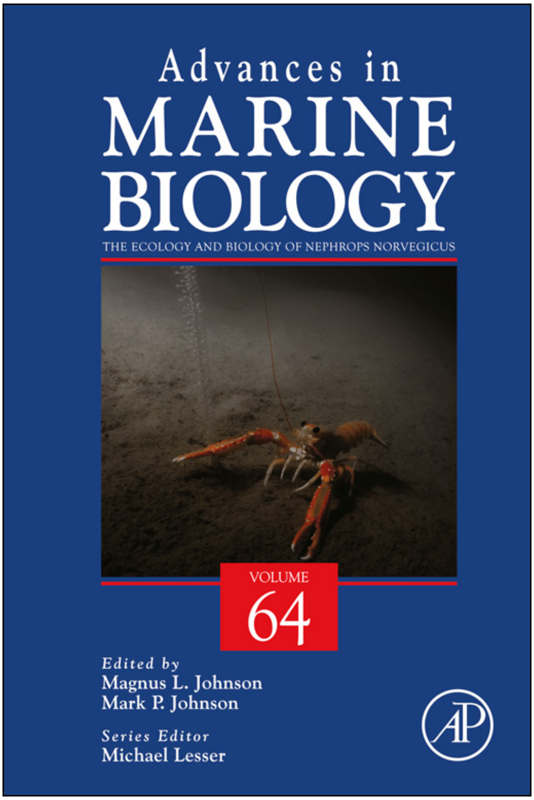

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CHAPTER SEVEN

Nephrops Fisheries in European Waters

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Contents

Abstract

This review focuses on the Norway lobster (*Nephrops norvegicus*) as a resource, describing how the fishery has developed from the 1960s to the present day to become one of the most economically important fisheries in Europe. In 2010, the total landings were 66,500 tonnes, of which UK fishers landed a significant part (58.1%). The *Nephrops* fishery is also important for countries such as Ireland (11.7% of the total) and Sweden (1.9%)

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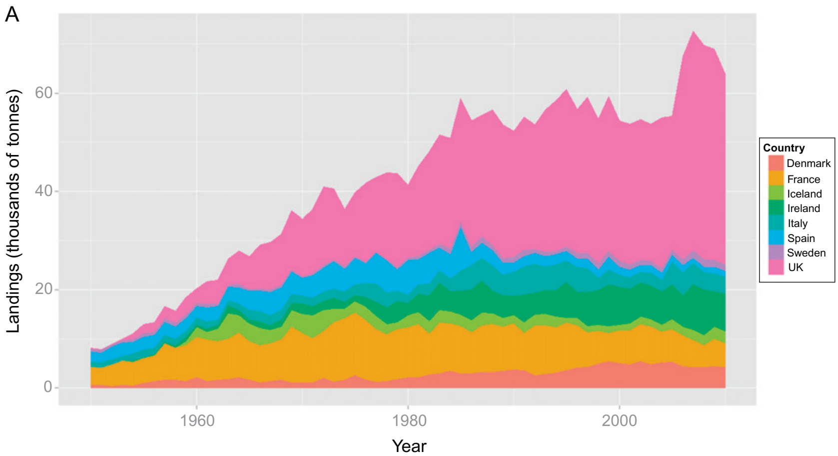
where it is of regional importance. Some are also taken in the Mediterranean, where Italian, Spanish and Greek fishers together take approximately 7% of the total landing. More than 95% of *Nephrops* are taken using single- or multi-rig trawlers targeting *Nephrops* or in mixed species fisheries. In regions such as Western Scotland and the Swedish West Coast, creel fisheries account for up to a quarter of the total landings. Across the range, a small proportion (<5%) is taken using traps in a fishery characterised by larger sized animals that gain a higher price and have lower discard and by-catches of ground fish with low mortalities. The trawling sector, however, is reducing the by-catches of ground fish with the aid of technical measures, such as square-mesh panels and grids and national systems of incentives. Assessments for *Nephrops* are operated via the 34 functional units (FUs) regarded as stocks. Changes in management procedures have arisen as a result of the advisory input from underwater TV fishery-independent stock surveys. The total allowable catch does not follow FUs but is agreed upon per management area.

