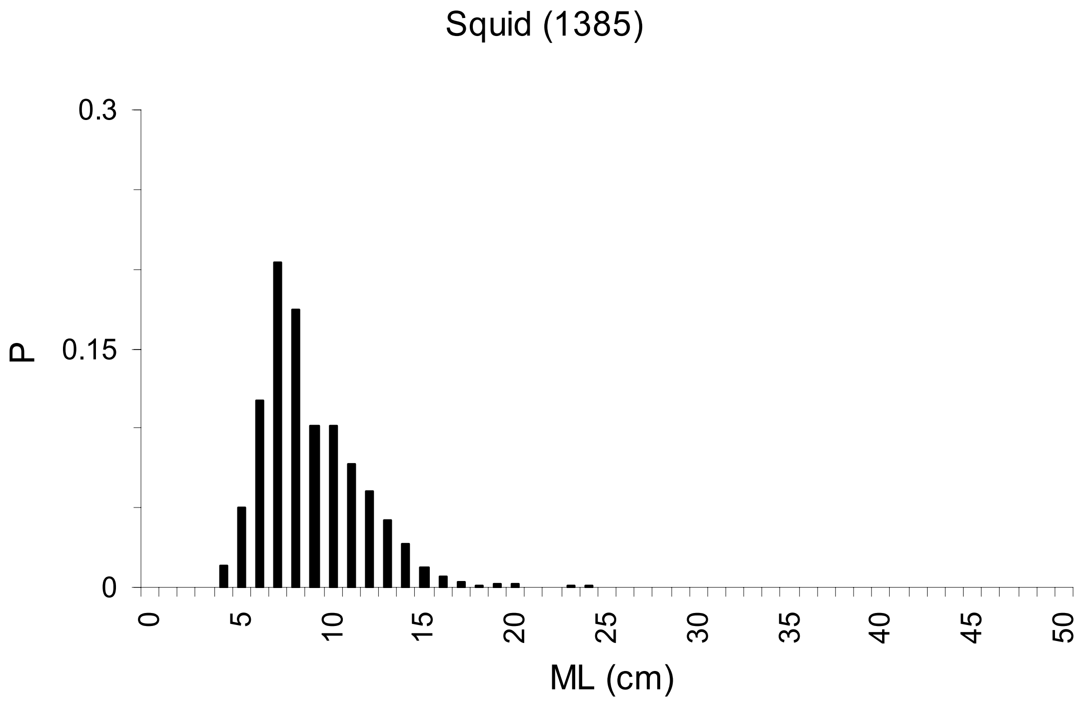

Figure 4. Size-frequency histogram of squid (*Loligo forbesi*) measured during discard monitoring trips. Sample size in parenthesis.

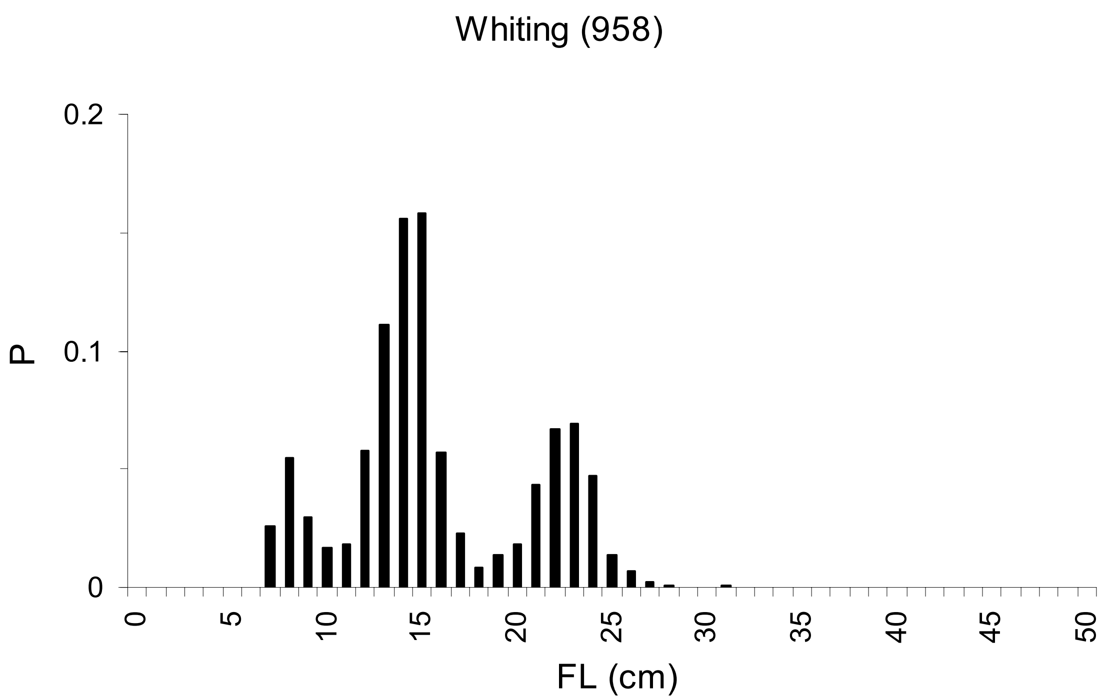

Figure 5. Size-frequency histogram of whiting (*Merlangius merlangus*) measured during discard monitoring trips. Sample size in parenthesis.

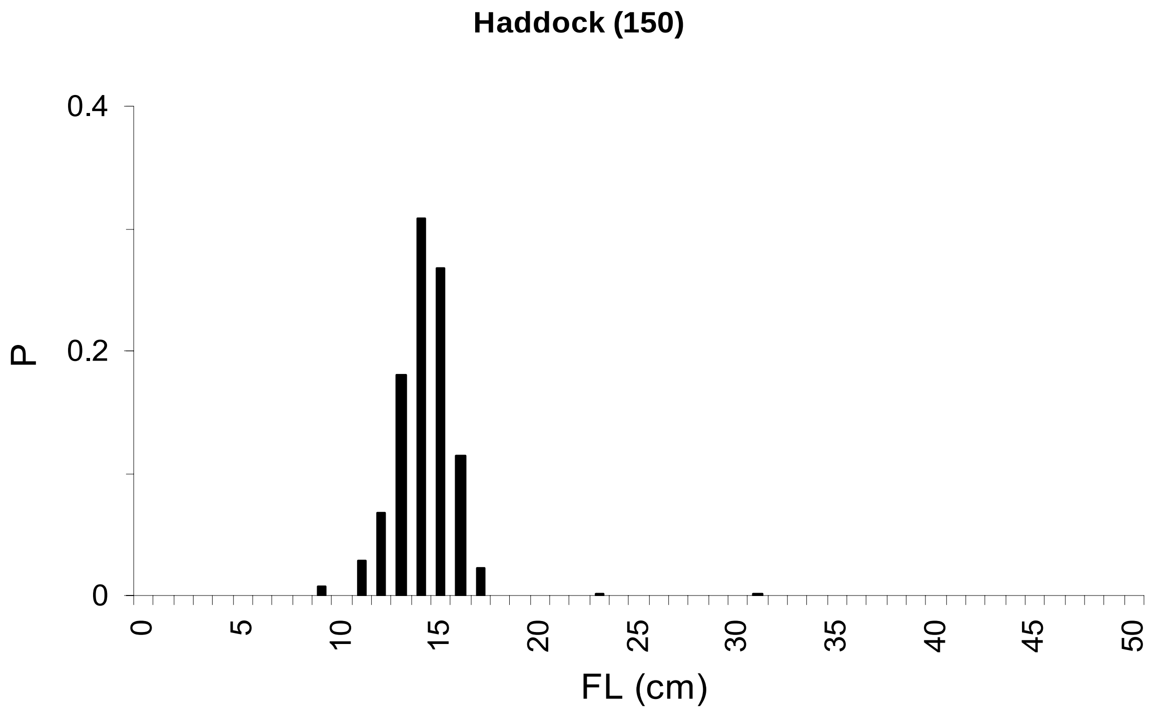

Figure 6. Size-frequency histogram of haddock (*Melanogrammus agelefinus*) measured during discard monitoring trips. Sample size in parenthesis.

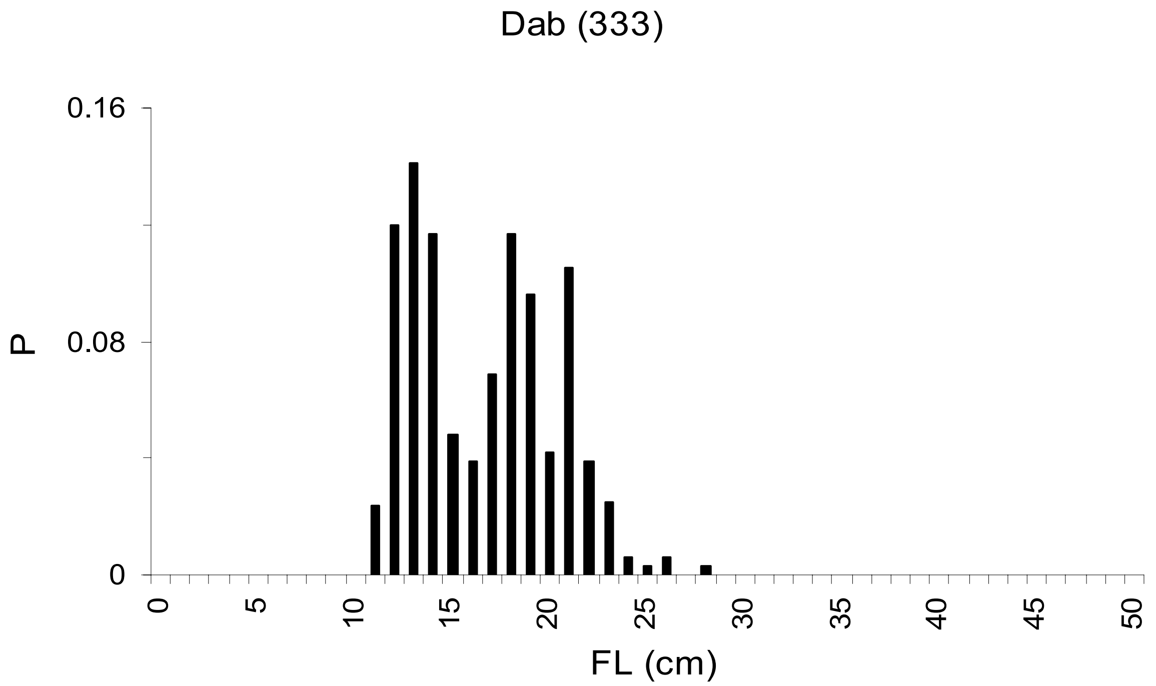

Figure 7. Size-frequency histogram of dab (*Limanda limanda*) measured during discard monitoring trips. Sample size in parenthesis.

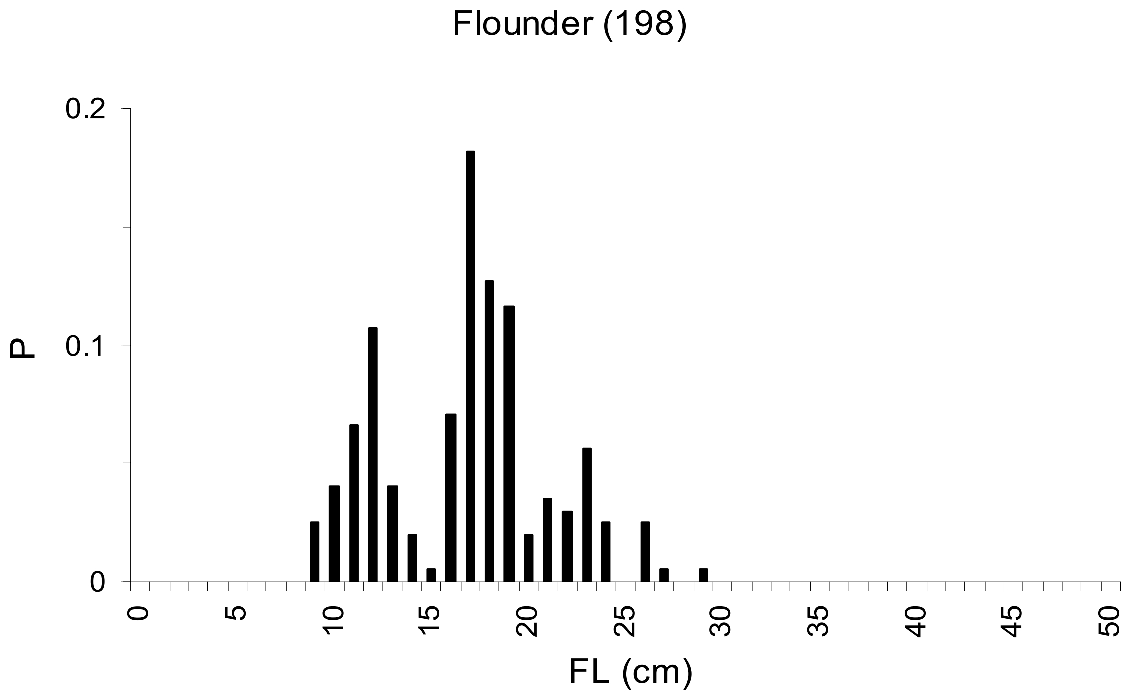

Figure 8. Size-frequency histogram of flounder (*Platichthys flesus*) measured during discard monitoring trips. Sample size in parenthesis.

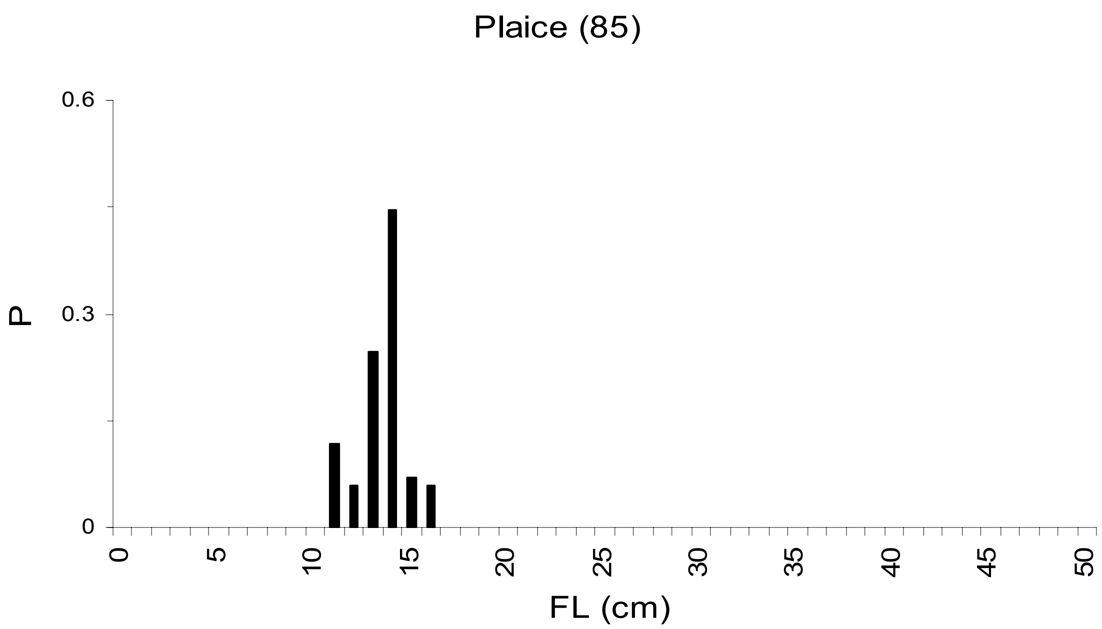

Figure 9. Size-frequency histogram of plaice (*Pleuronectes platessa*) measured during discard monitoring trips. Sample size in parenthesis.

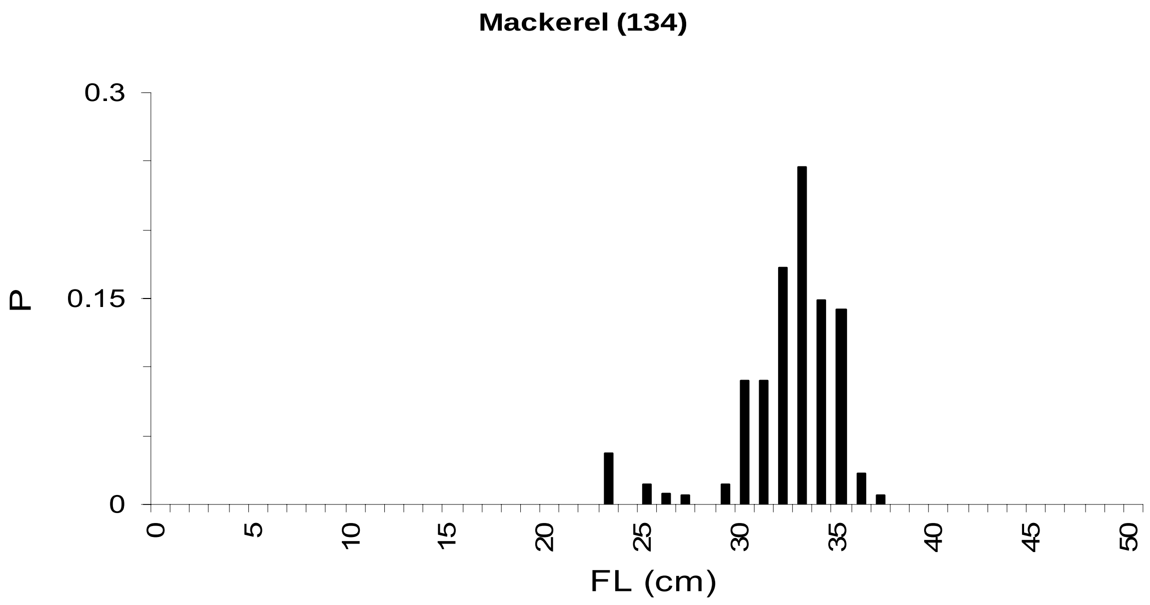

Figure 10. Size-frequency histogram of mackerel (*Scomber scombrus*) measured during discard monitoring trips. Sample size in parenthesis.

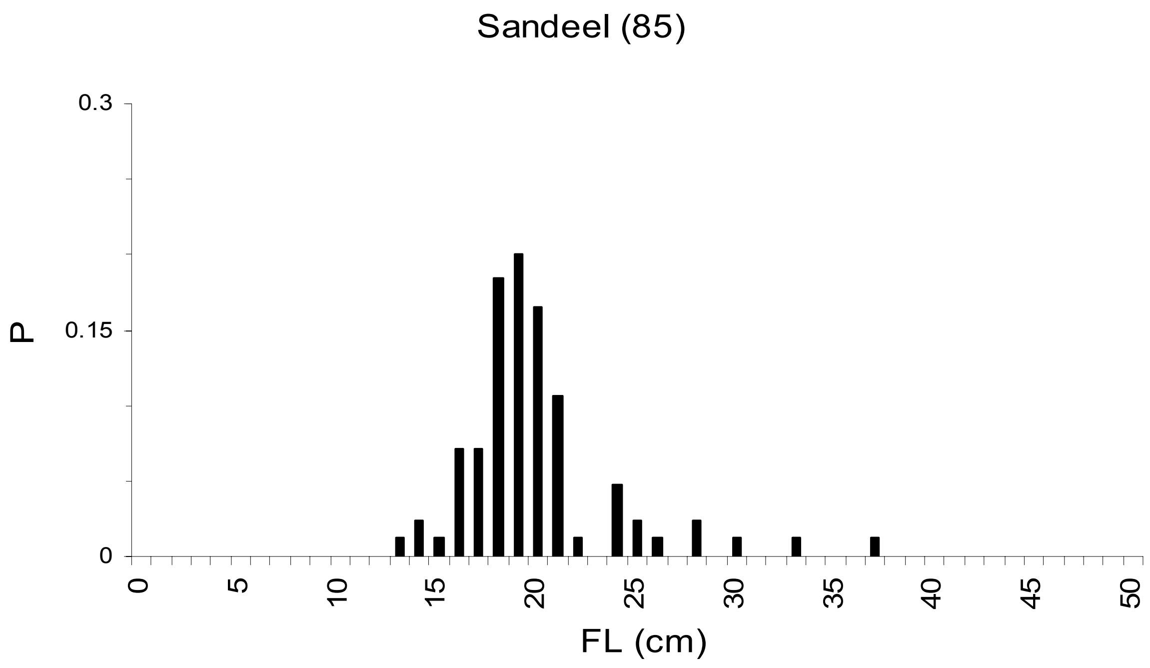

Figure 11. Size-frequency histogram of sandeel (*Ammodytes marinus*) measured during discard monitoring trips. Sample size in parenthesis.

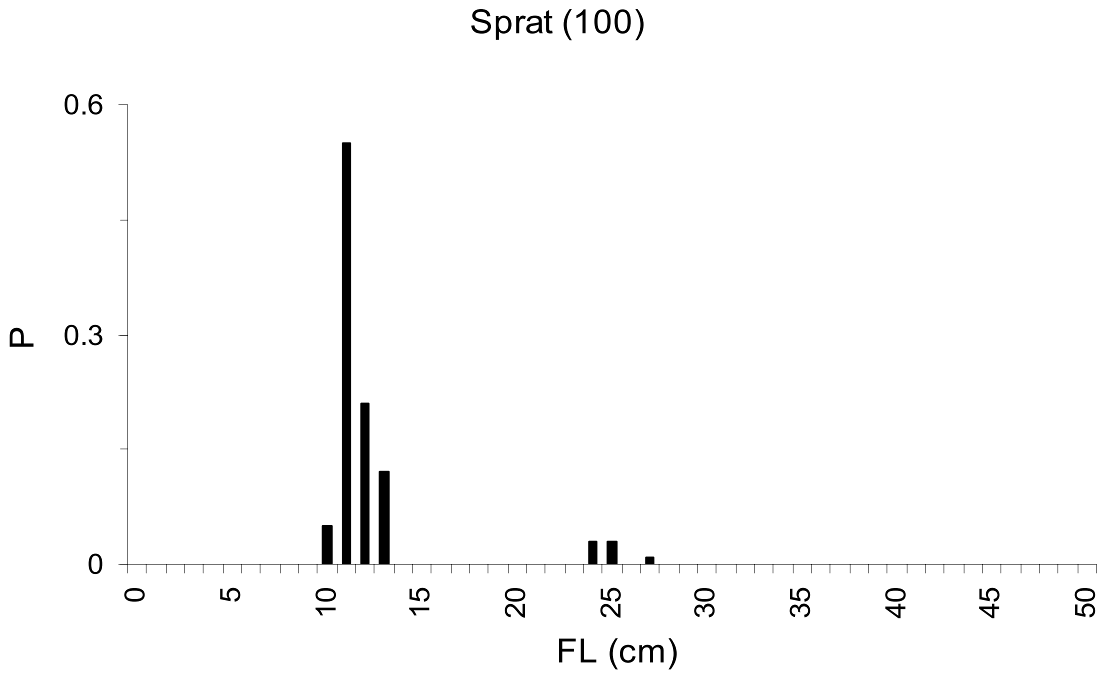

Figure 12. Size-frequency histogram of sprat (*Sprattus sprattus*) measured during discard monitoring trips. Sample size in parenthesis.

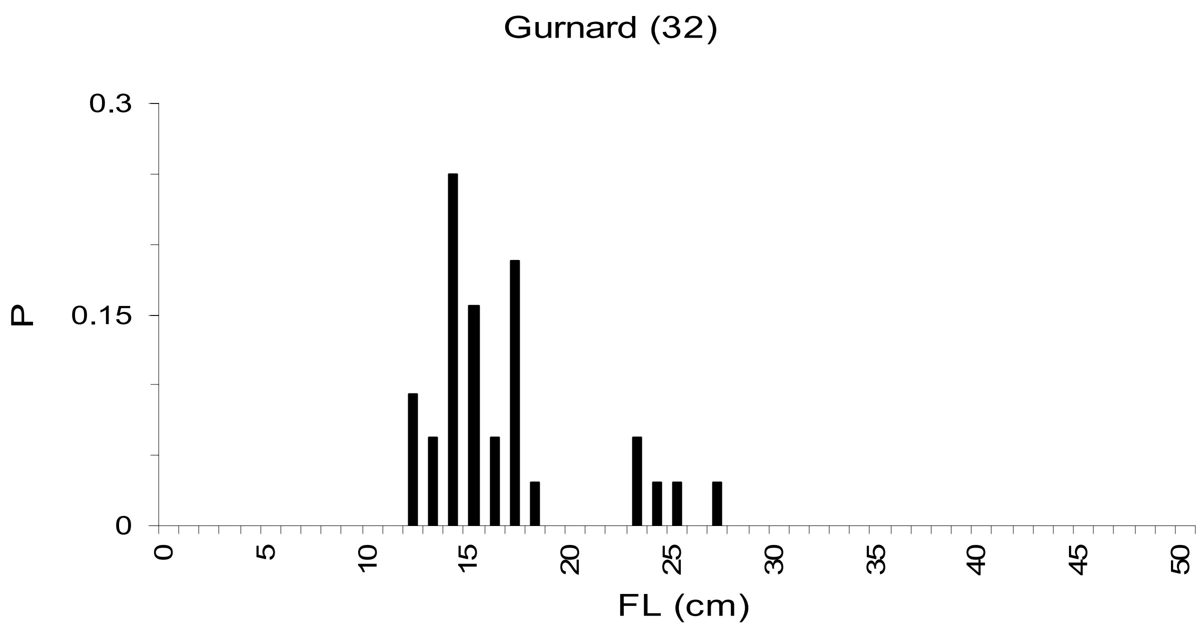

Figure 13. Size-frequency histogram of gurnard (*Trigla lucerna*) measured during discard monitoring trips. Sample size in parenthesis.

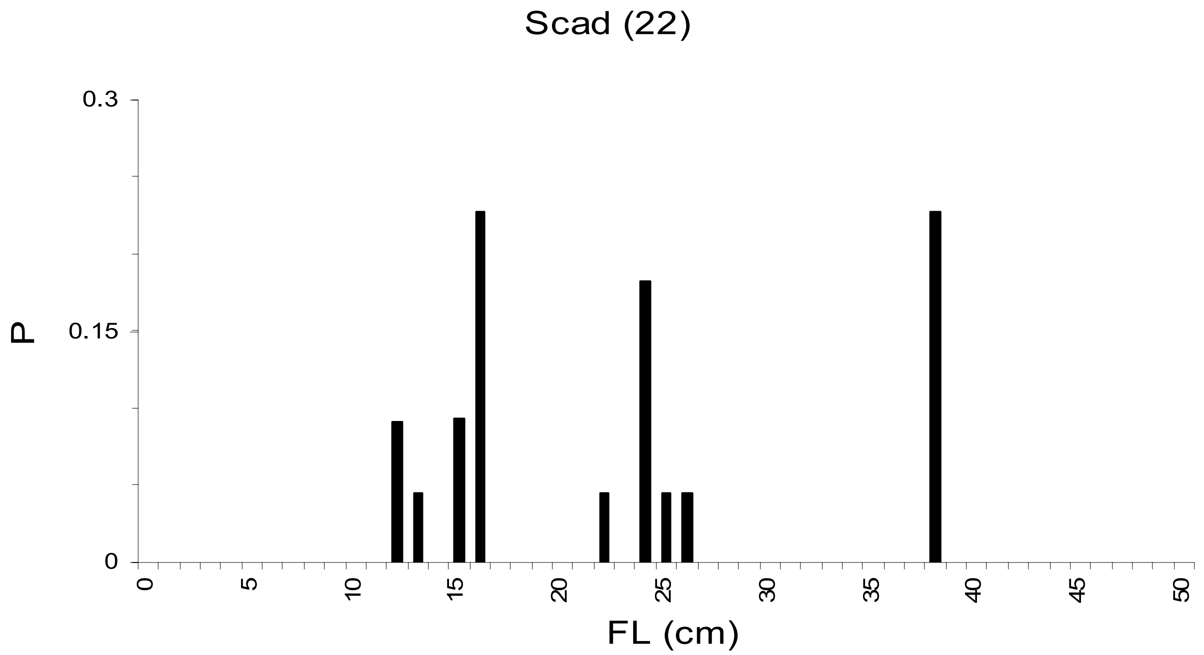

Figure 14. Size-frequency histogram of scad (*Trachurus trachurus*) measured during discard monitoring trips. Sample size in parenthesis.

The following strong modal size (FL) classes were observed in the by-catches of three relatively abundant species: whiting (7–8, 14–15, 22–23 cm, Figure 5), dab (12–13, 17–18, 20–21 cm, Figure 7) and flounder (11–12, 16–17, 22–23 cm, Figure 8). The samples of other by-caught species were too small to ascertain modal classes.

Squid caught during the discard monitoring trips ranged from 4–24 cm ML, depending on vessel and locality (overall mean = 8.8 cm ML, Table 7). Whiting caught ranged from 7–31 cm FL (overall mean = 15.8 cm FL). Overall mean lengths of other fish species by-caught are also provided in Table 7.

Table 7. Summary statistics of sizes (lengths) of squid (*Loligo forbesi*) and main fish species by-caught during discard monitoring trips in Firth of Forth and Moray Firth (2007).