Keywords: Norway lobster, Trawl evolution, Creel fisheries, Fisheries management, TAC, Functional units, Stock assessment, UWTV

1. FISHERY HISTORY

The fishery for the Norway lobster, *Nephrops norvegicus* (hereafter referred to as *Nephrops*), has increased significantly in the North Atlantic and the Mediterranean over the past five decades. *Nephrops* is marketed as scampi, langoustine, Dublin Bay prawn or Cigalas and, unlike 50 years ago, is now regarded as a delicious shellfish by chefs and consumers throughout Europe. Landings rose steadily and sharply until 1985 but have been more or less stable since then (Figure 7.1A, FAO). Recent landing statistics of *Nephrops* from all countries show that 66,544 tonnes were landed in 2010. Most of this came from the North-East Atlantic where 38,600 tonnes (58.1%) were taken by the United Kingdom, 7800 tonnes (11.7%) by the Irish, 4800 tonnes (7.2%) by the French, 4300 tonnes (6.5%) by the Danish, 2500 tonnes (3.8%) by Icelandic fishers and 1200 tonnes (1.9%) by the Swedish. Landings in Spain and Portugal have decreased significantly since the 1970s (Figure 7.1A). Some fishing occurs in the Mediterranean, a more deep-sea fishery compared to the North-East Atlantic shelf and slope fishery, where Italian, Spanish and Greek fishers take 3300 tonnes (5%), 700 tonnes (1%) and 500 tonnes (0.7%), respectively (FAO, 2010 landings).

However, as indicated in the country statistics and shown by landings per region (Figure 7.1B), landings by UK and Irish fishers and those in the North Sea (IV and IIIa) and the English Channel, and the Irish Sea and the Celtic Sea (VII) have increased during the past 20–30 years, while landings by



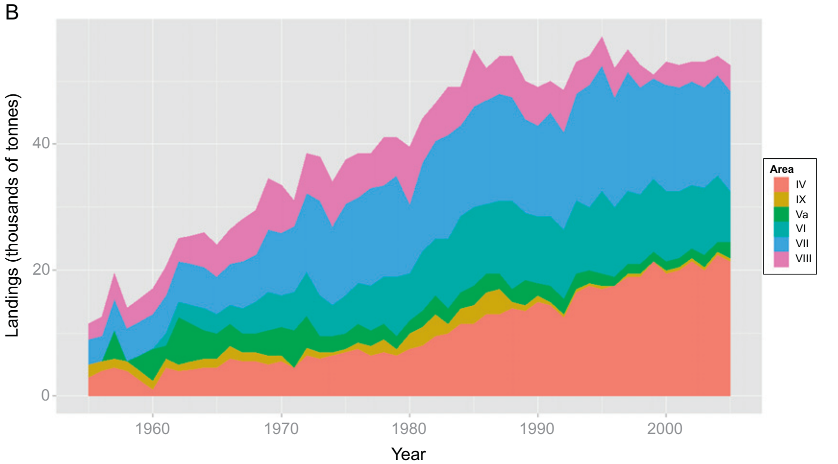


Figure 7.1 Total Norway lobster (*Nephrops norvegicus*) landings given (A) per country (tonnes) from 1950 to 2010, summarised for the North-East Atlantic and the Mediterranean. The landings rose sharply up to 1985 but since then have been more or less stable at around 60,000 tonnes. The United Kingdom is taking nearly 60% of the total landing, of which Scottish vessels are capturing around 80%. Ireland, France and Denmark otherwise contribute, but landings in Spain and Portugal have decreased. Countries with landings below 50 tonnes per year have been ignored, and the Spanish landing includes both the North-East Atlantic and the Mediterranean region (www.fao.org; FishStatJ database). (B) The total landings per fishing sea region from 1955 to 2005 (excluding the Mediterranean). It is to be noted that landings in the North (IV, VI, VII) have increased, but they have decreased to the South (IX). *Redrawn from ICES 2010 Climate report, Engelhard and Pinnegar (2010).*