		Length (cm)			
Species	Vessel	Mean	SD	Range	Sample (N)
Squid	Crusader	11.3	1.98	7 – 17	224
	Crusader	9.4	2.89	5 – 18	93
	Osprey	7.6	2.65	4 – 24	508
	Tamaralyn	8.3	1.90	5 – 15	371
	Wninaway	9.7	2.52	6 – 17	189
	Overall	**8.8**	**2.71**	**4 - 24**	**1385**
Whiting	Crusader	15.2	2.90	10 – 26	195
	Crusader	15.8	2.71	12 – 24	148
	Osprey	9.0	3.53	7 – 17	146
	Tamaralyn	17.8	4.45	11 – 27	115
	Wninaway	18.2	4.71	9 – 31	354
	Overall	**15.8**	**4.86**	**7 – 31**	**958**
Haddock	**Overall**	**14.3**	**2.04**	**9 – 31**	**150**
Dab	**Overall**	**16.6**	**3.60**	**11 – 28**	**333**
Flounder	**Overall**	**16.8**	**4.27**	**9 – 29**	**198**
Plaice	**Overall**	**13.5**	**1.26**	**5 – 11**	**85**
Mackerel	**Overall**	**32.3**	**2.73**	**23 – 37**	**134**
Sandeel	**Overall**	**19.8**	**3.82**	**13 – 37**	**85**
Sprat	**Overall**	**12.4**	**3.54**	**10 – 27**	**100**
Gurnard	**Overall**	**16.3**	**3.96**	**12 - 27**	**31**
Scad	**Overall**	**23.0**	**9.41**	**12 – 38**	**22**

4.4. Discussion

The targeted squid fishing operations in the Firth of Forth and Moray Firth resulted in fairly clean hauls, with very few species of fish by-caught in large numbers. The small amounts of haddock and cod caught (1–8% and <1%, respectively) were similar to those reported by Campbell & McLay (2006). However, whiting were caught occasionally in larger amounts (25% overall, compared to <9% previously (Campbell & McLay, 2006)). Anecdotal evidence indicates that large numbers of small fish are usually only caught at the start and end of the squid season. This is possibly due to exploratory fishing, when fishermen are actively seeking the expected large catches of small squid that appear inshore each summer. During the peak period of activity, fishermen report that catches are often almost entirely composed of squid, with very little by-catch.

Given the small numbers and sizes of vessels involved in the Firth of Forth and Moray Firth seasonal squid fisheries, it is unlikely that targeted squid fishing significantly impacts stocks of commercial fish species (as well as common, non-marketed species) in those areas. Significant catches of mackerel (<5%), a pelagic species, were unexpected and may represent fish that were caught when the gear was being hauled through the water column, at the end of each tow.

The discard monitoring study was quite limited, involving only four fishing vessels and 28 tows overall. Nevertheless, the data obtained are very useful, in terms of insight into targeted squid-fishing operations, contacts with fishermen involved and the provision of valuable baseline information. It is clear that more discard data is required. The numbers of small whiting by-caught should be assessed in order to produce accurate estimates of mortality associated with squid-fishing.

For future work, our knowledge of discarding associated with this activity would be greatly increased by the following approaches: 1) monitoring larger numbers of vessels (e.g. n = 10), thereby providing greater representation of the fishing fleet, and 2) monitoring one or two vessels over an entire fishing season, thereby indentifying any trends in discarding.

5. Environmental effects

5.1. Climatic variation

Squid are highly sensitive to environmental conditions and change at a range of spatial and temporal scales (Pierce *et al.,* 2008). Two main types of relationship between squid population dynamics and environmental conditions are recognised. These concern effects on the geographic distribution of species abundance, and on critical biological processes such as egg survival, growth, recruitment and migration. Species-environment interactions are influenced, by both large-scale atmospheric and oceanic processes, and local environmental variations (Pierce *et al.,* 2008). Mobile pelagic species, such as ommastrephid squids, are directly affected by oceanographic conditions, whilst shallow-water, neritic species such as cuttlefish may be impacted by coastal variations in water quality and salinity that are influenced by rainfall and run-off. Climate change, therefore, is expected to have a significant effect on many squid species in the north-east Atlantic and elsewhere.

The embryonic development and hatching, growth and maturation, timing of reproduction and migration and biogeographic distribution of many cephalopod species are influenced by temperature (Boyle, 1983). Observed changes in abundance of the squid *L. forbesi* in Scottish waters appeared to be related to climatic variation. Pierce & Boyle (2003) reported significant correlations between abundance of *L. forbesi* in coastal waters of the North Sea and a number of annual environmental indices, including winter North Atlantic Oscillation Index, average sea surface temperature and sea surface salinity. Sea surface temperature (SST), in particular appeared to influence recruitment strength (Pierce & Boyle, 2003).

North Atlantic climatic variation also appears to affect the timing of migration of *L. forbesi* in the English Channel. Analyses of historical research data by Sims *et al.,* (2001) indicated that the eastward migration of this species was earlier when water temperatures in the preceding months were higher, corresponding with warm (positive) phase of the North Atlantic Oscillation. The difference in timing of peak squid abundance between the warmest and coolest years was 120–150 days. Sea bottom temperature appeared to determine the extent of squid movement. It was also noted that these effects of water temperature and climatic fluctuations, on the timing and extent of squid movements, occurred irrespective of season (Sims *et al.,* 2001). Since the early 1990s, marked declines in catches of *L. forbesi* in Iberian waters indicated a disappearance of this species from much of the southern part of its range, possibly linked to a rise in SST observed during this period (Chen *et al.,* 2006).

Other loliginid species from different parts of the world also appear to be affected by climatic variations. On the Falkland Shelf, for example, seasonal changes in migratory patterns of Patagonian long-fin squid (*Loligo gahi*) have been associated with changes in water mass characteristics. A 5.5 ^{o}C isotherm appeared to limit the distribution of *L. gahi* to deeper waters, irrespective of season, whilst the distribution of squid on the feeding grounds was associated with the warmest possible water layers (Arkhipkin *et al.,* 2004). The extent of frontal waters and sea surface temperature are affected by climate in the South Atlantic and these appear to directly influence annual recruitment success of an ommastrephid species, the Argentinian shortfin squid, *Illex argentinus* (Waluda *et al.,* 2001). As Robinson *et al.,* (2005) point out, any significant long-term changes in these associated with climate change could therefore affect the distribution and abundance of *I. argentinus*.

Therefore, as mentioned previously, important changes in cephalopod biodiversity in the north-east Atlantic may occur within the next few decades. Global warming (sea temperature rise), for example, may result in the continued advance of a number of warm-water species into the north-east Atlantic, and the simultaneous retreat of certain cold-water species to higher latitudes.

Another process associated with climate change that may affect cephalopods is the general rise in oceanic $C0_2$ concentration that has been observed in recent years. For example, ommastrephid squid such as *I. argentinus* are characterised by high metabolic rates and extremely pH-sensitive blood oxygen transport systems, and elevated CO_2 may affect their growth and reproduction (Pörtner *et al.,* 2004).

5.2. Light colour and intensity

Squid use acute vision to locate and capture prey and have well developed eyes. Most species are probably able to distinguish the brightness, size, shape and orientation of submersed objects. Most cephalopods appear to be colour-blind, although many species (including squid) have excellent polarized vision (Gleadal & Shashar, 2004). This enables prey detection and intra-specific communication (squid have rapidly-changing, polarization body patterns and are sensitive to the plane of polarization of light: (Cronin *et al.,* 2003). Squid are known to respond differently to certain colours, and lures and lamps of different colours are widely used by the commercial squid jiggers. It is thought that squid may perceive the changes in wavelength as subtle changes in brightness. During jigging operations, powerful metal halide lamps (2–10 kW) are often used to illuminate the surrounding water. This attracts the squid, which tend to aggregate in the darker, shaded zone just below the vessel.

6. Fishery biology (market sampling)

6.1. Background

The veined squid, *Loligo forbesi*, is a neritic, demersal species occurring in sub-tropical/temperate, shallow coastal waters and continental shelf areas and is widely distributed in the north-east Atlantic, from the Azores (20^{o} N) to the Faroes and the north-west coast of Norway (63^{o} N). It also occurs in the North Sea between Scotland and Norway and, to a lesser extent the Mediterranean (Roper *et al.,* 1984). It is relatively rare south of the Bay of Biscay (45^{o} N). In UK waters, *L. forbesi* is often relatively abundant in the English Channel (Holme, 1974), Irish Sea (Collins *et al.,* 1995), off Rockall Bank and the Scottish west coats (Pierce *et al.,* 1994a) and in the Moray Firth (Young *et al.,* 2006). *Loligo forbesi* is one of three marketable loliginid squid species of commercial importance that occurs in the north-eastern Atlantic, and the most important species caught in Scottish waters (Pierce *et al.,* 1994a). Since the early 1990s, there has been a dramatic decline in catches of *L. forbesi* off the Iberian Peninsula (Chen *et al.,* 2006). At the same time, abundance in northern waters (around Scotland) has increased. According to Chen *et al.,* (2006), this apparent northerly shift in the range of *L. forbesi* may be associated with increasing seawater temperatures.

The main population in UK waters is distributed over the continental shelf and shelf edge, mostly 50–250 m in depth and within about 200 km of the coast (Pierce *et al.,* 1994a). Mangold-Wirz (1963) described the vertical distribution of *L. forbesi* as between 15–150 m in the North Sea and eastern Atlantic, and 150–400 m in the Mediterranean. Moreno *et al.,* (1994) reported *L. forbesi* to occur in depths of 100–200 m in Portuguese waters (where *L. vulgaris* is also present, but tends to occur in shallower water, indicating possible competition between the two species). At Rockall, survey catches were mostly in shallow waters <150 m (Pierce *et al.,* 1998). Recent data collected in UK waters showed that the depth distribution seemed to be correlated to season with squid predominantly found in deeper waters along the shelf-edge (100–200 m) at the beginning and the end of the spawning season (November and March), while during the peak of spawning most squid were caught in waters shallower than 50 m (Stowasser *et al.,* 2005) (see section 8 on squid movements). The maximum recorded depth for the species is 700 m, but in the Azores the fished population occurs in water depths >1000 m (Martins, 1982; Salman & Laptikhovsky, 2002). In areas where its distribution overlaps with that of its congener, *L. vulgaris*, it tends to be in deeper water and at greater depths than the other species (Hastie *et al.,* 2009).

Loligo forbesi is an annual, semelparous species (Holme, 1974) showing extended breeding seasons with 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 pulses of recruitment appear in April and August to 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). Early work on *L. forbesi* in the English Channel by Holme (1974) indicated the existence of distinct winter and summer breeding populations in UK waters. Examination of Scottish fishery data suggests that since the 1970s, 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).

Loligo forbesi is a relatively large loliginid squid. It matures over a range of sizes with males generally growing bigger than females, although some males mature at much smaller sizes (apparently an alternative reproductive strategy). In UK waters, maximum lengths and weights of 61 cm ML and 2.87 kg for males, and 42 cm ML and 1.54 kg for females have been recorded (Hastie *et al.,* 2009). The largest *L. forbesi* have been caught around the Azores, with reported maximum values of 94 cm ML and 8.31 kg for males and 46 cm ML and 2.18 kg for females (Martins, 1982), although the Azores population may belong to a distinct sub-species (Brierley *et al.,* 1995). According to Hughes (1998), the growth pattern of *L. forbesi* is influenced by a number of factors, including sex, maturation, season and reproduction. Although precise age determinations of cephalopods are difficult, it is generally accepted that *L. forbesi* is an essentially annual species, which may sometimes live for 24 months (Cordes, 2002).

Loligo forbesi has an annual reproductive cycle and is semelparous (Lum-Kong *et al.,* 1992; Pierce *et al.,* 1994a; Collins *et al.,* 1995). It exhibits intermittent, terminal spawning, in which the females lay eggs in batches and die shortly after spawning (Rocha *et al.,* 2001). However, an extended spawning pattern, with different seasonal peaks has been reported (Roper *et al.,* 1984; Lum-Kong *et al.,* 1992; Boyle & Ngoile, 1993; Guerra & Rocha, 1994, Moreno *et al.,* 1994; Pierce *et al.,* 1994a; Boyle *et al.,* 1995; Collins *et al.,* 1995). The timing of peak spawning activity varies across its range and secondary peaks have been observed in some areas (Pierce *et al.,* 1994a). Depending on the area and season, one or more associated pulses of recruitment occur. In the North Atlantic, concentrations of *L. forbesi* are usually found west of Scotland and Ireland in autumn and gradually shift from offshore to inshore waters as spawning progresses. By the following spring (January to March), the highest abundances are found in the Minch and Moray Firth areas and further south along the east coast of England. In summer, mature specimens are only found in the English Channel (Stowasser *et al.,* 2005). It is not clear how long an individual squid can remain in spawning condition and it is likely that extended seasonal peaks represent a series of microcohorts maturing out of phase with each other, while secondary peaks may indicate (for example) distinct winter and summer breeding populations (Hastie *et al.,* 2009).

The aims of this investigation were threefold: 1) to extend the historical record of population data, 2) to improve understanding of the life-cycle biology of the exploited squid (*Loligo forbesi*) population in the Moray Firth, including reproductive data, and 3) to provide empirical growth data required for stock assessments (section 7). Monthly samples of squid were purchased from the commercial fishery, and standard fishery biological parameters were calculated.

6.2. Methodology

Squid caught in the Moray Firth were sampled monthly over a two-year period (July 2006 to June 2008). A box of squid (n = 100–500) was obtained each month, from the commercial market at Fraserburgh. Squid (*Loligo forbesi*) were caught by demersal trawling gears, and normally stored and transported in ice prior to receipt. Upon receipt, dorsal mantle lengths (DML, mm) and wet body weights (BW, g) were recorded for each squid. A size-stratified sub-sample of 100 squid was taken for collection of detailed biological and reproductive data.

All data were initially logged on data sheets and subsequently transferred to MS-Excel spreadsheets. Squid length-weight equations were derived from bivariate scatterplots. The gonado-somatic index (GSI), a widely-used index of maturity (reproductive status) was calculated (Boyle & Ngoile, 1993):

(1) $$GSI = 100 \times GW / (BW - GW)$$

Where GW = gonad (testis or ovary) weight.

6.3. Results

6.3.1. General

A total of 8071 squid (816 kg) was sampled. *Loligo forbesi* was by far the dominant species present, with 7866 specimens (812 kg), representing ~97% and ~99% by number and weight, respectively. Four other potentially marketable squid species; *Loligo vulgaris*, *Alloteuthis subulata*, *Todarodes sagittatus* and *Todaropsis eblanae*, were also present, in very small numbers. The species composition of each monthly sample is provided in Table 8.

Total numbers of 2969 males and 3730 females were recorded overall, representing a sex ratio of 1:1.256 in favour of females. However, observed monthly sex ratios were quite variable, ranging from 0.27–2.26 for January 2007 and May 2008, respectively (Table 9).

6.3.2. Length-frequency distributions

Monthly size (length-frequency) distributions of *L. forbesi* varied considerably. As expected, a cyclical, annual pattern was observed in both sexes, with the modal size class influenced by the influx of large numbers of small male and female squid (recruits) in summer (May-June) each year (2006–2008). Multiple size modes were observed in both sexes, over winter (December–March), possibly due to the presence of several microcohorts, each associated with different hatching times and growth rates (Figures 15–16). Monthly mean lengths ranged from 81–260 mm ML in males (September 2006 and February 2007, respectively) and 81–236 mm ML in females (September 2006 and January 2007, respectively). Absolute lengths of 31–111 mm, 51–522 mm and 48–395 mm ML were observed in immatures (unsexed), males and females, respectively. Monthly length data are provided in detail in Table A5 (Appendix).

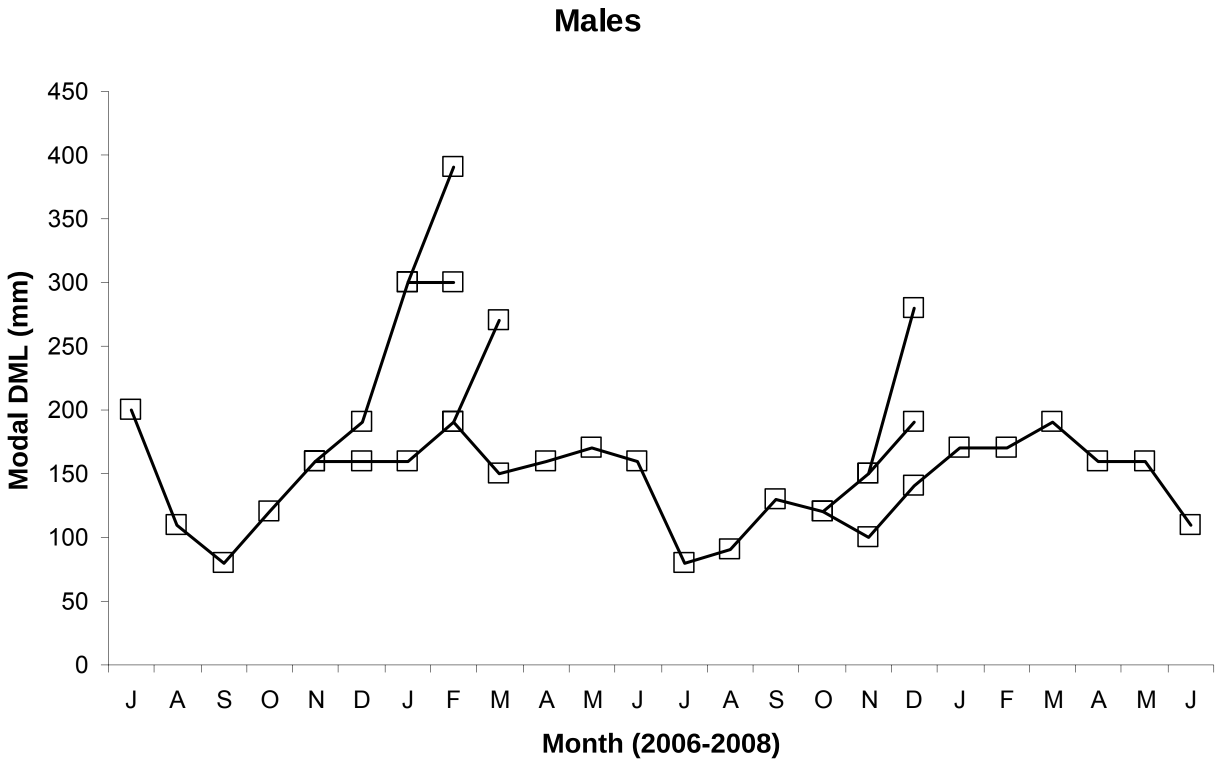

Figure 15. Monthly modal size (ML) progressions observed in male *Loligo forbesi* samples from the Moray Firth (2006–2008).

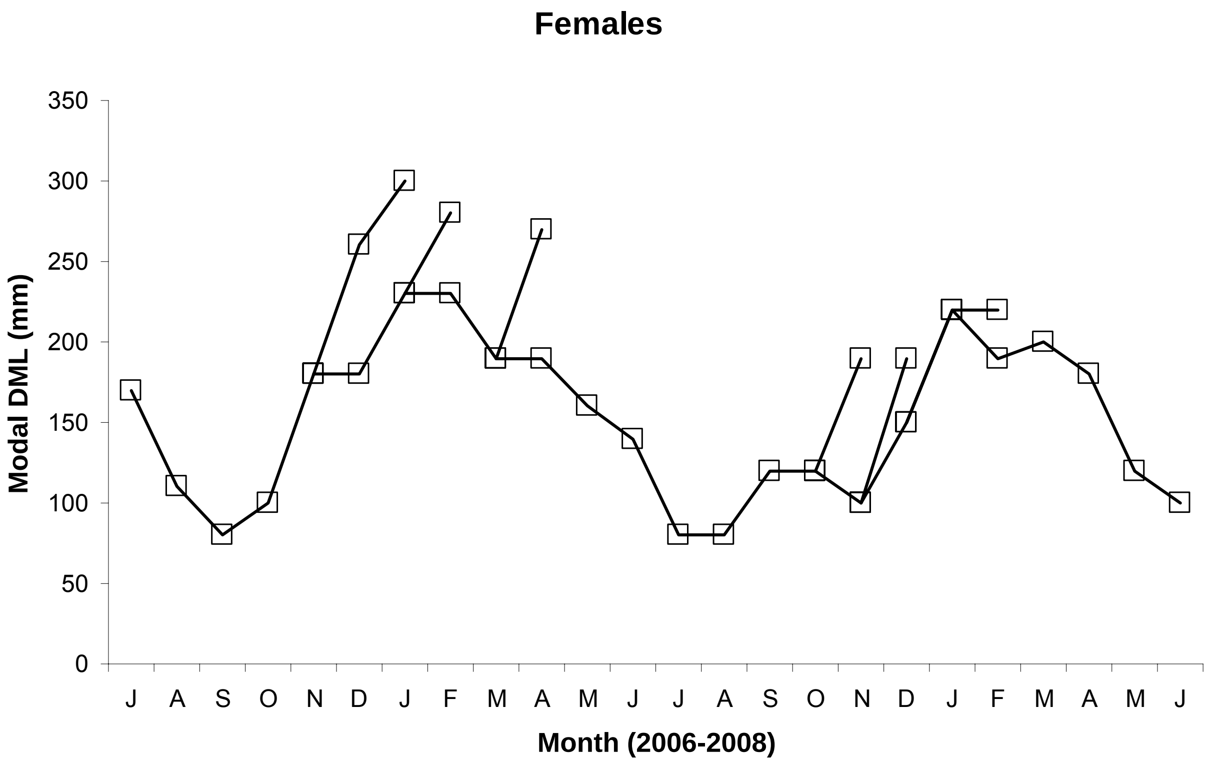

Figure 16. Monthly modal size (ML) progressions observed in female *Loligo forbesi* samples from the Moray Firth (2006–2008).

Table 8. Species compositions of squid recorded in monthly market samples from the Moray Firth (2006–2008).

		L. forbesi		*L. vulgaris*		*A. subulata*		*T. sagittatus*		*T. eblanane*	
Month	Year	*N*	Wt (kg)	*N*	Wt (kg)	*N*	Wt (kg)	*N*	Wt (kg)	*N*	Wt (kg)
Jul	2006	298	45.305	0	0	0	0	0	0	0	0
Aug	2006	500	43.766	0	0	30	0.166	0	0	0	0
Sep	2006	500	11.189	0	0	0	0	0	0	0	0
Oct	2006	500	31.197	0	0	35	0.038	0	0	0	0
Nov	2006	99	16.453	0	0	0	0	0	0	0	0
Dec	2006	274	56.873	0	0	0	0	0	0	0	0
Jan	2007	64	21.363	0	0	0	0	0	0	0	0
Feb	2007	268	92.923	0	0	0	0	0	0	0	0
Mar	2007	117	24.336	0	0	0	0	0	0	0	0
Apr	2007	194	42.336	0	0	0	0	0	0	0	0
May	2007	206	25.991	0	0	0	0	0	0	0	0
Jun	2007	500	57.186	0	0	0	0	0	0	0	0
Jul	2007	636	13.589	0	0	67	0.159	0	0	0	0
Aug	2007	954	26.704	0	0	34	0.26	0	0	0	0
Sep	2007	564	34.456	0	0	1	0.002	0	0	0	0
Oct	2007	611	34.871	0	0	2	0.008	0	0	0	0
Nov	2007	109	16.785	0	0	18	0.058	0	0	0	0
Dec	2007	211	41.217	0	0	0	0	0	0	0	0
Jan	2008	117	42.051	4	0.89	0	0	0	0	0	0
Feb	2008	121	33.601	9	1.906	0	0	0	0	0	0
Mar	2008	116	29.443	0	0	0	0	0	0	0	0
Apr	2008	146	25.440	0	0	0	0	0	0	0	0
May	2008	261	27.565	0	0	0	0	1	0.023	0	0
Jun	2008	500	17.942	0	0	2	0.017	0	0	2	0.405

6.3.3. Length-weight relationships

Monthly weight data were collated and length-weight relationships were computed for the monthly samples (see Tables A6–A7, Appendix). The equations obtained were used in order to calculate overall numbers of squid caught by the fishing fleet, in order to assess the size of the Moray Firth squid (*L. forbesi*) stock (section 7).

Table 9. Numbers of male, female and immature *L. forbesi* recorded in the monthly samples from the Moray Firth (2006–2008).

Month	Year	Males	Females	Unsexed (immature)	Total	Sex ratio (m/f)
Jul	2006	157	134	7	298	1.17
Aug	2006	179	262	59	500	0.68
Sep	2006	148	249	103	500	0.59
Oct	2006	222	262	16	500	0.85
Nov	2006	35	64	0	99	0.55
Dec	2006	101	173	0	274	0.58
Jan	2007	13	51	0	64	0.25
Feb	2007	90	178	0	268	0.51
Mar	2007	57	60	0	117	0.95
Apr	2007	64	130	0	194	0.49
May	2007	111	87	8	206	1.28
Jun	2007	236	263	1	500	0.90
Jul	2007	164	201	135	500	0.82
Aug	2007	217	255	28	500	0.85
Sep	2007	233	255	12	500	0.91
Oct	2007	233	263	4	500	0.89
Nov	2007	52	56	1	109	0.93
Dec	2007	71	140	0	211	0.51
Jan	2008	40	77	0	117	0.52
Feb	2008	47	74	0	121	0.64
Mar	2008	34	82	0	116	0.41
Apr	2008	74	72	0	146	1.03
May	2008	179	79	3	261	2.27
Jun	2008	212	263	25	500	0.81

6.3.4. Maturation and reproduction

A clearly defined annual cycle of maturity was observed, with the proportions of mature squid (both sexes) remaining high over the winter-spring period (December to April). A sharp drop in maturity occurred in May in both years, owing to the influx of small, immature recruits alongside the breeding adults (Figure 17). Post-breeding (spent) squid were very rare in samples.

The proportion of mated females in the samples remained high from May through to December, indicating an extended breeding season (Figure 18).

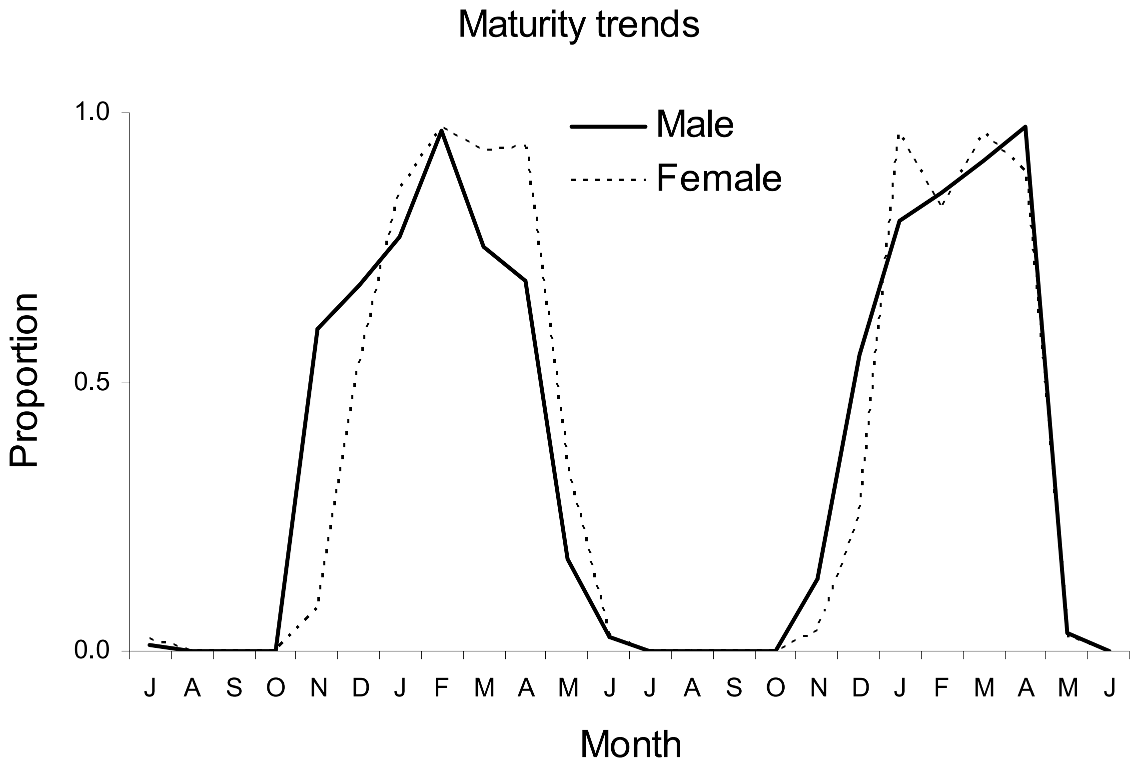

Figure 17. Proportions of mature squid (*L. forbesi*) in monthly samples from the Moray Firth (July 2006–June 2008).

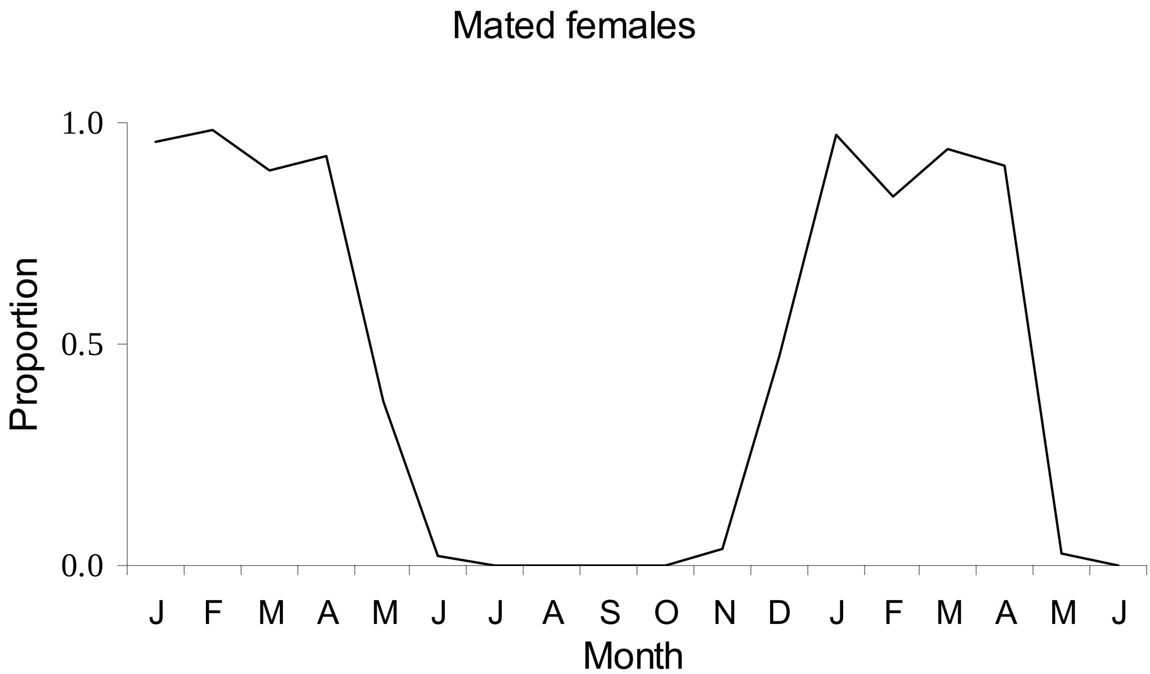

Figure 18. Proportion of mated female squid (*L. forbesi*) recorded in monthly samples from the Moray Firth (July 2006–June 2008).

6.3.5. Recruitment

Fishery recruits may be defined formally as those squid below modal body size (~110 mm ML, Figure 19). This assumes a stable population structure, and the initial upward trend represents the increasing catchability of larger squid. At the modal size, squid are fully recruited and the final, downward trend reflects mortality and decreasing catchability of older squid. An apparent, secondary peak in recruitment (at ~180 mm ML) was also observed in the samples (Figure 19).

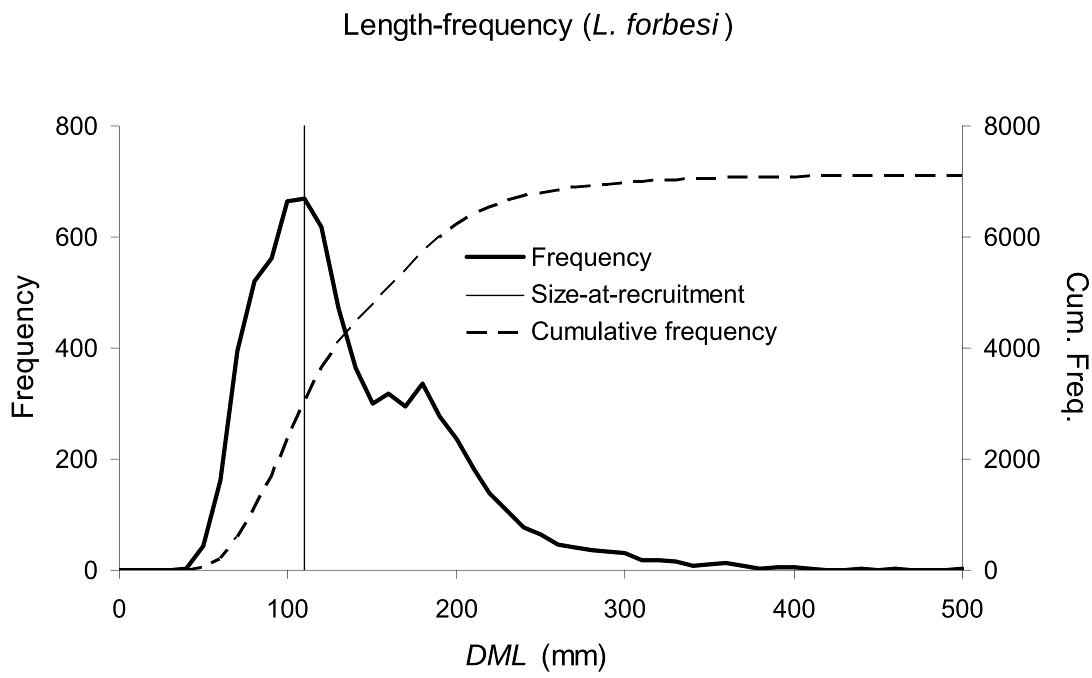

Figure 19. Length-frequency curves for the entire 2-year data set (2006-2008). The size (D*ML*) at full recruitment to the fishery is indicated.

6.4. Discussion

The overall patterns of growth, maturation, reproduction and recruitment observed during the present study were in general agreement with the findings of previous studies of *L. forbesi* in Scottish waters (Pierce *et al*., 1994a; Boyle *et al*., 1995; Collins *et al*., 1997). Although the timing of the main recruitment event appeared to be same as that reported in the previous decade, a secondary pulse in recruitment (in April), previously reported in Scottish waters (Pierce *et al*., 1994a) was not evident in the Moray Firth samples examined during the present study. There are a number of possible explanations for this discrepancy, including sample size, area differences (the 1990s sampling was mainly on the west coast), fishery effects (e.g., squid is targeted in the Moray Firth, whereas in other areas, it may be by-caught) or the influence of environmental changes on squid growth and reproduction patterns. The presence of several microcohorts of male and female squid has been reported previously for this species in Scottish waters, and may be associated with different hatching times, growth rates and variable environmental conditions (Collins *et al*., 1998).

The observed size-at-recruitment (~110 mm ML) was considerably smaller than that previously reported in Scottish waters (~150 mm ML, Pierce *et al*., 1994a). This may be explained by the fact that the Moray Firth samples were composed of targeted squid, caught using a small mesh (40 mm), whereas the Scottish samples analysed by Pierce *et al*. (1994) were composed largely of by-caught squid from demersal trawl and seine fisheries, that employ larger mesh gear, e.g., 120 mm (Hastie, 1996). However, the appearance of a secondary recruitment peak at ~180 mm, indicate that some of the squid from the Moray Firth had been by-caught. This is not unexpected, since the Moray Firth targeted squid fishery is seasonal, with vessels changing to small mesh gear when the squid become abundant (Young *et al*., 2006).

7. Stock assessments

7.1. Background

Squid fisheries around the world exhibit considerable variations in annual catch, mainly as a result of large fluctuations in abundance (recruitment success) that appear to be environmentally driven (Starr & Thorne, 1998). This presents considerable difficulties for fishery managers attempting to estimate and forecast squid abundance in any given year. The short life cycle of squids poses particular problems for fishery management (Caddy, 1983; Pierce & Guerra, 1994). There is little opportunity to adjust fishing effort during one generation (Bravo de Laguna, 1989) and squid stocks are particularly vulnerable to overfishing (Rosenberg *et al.,* 1990).

A number of direct and indirect methods have been used to assess squid stocks, with limited success (Pierce & Guerra, 1994). For example, egg and larval surveys, trawl surveys, video surveys and acoustic surveys have been used to estimate squid abundance directly (Sato & Hatanaka, 1983; Augustyn *et al.,* 1993; Starr & Thorne, 1998; Payne *et al.,* 2006). However, most surveys for squid have been affected by considerable sampling bias, including under-estimates caused by gear avoidance (Sato & Hatanaka, 1983) and occasional dense aggregations of squid over spawning grounds (Augustyn *et al.,* 1993).

Indirect estimates of relative abundance have been based on either biological parameters, such as the numbers of squid beaks in marine mammal stomachs (Clarke, 1987); or fishery parameters such as commercial catch and effort data (length/age-based cohort analysis, VPA, stock-recruit models, production models, yield-per-recruit models, spawner-recruit models; see reviews by Pierce & Guerra, 1994; Payne *et al.,* 2006). However, these have been largely unsuccessful due to the difficulties in developing robust spawner-recruit models, and the technical and logistical problems associated with using squid age and catch data (Starr & Thorne, 1998). Furthermore, it is difficult to use cohort analysis for predictions, because of the considerable variation in squid growth patterns (Rodhouse & Hatfield, 1990) and the face that larval survival is greatly influenced by environmental conditions (Starr & Thorne, 1998).

A relatively successful method of assessing squid stocks is by constructing a population depletion model. This approach is derived from Leslie & Davis (1939) and De Lury (1947) and is based on the assumption of a closed population that declines as a direct result of fishing mortality. The management of the fishery for the Argentine short-fin squid, *Illex argentinus*, in waters around the Falklands Islands waters is based on a modified Leslie-De Lury analysis (Rosenberg *et al.,* 1990). Catch-per-unit-effort (CPUE) is used as an index of abundance, and it is assumed that after CPUE reaches a peak, it subsequently declines in proportion to population size, and also that catchability is constant across the entire fishing fleet.

Stock depletion methods have been applied to assess other ommastrephid squid species, notably *Dosidicus gigas* in the Gulf of California (Erhardt, 1983) and *Todarodes pacificus* in the Sea of Japan (Murata, 1989). They have also been used to assess loliginid stocks, including *Loligo pealei* in the north-west Atlantic (Brodziak & Rosenberg, 1993), and more recently, *Loligo vulgaris* in the English Channel (Royer *et al.,* 2002) and *Loligo forbesi* in Scottish waters (Young *et al.,* 2004).

7.2. Scottish squid stocks

Most squid caught in Scottish waters are taken as by-catch during demersal trawl and seine net fisheries for whitefish (Young *et al.,* 2006). Scottish squid landings are not currently differentiated and recorded by individual species, but are almost exclusively *Loligo forbesi* (Boyle & Pierce, 1994; this study). In UK waters, directed squid fishing is unregulated, apart from a minimum legal mesh size (cod-end) of 40 mm (Pierce *et al.,* 1998). There appears to be little incentive, therefore, for Scottish fishermen to deliberately misreport squid catches. However, poor levels of reporting have seriously compromised the accuracy of official fishing effort data for the Scottish fleet since 1998 (Young *et al.,* 2006).

In a preliminary study, Young *et al.,* (2004) used depletion models and monthly catch and effort data to assess the entire squid (*Loligo forbesi*) stock in Scottish waters. Their results indicated typical, initial population sizes in the order of one million squid (recruits, ML >15 cm) in Scottish coastal waters (prior to seasonal exploitation). However, annual population size and seasonal patterns of growth (body weight) and recruitment appeared to vary considerably between years. For example, initial population size estimates ranged from 0.1

million to 6 million squid, estimated for 1996 and 1991, respectively (Young *et al.,* 2004). However, the accuracy of these estimates is affected by the quality of the data used and the assumptions that must be made for the assessments, e.g., about natural mortality (Young *et al.,* 2004). Analyses are also complicated by the fact that a number of different fleets exploit squid in Scottish waters. Scottish vessels (light trawlers) account for the majority of squid caught in Scottish waters. However, substantial squid catches are also occasionally landed by French trawlers and other sectors of the UK fleet (Pierce *et al.,* 1996). Spanish boats that target other species in Scottish waters may also catch insignificant numbers of squid that are either discarded or not reported (Young *et al.,* 2004).

7.3. The Moray Firth stock

7.3.1. Background

The Moray Firth represents an extremely important area for squid fishing in UK waters. During the past 20 years, landings of squid from the Moray Firth have ranged from 50 to 1300 t per annum, representing 5–70% of total Scottish landings (Figure 2). To date, however, no assessments of the Moray Firth squid stock(s) have been undertaken, and there is currently no management of the fishery, except for the imposition of a legal minimum mesh size of 40 mm for vessels targeting squid (Young *et al.,* 2006). Estimates of the Moray Firth squid population are required in order to monitor historical trends and determine the long-term impact of sustained fishing pressure.

The aim of the following study, therefore, was to assess the squid (*Loligo forbesi*) stock(s) and provide preliminary estimates of the population size, in order to inform fishery managers developing an appropriate strategy for the sustainable exploitation of this resource in the Moray Firth.

7.3.2. Methodology

Historical squid catch (landings) and effort data (1970–2002) were extracted from the FRS fishery database. Monthly data for the Moray Firth and adjacent waters (ICES rectangles 44E6–8, 45E6–8, 46E6–8) were pooled to represent the entire Moray Firth *L. forbesi* population, based on the assumption that there were no significant movements of squid between this semi-enclosed area and other parts of the North Sea where squid are found. Although Waluda & Pierce (1998) suggested that small numbers of squid may occasionally move into the North Sea from the North east Atlantic, more recent investigations indicate that the only significant movements that occur are between inshore and offshore localities within the Moray Firth (Viana, 2007).

Biological data (mean monthly body weights) of squid recorded during market sampling were collated from a number of different project databases (Ngoile, 1987; Lum-Kong, 1989; Pierce *et al.,* 1994b; Collins *et al.,* 1999; Young *et al.,* 2004) and supplemented by additional data recorded during the present study (2006–2008). Average body weight was used to estimate the numbers of squid caught.

The Moray Firth squid fishery and population data were analysed using Catch and Effort Data Analysis (CEDA Version 3.0) software, developed and provided by the Marine Resources Assessment Group (MRAG), Imperial College, University of London (Kirkwood *et al.,* 2001). Depletion estimators were derived using two basic sub-models and a log-transformed (error) model:

(1) Abundance index model

$$N_t = q\, CPUE_t$$

where:

Nt = population size at time t

q = catchability coefficient

$CPUE$ = catch-per-unit-effort

(2) Population dynamics model

$$N_{t+1} = e^{-m}(N_t - L_t + ʎR_t)$$

where:

m = natural mortality rate (set here at 0.2)

L_t = total catch during time t

ʎ = recruitment constant of proportionality

R_t = catch-per-unit-effort

(3) Log transform (error) model

$$\ln (C) \sim N(\ln(qEN),\sigma^2)$$

where:
N = normal distribution
E = expected value

Further information on these models is provided by Holden *et al.,* (1995) and Kirkwood *et al.* (2001). Stock assessment by depletion requires fairly accurate estimates of CPUE (i.e. reliable catch and effort data). These were obtained for the Moray Firth and adjacent waters, for the period 1980–2000. Detailed analysis of the Moray Firth squid population was therefore focussed on this period. Unfortunately, more recent (FRS) fishing effort data (post 2000) are thought to be compromised by poor levels of reporting (Young *et al.,* 2006) and thus were not included in the analyses.

7.3.3. Results

Annual (autumn-winter) declines in squid CPUE were identified in historical fishery data (1980–2000), and these provided depletion-based estimates of the *Loligo forbesi* population in the Moray Firth, ranging from initial (pre-exploitation) estimates of 0.3 to 5.8 million squid, in seasons 1985–86 and 1990–91, respectively (Figure 20). End-of-season (post-exploitation) population estimates ranged from 0.02 to 0.23 million, in 1984–85 and 1996–97, respectively.

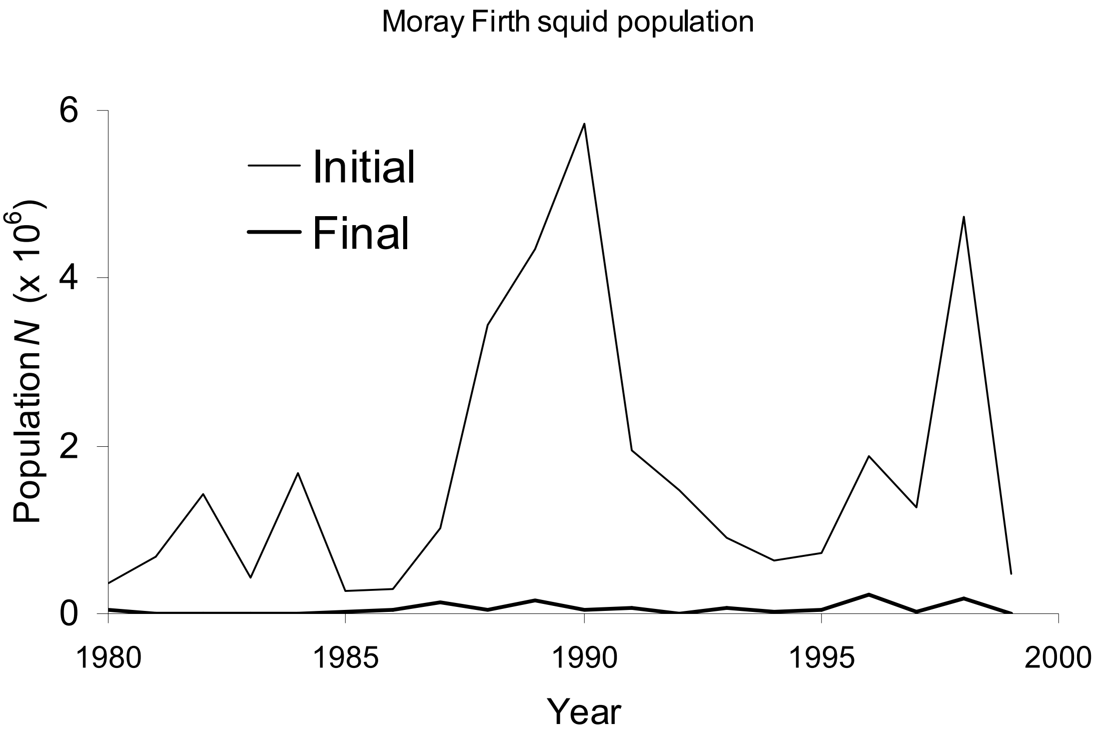

Figure 20. Moray Firth squid (*Loligo forbesi*) annual population size estimates during period 1980-1999. Initial and final (pre- and post-exploitation) population estimates are shown.

7.3.4. Discussion

The estimates of the *Loligo forbesi* population in the Moray Firth, ranging from ~0.5 to 5.8 million, are larger than those of Young *et al.,* (2004), who reported initial population size estimates of ~0.1 to 6.0 million for the entire Scottish inshore stock. However, given the relatively large size of the Moray Firth *L. forbesi* stock, and the fact that this area alone can account for up to 70% of the total Scottish squid catch in coastal waters, it appears that our estimates here are, in fact, in general agreement with those of Young *et al.,* (2004).

It was not possible to obtain reliable fishing effort data in order to estimate the size of the Moray Firth squid stock in more recent years (e.g. 2001–2008). In theory, however, the Moray Firth squid-fishing fleet is quite small, and it should be possible to use a Gomez-Munoz model in order to obtain general estimates of effort (days and/or hours at sea), based on data provided by fishermen (through interviews and questionnaires) (see Young *et al*., 2006).

The Moray Firth *L. forbesi* population appears to exhibit very large annual fluctuations, occasionally increasing by an order of magnitude during a very productive year and quickly declining again the following year. This natural variability observed indicates that it may not be possible to sustain high squid yields in the Moray Firth fishery every year, due to fluctuating environmental conditions. This phenomenon has been observed in a number of cephalopod stocks around the world and appears to be a general characteristic of this group (Pierce *et al.,* 2008).

Another important feature to note is the relatively small (final) number of squid remaining at the end of the season (post-exploitation). This is a characteristic of short-lived, semelparous species that reproduce once and then die shortly after spawning. Previous studies indicate that small numbers of *L. forbesi*, particularly males, may survive for >18 months, until the spawning event the following year, thus providing the potential for a small overlap between successive generations.

8. Movements of squid in Scottish waters

8.1. Background

To protect and sustainably manage fishery resources, it is essential to understand the temporal and spatial patterns of habitat utilization by exploited species (Arendt *et al.,* 2001), including migration patterns. In the veined squid *Loligo forbesi*, such knowledge is important because squid fishing in UK waters is largely unrestricted (Pierce *et al.,* 1998; Young *et al.,* 2006*a*).

Previous studies (e.g. Lum-Kong *et al.,* 1992; Pierce *et al.,* 2005) indicate a clear winter peak in maturation and spawning for *L. forbesi* in Scottish waters, which is consistent with the landings peak that occurs between October and December (Pierce *et al.,* 1994; Bellido *et al.,* 2001). Holme (1974) and Collins *et al.,* (1997, 1999) give evidence for winter and summer breeding cohorts - with the former tending to be the more important. Two distinct recruitment peaks are also reported, the main one in late summer and beginning of autumn, presumed to derive from winter spawners (Collins *et al.,* 1997), and a second peak in spring, presumably derived from the summer breeding population. It is also possible that individual squid may live 18 months or longer, so that the offspring of winter breeders become the summer spawners of the following year, as discussed by Boyle *et al.,* (1995). Even the division into winter and summer breeders may be an oversimplification. It has been argued that some of the apparent variability in seasonality of the life cycle of *L. forbesi* reflects variation in the relative strength of summer and winter breeding populations (Zuur & Pierce 2004). Nevertheless, the dominant seasonal cycle in *L. forbesi* (that of winter breeders) seems to involve recruitment between July and November, spawning in December to March and disappearance from the fished population by June (Pierce *et al.,* 1994; Boyle *et al.,* 1995; Collins *et al.,* 1997).

Some loliginid squid species are known to move within their distribution range, as Hatfield & Rodhouse (1994) and Arkhipkin *et al.,* (2004*a*) suggested for *L. gahi* around the Falkland Islands which, over the course of the annual life-cycle, move offshore to feed and inshore to spawn. *L. forbesi* occurs in coastal waters of the Northeast Atlantic from 20° to 60°N and, according to Holme (1974) and Sims *et al.,* (2001), off the South-west of England, they perform seasonal migrations. This population hatches in the western English Channel during the winter (December-January) and migrates east towards southern North Sea. After a few months of rapid growth, they move back to the west area to spawn and die during the following December-January. In Scottish waters there have been numerous studies on the biology and abundance of *L. forbesi*, however until recently there has been few comprehensive evaluations of evidence on their migration patterns and distribution. The objective of this section is therefore to provide a summary of the studies on *L. forbesi* migration patterns and distribution in Scottish water and its relationship with both the life cycle and environmental conditions.

8.2. West Coast to North Sea migrations

Loligo forbesi appears to be widely distributed around the Scottish coast (*Viana et al.,* 2009). A first study with Geographic Information Systems (GIS) on squid fisheries data to detect migration movements in Scottish waters was developed by Waluda & Pierce (1998). The study suggested that *L. forbesi* move from the West Coast of Scotland into the North Sea to spawn in winter, while the post-spawning adults move towards the northwest of Scotland, as mentioned above. Following this scenario, the next generation of pre-recruit squid might be expected to migrate westwards in the spring. However, this study was based on analysis of fishery data from a 5-year period (1989–1994). Recently, Viana *et al*., (2009) developed a similar study to confirm the possible West Coast to East Coast of Scotland *L. forbesi* migration by looking at a longer time series of 24 years (from 1980 to 2004).

After analysis on month-to-month spatial shifts in the centres of high abundance on GIS maps, Viana *et al.* (2009) showed that *L. forbesi* does not routinely migrate from west coast to east coast of Scotland during winter or back towards the west coast in spring as had been suggested by Waluda & Pierce (1998). However, apart from small differences due to those divergent techniques, re-analysis of the five-year series used in Waluda & Pierce (1998) revealed no contradictory results since for those few years the patterns are quite similar in both studies. During the five years analysed by Waluda & Pierce (1998), a major abundance peak was registered for *L. forbesi* in Scottish waters (Zuur & Pierce 2004), possibly due to the mildest winter climate seen in the North Sea for 50 years (Becker & Pauly 1996), which could have influenced squid distribution in several ways. Squid may actively seek waters of a particular temperature (since they are poikilothermic) or may follow the distribution of their prey. Migration of squid into Scottish waters from further south, as Pierce & Boyle (2003) suggested, for example due to the strong coastal current flow along the West Coast of Scotland that brings Atlantic water into the area and increases nutrient supplies, might also be a reason that led to the apparent migration pattern, described by Waluda & Pierce (1998). This inflow of Atlantic waters into the North Sea is higher in warmer years (Turrel *et al.,* 1992).

Bellido (2002) suggested that the west coast represents the main “reservoir” of squid abundance in Scottish waters since its distribution is characterised by a more or less stable spatial structure, while the east coast is occupied seasonally (although with a widespread coverage in seasons of high abundance), by a population made up of small, fast moving aggregations. Later, Viana *et al*. (2009) showed that squid spread out from a rather localised area, which may occur in the west or east of Scotland but is more usually to the north (Figure 21). This spatially restricted peak of abundance in the North of Scotland usually appears around June and is followed by a spatial expansion of abundance when approaching the winter season. Although the pattern is not evident in every year, *L. forbesi* seems to concentrate in the North of Scotland, which constitutes a possible spawning and/or recruitment site.

Viana *et al*. (2009) also shows for some years and some months, two distinct abundance peaks either in different coasts or one further south than the other (Figure 21). This may suggest that two cohorts or microcohorts exist (see Collins *et al.,* 1997, 1999; Pierce *et al.,* 2005), with different migratory behaviour, as Arkhipkin *et al.,* (2004) discussed for the migratory squid *L. gahi*. However, these two abundance peaks are not visible in all years. One other possibility is the migration of *L. forbesi* from English or Irish waters into more northern waters in some years. Sims *et al.,* (2001) reported that, according to environmental conditions, this species could vary the timing and range of its migration. However, as reported in Young *et al.,* (2006b), the summer directed fishery for *L. forbesi* in the Moray Firth, in the northern North Sea, takes very small squids, suggesting that recruitment may occur at several points along the coast indicating that a west-east migration could not be the dominant pattern in all years.

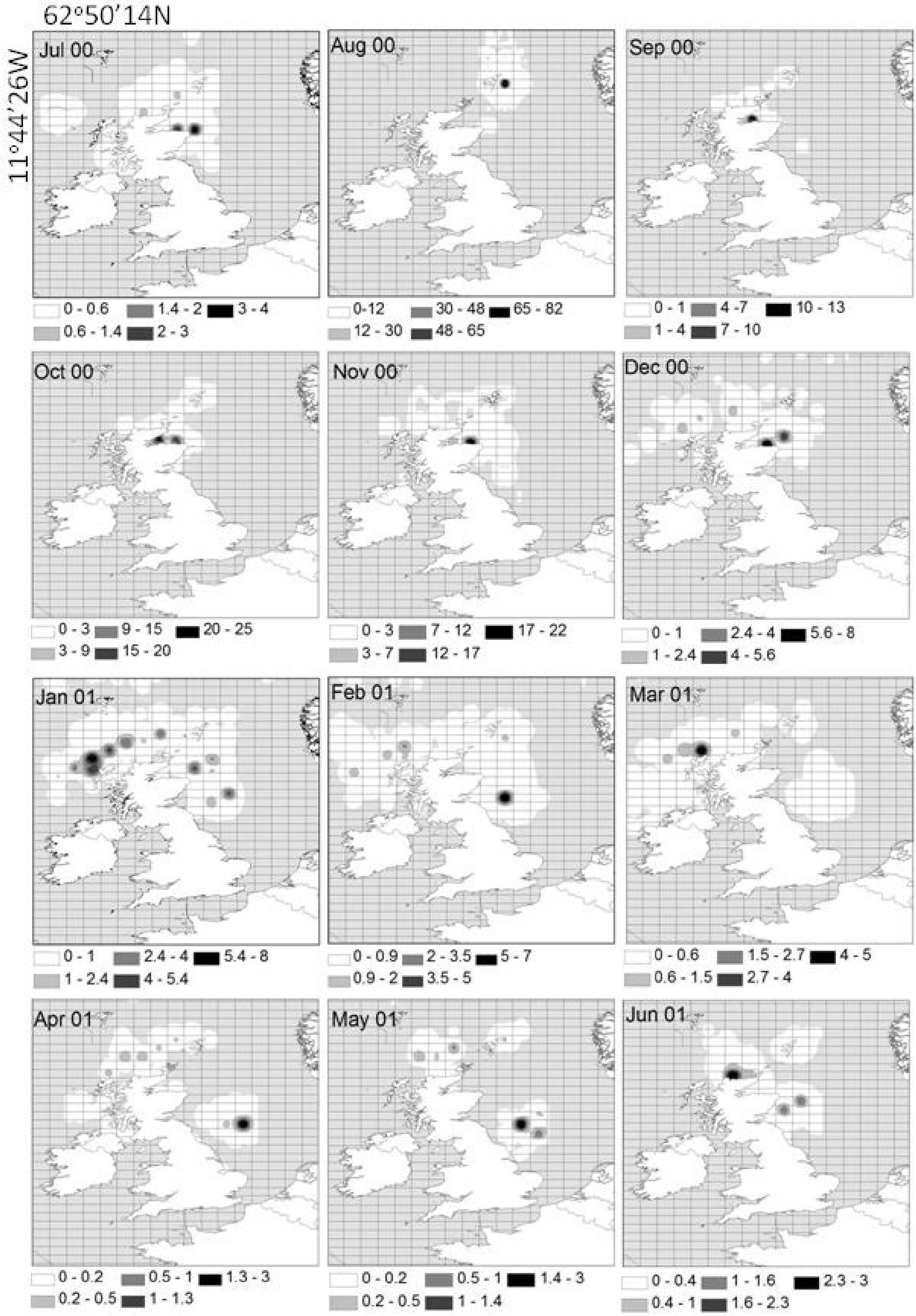

Figure 21. Annual distribution of *Loligo forbesi* “fishery abundance” (landed catches, ton) from July 2000 to June 2001 (Viana *et al.* 2009).

Length–frequency analysis has been used in several studies to establish geographic and temporal patterns of squid abundance (Hatfield & Cadrin 2001; Arkhipkin *et al.,* 2006). For Scottish waters, Viana *et al*., (2009) used length frequency histograms based on Scottish survey data from 1987 until 2004 (performed by FRS Marine Laboratory). The data revealed no evidence of a consistent migration pattern from one coast to another.

According to Holme (1974), Collins *et al.,* (1997, 1999), and Pierce *et al.,* (2005), veined squid have two spawning seasons, in winter (around January) and in summer, although the latter is not as important as the first. Two recruitment seasons also occur in Scottish waters, the most important in late summer/autumn and the other in spring. Recently, Viana *et al*., (2009) suggested for August in the North Sea a consistent dominance of small squid making further evidence for a (dominant) summer recruitment season, future winter spawners, already reported by Pierce *et al.,* (2005). Full recruitment to the main commercial (by-catch) fishery occurs at a mantle length of approximately 15 cm (Pierce *et al.,* 1994) although finer mesh nets are used for directed fishing in the Moray Firth (Young *et al*., 2006b), which will effectively result in a smaller size at (fishery) recruitment. In spring (April), a second wave of recruitment (i.e. smaller animals) is expected to appear on the west coast (Pierce *et al.,* 1994; Viana *et al*., 2009).

8.3. Inshore/Offshore migrations

Studies on other loliginid squid species, such as *L. pealeii* from the northern United States (Hatfield & Cadrin 2001) or *L. gahi* from the SW Atlantic, suggest a movement of young squid from their nurseries in shallow inshore waters to feeding grounds in deeper waters (Hatfield & Rodhouse 1994).

The hypothesis of an inshore-offshore migration in Scottish *L. forbesi* was first considered in Viana *et al*. (2009). The authors analysed for each month (from 1980 to 2004), the sum of monthly commercial catches (kg) from each ICES rectangle in each year (and average for all years combined), against the distance of the centre of each ICES square to the nearest coastal point (distance to coast). They found that *L. forbesi* is present close to the coast all year around, and very few squid are recorded offshore in spring and (especially) summer suggesting one cohort is resident in inshore waters. For autumn and winter, the same study also refers to a possible distinct cohort (or part of the inshore cohort) migrating to offshore grounds since squid also appear far from the coast. The hypothetical migratory cohort may derive from Scottish coastal waters, interacting with the hypothetical non-migratory cohort between May and October, or could migrate to into offshore areas from the south as Pierce & Boyle (2003) discussed, or elsewhere.

Viana *et al*. (2009) also report that between May and October (spring and summer), squid appear almost exclusively close to the coast, suggesting that summer spawning and possibly spring recruitment take place in inshore grounds. This period also encompasses the start of the autumn recruitment period, and data from the commercial fishery in the Moray Firth suggests that small squid first appear close inshore in July and August (Young *et al.,* 2006*b*). So far there is no clear evidence for where winter breeders spawn or where late autumn recruitment occurs.

According to Zuur & Pierce (2004) the mis-match in abundance trends for *L. forbesi* autumn recruits and winter breeders in Scottish waters, could indicate that part of the adult spawning population migrates into Scottish waters from elsewhere in winter rather than arriving as immature animals in the autumn. Holme (1974) reported that the main spawning season of *L. forbesi* in the English Channel occurs during winter in offshore grounds, and Lordan & Casey (1999) described the appearance of *L. forbesi* egg masses in offshore areas of Irish waters suggesting that spawning should occur in waters distant from the coast. Viana *et al*., (2009), after analysing the monthly survey length-frequency data in relation to distance from the coast, suggests that both summer spawning and spring recruitment occurs in inshore grounds. This same suggestion have been made by Collins *et al.,* (1995) and Lum-Kong *et al.,* (1992) for Ireland and Scotland, based on finding some egg masses on static fishing gear during summer.

8.4. *Loligo forbesi* size distribution

Several studies have been carried out on how environmental conditions affect squid movements and distribution, in particular the effect of sea surface temperature (SST) (e.g. Arkhipkin *et al.,* 2004*a*). Pierce *et al.* (1998) found that the catch rates for *Loligo* in trawl survey hauls in the North Sea in February, revealing a spatial pattern that could be related to sea bottom temperature (SBT). Subsequent analysis of fishery data showed that squid abundance in Scottish waters was positively correlated with winter SST, with higher abundance in areas with higher temperature, and negatively correlated with summer SST (Bellido *et al.,* 2001; Pierce *et al.,* 2001). Even more recent analysis on Scottish survey data showed evidences of possible depth-related size segregation, perhaps reflecting inshore-offshore movements (Viana *et al*., 2009).

This last study also reports an increase in squid mantle length with proximity to coast in winter and spring, and a decrease in squid mantle length in summer and autumn. The body size was also found to increase with depth in all seasons except for spring, where bigger squid tend to be in deeper waters than small squid. These findings seem to be consistent with studies of other loliginid species such as *L. gahi* from the Falkland Islands (Arkhipkin *et al.,* 2004*a*). The authors suggest that *L. gahi* juveniles move from spawning grounds located in shallow, inshore waters to feeding grounds near the shelf edge. Immature squid feed and grow in these offshore feeding grounds and, upon maturation, migrate back to inshore waters to spawn. Assuming that larger squid are breeding animals, Viana *et al*., (2009) suggests that breeding *L. forbesi* are present in inshore waters in winter. In summer the apparent trend is for larger squid to be found further offshore. However, most squid were found close to the coast in summer (the main recruitment period), so that strong recruitment close inshore may dominate the relationship between average size and distance to coast regardless of where breeding takes place. Nevertheless, almost all *L. forbesi* spawning records come from inshore areas, e.g. Lum-Kong *et al.,* (1992) found egg masses attached to inshore creel lines in Scotland. However, Lordan & Casey (1999) reported egg masses from this species in trawls at water depths of 135, 302 and 507 m.

Bellido (2002) referred to the importance of using spatial data such as longitude to examine *L. forbesi* distribution patterns. Subsequent studies (Viana *et al*., 2009) incorporated this longitudinal data in survey data analysis and reported that squid mantle length also tends to increase from west to east in winter and spring as far as 3^{o} W (mid-way along the northern Scottish coast and also the western part of the Moray Firth). They argue that the concentration of the largest animals in this zone could signify that larger animals migrate into this area, presumably to breed, or that the life-cycle is more advanced in this zone and animals start to breed earlier. In summer and autumn there seem to be an increase in size from east to west, which could represent a recruitment zone in the north-eastern Scottish coast.

Collins *et al.,* (1995) suggests that recruitment (therefore smaller squid) appears to be associated with low temperature on *L. forbesi* from the English Channel. In Scottish waters temperature was also found to have a positive effect on *L. forbesi* length in summer as bigger squid prefer sea surface temperatures at around 12^{o}C (Viana *et al*., 2009). Nevertheless, *L. forbesi* is one of the most cold water *Loligo* species and it has been reported that juveniles and post-larval stages are highly sensitive to temperature (Challier *et al.,* 2005).

8.5. *Loligo forbesi* abundance distribution

Several studies on squid in UK waters have demonstrated empirical spatial relationships between the spatial distribution of *Loligo* abundance and environmental variables (Holme, 1974; Pierce *et al.,* 1998; Bellido *et al.,* 2001). Pierce *et al*., (1998) suggests that *Loligo* abundance is patchily distributed in space and time.

Loligo forbesi distribution patterns in the North Sea in February appeared to be strongly related to bottom temperature (squid avoided waters <7°C) and, to a lesser extent, salinity (more squid in more saline water) (Pierce *et al*., 1998). Waluda & Pierce (1998) also showed that the spatial pattern of *L. forbesi* abundance in the North Sea in the winter is strongly related to water temperature and salinity, with higher abundance in areas with higher temperature and salinity. Such a relationship was also suggested by Viana *et al*., (2009) for Scottish *L. forbesi* in waters between 6^{o}C and 9^{o}C. Bellido *et al.,* (2001) analysed fishery abundance of *L. forbesi* in the years 1983, 1988, 1989 and 1991 and found that, once seasonal variation was taken into account, high abundance was consistently restricted to a narrow temperature range of 8-13^{o}C. A similar approach in Viana *et al*. (2009) for fishery data from 1980-2004 suggests an abundance peak at approximately 11^{o}C during summer and autumn, seasons.

L. forbesi abundance in coastal waters was also found to be correlated with several annual environmental indices, including the winter North Atlantic Oscillation index and the average sea surface temperature and sea surface salinity (SSS) in the northern North Sea (Pierce & Boyle, 2003). Other studies detected lower abundance of squid on the east of Scotland than the west coast (Waluda & Pierce, 1998). However, *L. forbesi* abundance also seems to increase from west to east until at approximately 3^{o} west after which the abundance was shown to start decreasing. This pattern revealed a possible abundance peak situated in the north of Scotland throughout the whole year (Viana *et al*., 2009).

Recent studies also reveal a squid preference for intermediate depth in all seasons, but over shallow waters in summer than in the other seasons, consistent with an inshore-offshore migration and summer cohort inshore spawning (Viana *et al*., 2009).

9. Implications for management

At present, there are no restrictions on the amount of squid caught in UK waters. However, given the size of the local fleet and the vessels involved, it seems unlikely that targeted squid fishing seriously impacts the *L. forbesi* population in the Moray Firth. The size of the Moray Firth *L. forbesi* stock varies considerably from year to year, from an estimated 0.3 to 5.8 million squid. However, this variability is probably more influenced by environmental conditions than the effects of targeted squid fishing. There is a possibility that growth overfishing is occurring (since large numbers of very small squid are removed from the population each year). In other words, the squid yield may be increased by delaying fishing by 2–4 weeks, and allowing the squid to grow larger prior to capture. However, given that larger squid become more spatially dispersed (and possibly more difficult to catch), it is apparent that further work is required in order to estimate the optimal fishing period and maximise yield. It is also worth considering that increased fishing effort to catch larger squid may also increase by-catches of small whiting, for example, leading to greater wastage by discarding.

The potentially deleterious effects of demersal trawling on the squid spawning grounds may be more important than fishing mortality. Severe damage to the squid egg masses (or available substrate) could potentially lower the survival of hatchlings and subsequent recruitment levels. According to some fishermen, the squid do not spawn in exactly the same area within three years of a major spawning event. However, the overall area available for spawning may be limited, since the squid (*L. forbesi*) may have specific spawning habitat requirements.

9.1. Management recommendations

A considerable amount of further research is required in order to optimise and sustain squid fishing in UK waters in a sustainable. Based on the findings of the present investigation and previous studies, however, we can list a number of options that are worth considering in this respect:

1) Choice of gear – it appears that the small mesh bottom trawl is a very effective way of capturing small squid in shallow, inshore waters around the UK. No jig

data were obtained for comparison, although this method has also been used successfully for *Loligo* species (e.g. in Cornish waters).

2) Fishing period – early entry to the directed fishery should be avoided, where possible, in order to allow the squid to grow and reduce the amount of small fish (whiting) by-catch.

3) Fishing fleet – given that directed squid fishing occurs in relatively small, inshore areas, perhaps the number of large vessels participating in this fishery could be limited (e.g. by licensing for squid-fishing).

4) Seabed effects – areas of seabed potentially vulnerable to the effects of bottom-trawling (e.g. squid spawning grounds) could be monitored and/or avoided completely.

5) Conflicts – the different stakeholder groups (e.g. small vessel fleets, large vessel fleets, conservation bodies) should meet formally prior to each season, in order to minimise conflicts and perceived conflicts.

6) Spawning areas – seabed surveys should be undertaken each year, in order to identify the locations of important squid spawning areas.

It is stressed that these are preliminary considerations, based on available information of squid fishing operations in UK waters and squid (*Loligo forbesi*) fishery biology. Further information on these topics is required before they are formally recommended.

10. Conclusions

Squid fishing in UK waters is a relatively minor activity, in comparison to the effort directed towards various demersal fin-fish species such as whiting and haddock, and much larger squid fisheries in other parts of the world (e.g., eastern Pacific and south-west Atlantic). However, during the past decade, the fishery for *L. forbesi*, in particular has become an important component of inshore activity in UK waters.

Much of the national catch is taken as by-catch. However, there are a number of important seasonal, targeted squid fisheries currently in operation. These include squid fishing in the Moray Firth, the Firth of Forth, Rockall (intermittently) and off the coast of Cornwall.

Discarding is not considered to be a serious problem in targeted squid fishing, except perhaps for large numbers of whiting that are occasionally by-caught at the start and end of the fishing season, before and after the appearance of large numbers of small squid.

The Moray Firth squid population is thought to number 0.3 to 6 million approximately, and varies considerably from year to year, possibly due to largely environmental effects. Growth overfishing may occur, since the small squid are growing rapidly and are capable of reaching a much larger size within a few weeks. However, this is difficult to ascertain, since with the progression of the fishing season, the changes in spatial dispersion, catchability and relative numbers of larger squid in the Moray Firth are unknown.

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Appendix

Table A1. Discard monitoring haul log (Crusader).

SUSTAINABLE SQUID FISHERY

Details recorded by	M. Edmonds	Date	12/09/2007
VESSEL M.F.V.	Crusader	REG. NO.	KY997
Net	Harvester squid trawl		
Headline length			
Footrope length		Trawl doors	Vee doors
fishing circle			
cod end mesh size	40 mm	Type of fishing	Squid trawl

Haul No	Date	SHOOT time	SHOOT POSITION Lat.	SHOOT POSITION Long.	HAUL time	HAUL POSITION Lat.	HAUL POSITION Long.	Depth in fathoms	Duration in minutes	water temp recd	salinity recd	CATCH (baskets) SQUID	CATCH (baskets) FISH	CATCH (baskets) DISC	Weather wind strength and sea state etc
1	12/09/2007	0720	56°05.1N	02°45.8W	0920	56°04.7N	02°45.5W	13	120			2	0	3	SW F2/3 overcast
2	12/09/2007	0930	56°04.7N	02°45.5W	1130	56°04.6N	02°43.5W	8	120			0.5	0	2	SW F2/3 overcast
3	12/09/2007	0945	56°04.6N	02°43.5W	1400	56°04.7N	02°46.5W	17	135			0.5	0	2	SW F2/3 overcast
4	12/09/2007	1430	56°04.7N	02°46.5W	1630	56°03.8N	02°58.1W	14	120			0.5	0	2.5	SW F2/3 overcast
5	12/09/2007	1645	56°04.5N	02°59.7W	1800	56°06.8N	02°55.2W	16	75			0.5	0	2	SW F2/3 overcast
6	13/09/2007	0700	56°11.3N	02°43.5W	0900	56°11.9N	02°39.2W	13	120			1	0	2	W F2 overcast
7	13/09/2007	0930	56°11.9N	02°39.2W	1130	56°10.4N	02°48.4W	17	120			1	0	1	W F2 overcast
8	13/09/2007	1200	56°10.4N	02°48.4W	1400	56°09.9N	02°52.9W	12	120			0.5	0	1.5	W F3 overcast
9	13/09/2007	1430	56°09.9N	02°52.9W	1630	56°09.4N	02°50.1W	10.5	120			0.5	0	2	W F4 overcast
10	13/09/2007	1700	56°09.4N	02°50.1W	1820	56°10.1N	02°46.5W	20	80			0.5	0	1	W F4 overcast
11															
12															
13															
14															

Appendix

Table A2. Discard monitoring trip: Haul log (Osprey).

SUSTAINABLE SQUID FISHERY

Details recorded by	M. Edmonds	Date	15/08/2007
VESSEL M.F.V.	Osprey	REG. NO.	BF500
Net	25ftm		
Headline length	80'		
Footrope length	102' (30' of 16" discs)	Trawl doors	Bison Pat, B
fishing circle			
cod end mesh size	40 mm	Type of fishing	[illegible] trawl

Haul No	Date	SHOOT			HAUL			Depth in	Duration in	water temp recd	salinity recd	CATCH (baskets)			Weather
			POSITION			POSITION									wind strength and sea state etc
		time	Lat.	Long.	time	Lat.	Long.	fathoms	minutes			SQUID	FISH	DISC	
1	15/08/2007	0500	57°43.5	2°53.7	900	57°42.0	2°34.9	18	240			6.00	0.00	0.50	W. F4 Overcast
2	15/08/2007	0935	57°42.0	2°35.4	1100	57°42.0	2°40.2	14	85			2.00	0.00	0.25	"
3	15/08/2007	1000	57°42.0	2°35.4	1430	57°43.3	2°54.4	13	270			1.50	0.00	0.75	W. F4/5 Vis good. Sun
4	15/08/2007	1630	57°43.2	2°56.7	1940	57°42.0	2°40.8	12	190			3.00	0.00	0.50	W. F3. Vis mod. Rain showers
5	15/08/2007	2000	57°42.1	2°41.7	2215	57°43.5	2°51.0	13	135			2.00	0.00	0.50	W. F4.
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13															
14															

Appendix

Table A3. Discard monitoring trip: Haul log (Tamaralyn).

SUSTAINABLE SQUID FISHERY

Details recorded by	M. Edmonds		Date	05/09/2007
VESSEL M.F.V.	Tamaralyn		REG. NO.	DE35
Net	Prawn net	Prawn net - no discs, light chain on footrope.		
Headline length		Using 40ftm sweeps. Winaway only using 20ftm		
Footrope length			Trawl doors	Vee doors 5'6
fishing circle				
cod end mesh size	30mm		Type of fishing	Squid trawl

landings	11 boxes squid	25-30kg per box
	1 box prawns	

Haul No	Date	SHOOT			HAUL			Depth in fathoms	Duration in minutes	water temp recd	salinity recd	CATCH (baskets)			Weather wind strength and sea state etc
		time	POSITION Lat.	Long.	time	POSITION Lat	Long.					SQUID	FISH	DISC	
1	05/09/07	0600	56°10.5N	02°46.8W	0815	56°09.7N	02°47.9W	20	135			2	0	1	W F4/5
2	05/09/07	0830	56°09.7N	02°47.9W	1100	56°08.2N	02°50.5W	24	150			3	0	2	W F4/5
3	05/09/07	1115	56°08.2N	02°50.5W	1330	56°08.0N	02°53.3W	21	135			3.5	0	3	W F4/5
4	05/09/07	1400	56°08.0N	02°53.3W	1630	56°07.8N	02°54.4W	20	150			1.5	0	2.5	W F4/5
5	05/09/07	1700	56°07.8N	02°54.4W	1900	56°09.8N	02°47.5W	22	120			4	0	3	W F4/5
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13															
14															

Appendix

Table A4. Discard monitoring trip: Haul log (Winaway).

SUSTAINABLE SQUID FISHERY

Details recorded by M. Edmonds

Date 04/09/2007

VESSEL M.F.V. Winaway

REG. NO. KY279

Net Harvester Squid trawl

Headline length

Footrope length 85'

Trawl doors Vee doors 5'9

fishing circle

cod end mesh size 30mm

Type of fishing Squid - benthic trawl

landings 7 boxes squid

1 box prawns

squid packed 25-30 kg per box

Haul No	Date	SHOOT time	SHOOT POSITION Lat.	SHOOT POSITION Long.	HAUL time	HAUL POSITION Lat.	HAUL POSITION Long.	Depth in fathoms	Duration in minutes	water temp recd	salinity recd	CATCH (baskets) SQUID	CATCH (baskets) PRAWNS	CATCH (baskets) DISC	Weather wind strength and sea state etc
1	040907	0530	56°10.6N	02°44.0W	0700	56°07.8N	02°49.6W	19	90			1	0.25	2.5	W F2 Good vis, sun
2	040908	0700	56°07.8N	02°49.7W	0900	56°06.5N	02°52.8W	24	120			1.5	0.25	1.5	W F2 Good vis, sun
3	040909	0900	56°06.5N	02°52.8W	1045	56°07.3N	02°50.8W	25	105			1.5	0	1	W F2 Good vis, sun
4	040910	1045	56°07.3N	02°50.8W	1220	56°05.9N	02°56.3W	18	95			0.5	0	0.5	W F2 Good vis, sun
5	040911	1220	56°05.9N	02°56.3W	1420	56°05.5N	02°58.6W	15	120			1	0	1	W F2 Good vis, sun
6	040912	1420	Nil	Nil	1520	Nil	Nil	18	60			0.5	0	0.5	W F2 Good vis, sun
7	040913	1600	56°05.5N	02°57.8W	1730	56°07.3N	02°52.1W	15	90			0.5	0	2.5	W F3
8	040914	1800	56°07.3N	02°52.1W	1920	56°09.3N	02°47.6W	24	80			1	0	1.5	W F3
9															
10															
11															
12			Haul 6,7,8 no catch sampling												
13															
14															

Appendix

Table A5. Observed monthly length data in *L. forbesi* samples from Moray Firth (2006-2008).

Year	Month	Female (mm)					Immature (mm)					Male (mm)					Total (mm)				
		Min	Max	Mean	Sd	N	Min	Max	Mean	Sd	N	Min	Max	Mean	Sd	N	Min	Max	Mean	Sd	N
2006	July	92	218	165.12	17.01	134	50	84	62.86	11.77	7	122	240	185.35	23.34	157	50	240	173.38	28.51	298
	August	58	140	99.336	17.44	262	31	111	65.46	11.46	59	58	151	105.91	16.69	179	31	151	97.692	20.55	500
	September	57	120	81.462	13.53	249	42	94	64.54	7.887	103	59	129	81.054	14.68	148	42	129	77.856	14.6	500
	October	69	148	104.29	12.61	261	66	102	84.19	10.73	16	80	141	109.29	12.76	222	66	148	105.87	13.43	499
	November	124	289	179.66	28.58	64	0	0	0	0	0	138	262	184.54	33.48	35	124	289	181.38	30.33	99
	December	112	343	192.9	38.06	173	0	0	0	0	0	108	500	185.51	59.94	101	108	500	190.18	47.34	274
2007	January	165	340	236.77	43.76	48	0	0	0	0	0	135	300	207.92	59.99	13	135	340	230.62	48.6	61
	February	162	395	232.74	44.99	178	0	0	0	0	0	128	522	260.68	94.78	90	128	522	242.12	67.16	268
	March	120	315	192.48	42.19	60	0	0	0	0	0	99	380	180.65	56.75	57	99	380	186.72	49.95	117
	April	139	301	194.38	23.46	130	0	0	0	0	0	121	395	212.66	59.54	64	121	395	200.41	39.99	194
	May	85	249	155.94	35.04	87	81	102	90	7.783	8	80	323	159.63	36.47	111	80	323	155.37	37.51	206
	June	90	195	138.3	15.77	263	68	68	68	.	1	98	325	164.68	28.68	236	68	325	150.61	26.55	500
	July	48	118	78.388	13.54	201	34	90	58.66	10.14	135	52	148	86.512	19.27	164	34	148	75.726	18.5	500
	August	56	128	83.376	12.32	255	46	83	66.82	8.836	28	60	136	84.756	13.08	217	46	136	83.048	13.1	500
	September	66	163	114.37	19.28	254	60	85	74.08	6.345	12	70	165	115.04	19	232	60	165	113.71	19.92	498
	October	85	160	117.68	12.5	263	90	94	91.5	1.915	4	80	164	118.74	14.65	233	80	164	117.97	13.7	500
	November	82	285	154.27	49.41	56	85	85	85	.	1	71	321	176.17	70.02	52	71	321	164.08	61.13	109
	December	94	304	182.19	34.83	140	0	0	0	0	0	118	454	209.61	72.71	71	94	454	191.41	52.29	211
2008	January	157	325	233.53	33.03	77	0	0	0	0	0	129	456	265.1	86.29	40	129	456	244.32	58.69	117
	February	137	356	214.19	36.68	74	0	0	0	0	0	97	400	220.15	68.13	47	97	400	216.5	51.05	121
	March	162	283	208.26	24.45	82	0	0	0	0	0	135	334	222.38	56.26	34	135	334	212.4	37.03	116
	April	120	263	187.42	22.72	72	0	0	0	0	0	84	368	180.69	46.09	74	84	368	184.01	36.52	146
	May	78	189	127.52	21.06	79	57	72	66.33	8.145	3	72	310	149.72	28.43	179	57	310	142.04	29.29	261
	June	57	143	97.262	13.78	263	45	103	64.96	16.59	25	51	210	99.259	17.03	212	45	210	96.494	17	500

Appendix

Table A6. Observed monthly weight data in *L. forbesi* samples from Moray Firth (2006-2008).

Year	Month	Female (g)					Immature (g)					Male (g)					Total (g)				
		Min	Max	Mean	Sd	N	Min	Max	Mean	Sd	N	Min	Max	Mean	Sd	N	Min	Max	Mean	Sd	N
2006	July	28	266	137.5	31.99	134	7	28	13.43	7.5	7	64	319	170.6	49.7	157	7	319	152	49.88	298
	August	11	79	42.1	16.17	262	2	47	15.07	6.4	59	12	101	48.42	16.77	179	2	101	41.17	18.49	500
	September	9	64	24.87	11.07	249	3	32	13.63	4.1	103	10	68	24.27	11.33	148	3	68	22.38	11.06	500
	October	17	98	46.64	14.03	261	15	40	26.81	7	16	25	90	51.15	14.22	222	15	98	48.01	14.62	499
	November	70	604	168.8	79.86	64	0	0	0	0	0	79	353	165.7	71.99	35	70	604	167.7	76.81	99
	December	52	1005	214.8	130.1	173	0	0	0	0	0	57	1845	195.1	232.3	101	52	1845	207.6	174.7	274
2007	January	145	905	361.9	187.8	48	0	0	0	0	0	75	514	221.4	146	13	75	905	331.9	187.7	61
	February	123	1025	336.9	175.3	178	0	0	0	0	0	70	1672	368.1	310.1	90	70	1672	347.4	229.4	268
	March	73	828	241.8	161.3	60	0	0	0	0	0	42	823	174.4	138	57	42	828	209	153.5	117
	April	103	656	208.4	68.04	130	0	0	0	0	0	56	886	238.1	157.6	64	56	886	218.2	106.7	194
	May	22	363	131	67.8	87	20	46	29.13	8.6	8	23	502	129.4	71.8	111	20	502	126.2	71.28	206
	June	30	239	92.67	27.43	263	16	16	16	.	1	35	572	139	61.92	236	16	572	114.4	52.48	500
	July	7	71	23	10.67	201	3	28	10.05	4.5	135	5	103	29.7	18.01	164	3	103	21.7	14.68	500
	August	10	80	28.4	10.84	255	6	25	16.07	4.7	28	13	82	29.05	11.26	217	6	82	27.99	11.15	500
	September	13	140	62.65	25.23	254	11	35	20.08	5.9	12	16	136	61.57	24.07	232	11	140	61.12	25.22	498
	October	27	124	57.83	15.76	263	25	33	29.25	3.3	4	26	114	56.7	17.12	233	25	124	57.07	16.53	500
	November	27	538	130.5	99.21	56	22	22	22	.	1	17	717	181.8	167.4	52	17	717	154	138.1	109
	December	29	710	167.1	83.1	140	0	0	0	0	0	57	1515	251.1	252.4	71	29	1515	195.3	165.5	211
2008	January	128	835	344.1	143.9	77	0	0	0	0	0	70	1160	389	283.1	40	70	1160	359.4	202.4	117
	February	75	1085	287.5	153.9	74	0	0	0	0	0	37	975	262.2	194.7	47	37	1085	277.7	170.6	121
	March	127	488	254.7	72.77	82	0	0	0	0	0	77	565	251.7	141	34	77	565	253.8	97.13	116
	April	59	420	195.1	60.75	72	0	0	0	0	0	19	755	153.9	112.4	74	19	755	174.2	92.68	146
	May	12	187	81.22	32.85	79	13	18	16.33	2.9	3	18	475	117.9	53.66	179	12	475	105.6	51.69	261
	June	9	98	36.24	12.86	263	5	34	14.44	8.5	25	6	238	38.08	19.27	212	5	238	35.93	16.51	500

Appendix

Table A7. Fitted monthly length-weight parameters for *L. forbesi* in Moray Firth (2006 – 2008). Power model $W = aL^b$.

Type	Remark	a	b	R^2	N
All data	editted data	0.000649	2.3923	0.984	7095
Male	editted data	0.001023	2.2934	0.981	2968
Female	editted data	0.000529	2.440015	0.986	3725
Immature	editted data	0.000548	2.4175	0.876	402
2006	Jul	0.000826	2.3438	0.972	298
2006	Aug	0.000815	2.348304	0.957	500
2006	Sep	0.000553	2.42101	0.944	500
2006	Oct	0.001068	2.291684	0.916	500
2006	Nov	0.000646	2.387521	0.965	99
2006	Dec	0.000515	2.437038	0.961	274
2007	Jan	0.000236	2.584542	0.961	61
2007	Feb	0.002275	2.155797	0.89	268
2007	Mar	0.001291	2.272342	0.928	117
2007	Apr	0.002356	2.148005	0.921	194
2007	May	0.000542	2.43105	0.973	206
2007	Jun	0.001119	2.290535	0.943	500
2007	Jul	0.000316	2.544172	0.913	500
2007	Aug	0.000813	2.354085	0.941	500
2007	Sep	0.000548	2.443561	0.964	498
2007	Oct	0.000964	2.313879	0.926	499
2007	Nov	0.000918	2.319138	0.99	109
2007	Dec	0.000938	2.307051	0.971	211
2008	Jan	0.001416	2.248507	0.914	117
2008	Feb	0.000587	2.412013	0.933	121
2008	Mar	0.002107	2.175546	0.893	116
2008	Apr	0.000484	2.440018	0.905	146
2008	May	0.000818	2.361742	0.948	261
2008	Jun	0.000628	2.385539	0.97	500