Spanish fishers and those from the Portuguese coast (IX) and the Bay of Biscay (VIII) have decreased. The potential effect of climate on *Nephrops* abundance is reviewed in the ICES climate report (Engelhard and Pinnegar, 2010), along with other factors that could have caused the regional change in landing patterns: (1) The climate change hypothesis is tempting, as southern populations at the species border are decreasing, while northern stocks are increasing. This is a pattern noted in other exploited stocks (Heath et al., 2012). However, 13 LPUE (landings per unit effort) series from the northern functional units (3–16) were investigated for correlations with surface seawater temperature (SST) and the North Atlantic Oscillation (NAO; Zuur et al., 2003). Neither SST nor NAO was shown to correlate significantly with the LPUE of *Nephrops*, but six groups with similar fluctuations were found. The three other hypotheses for the South–North change in landings are as follows: (2) differences in fishing pressure related to the regional maturity of the fishery, (3) trends in targeted fishing effort with decline in multi-gear fisheries in the South and (4) indirect effects of fishing through reduction in natural predators leading to increases in crustaceans as a result of their main predator cod (*Gadus morhua*) being over-exploited (Brander and Bennett, 1989). Interestingly, a fifth suggestion relating to the decrease in *Nephrops* in the South is that the decrease in discards after the multi-gear crash has led to reduced feeding opportunities contributing to reduced stocks (see Grabowski et al., 2010). Cheung et al. (2012) review the potential effects of climate change on the future UK and Irish fisheries, and suggest that changes in temperature, ocean pH and oxygen levels are likely to affect marine ecosystems and their associated fisheries. Simulations of high scenario CO_2 levels on another commercially important crustacean, the European lobster (*Homarus gammarus*), have suggested that carapace mass may be lowered at the final larval stage (Arnold et al., 2009). Impacts from ocean acidification on, for example, UK and Irish fisheries have yet to be detected, but estimations of potential losses are huge.

The United Kingdom receives the majority of the EU quota allocations for the North Sea (IV, IIIa) and Western Scotland (VIa). Scottish vessels take 75–80% of the UK landings, and Northern Ireland and England take around 10% each. *Nephrops* from Scotland can have a higher value, especially larger whole animals, which can be sold at a higher price per kilogram, equivalent to that of European lobster, *Homarus gammarus* (D.R. Collin & Son Ltd., personal communication; Sandberg et al., 2004). Around 50% of the UK landings are exported to Spain, France and Italy. One-third of the total *Nephrops* landings are taken from Scottish waters and have risen from a few tonnes in the

1960s to over 31,000 tonnes in 2009 with a value of £78.3 million, making it the second most valuable fishery in Scotland after mackerel (*Scomber scombrus*). The first-hand sale value for Irish fishers selling *Nephrops* (€33.4 million) is ranked second in Ireland, behind the lower value but higher bulk of Atlantic mackerel (42.3 tonnes, €44.7 million; Marine Institute, 2012).

Nephrops fisheries occur on muddy bottoms with specific silt and clay content (Farmer, 1975), a sediment-type necessary to fulfil the requirement of a burrowing behaviour (see Chapter 2). Often, this habitat and, therefore, fishery are deeper than for other commercial crustacean fisheries in Europe, such as brown crab (*Cancer pagurus*) and European lobster. The depth varies in Northern Europe from 20 m in the sea lochs of Scotland to over 500 m on the shelf ridge west of the Hebrides. The fishery within the Mediterranean is notably deeper compared to the North-East Atlantic, mainly located on the upper and middle continental slope (300–600 m depth) or at even 500–800 m depth East of Corsica and NW and W of Sardinia (MEDITS trawl surveys 1994–1999 in Abelló et al., 2002), and also at a shallower 200–300 m depth in the Central Adriatic Sea (Morello et al., 2009).

There are variations in the biological parameters of *Nephrops* from different grounds in the North Atlantic East and in the Mediterranean, which have received a lot of attention over the years (e.g. Abelló et al., 2002; Bell et al., 2006; Farmer, 1975; ICES, 2004b, 2006; Ulmestrand and Eggert, 2001). There has been a particular focus on defining the parameters of importance for assessment and management, such as growth and maturation size as well as size frequencies at different depths and sediment types. In the management section, we report on the size at onset of maturity (SOM), and in Section 4.1, we discuss the shortcomings of growth data as a parameter for stock assessments. For a detailed review of the distribution of *Nephrops* by sediment type, see Chapter 2.

Here, we give a geographical overview of the different fisheries within five main areas: (1) the North Sea, (2) Western Scotland, (3) the Celtic Sea, the Irish Sea, and W Ireland, (4) the Iberian Peninsula, and (5) the Mediterranean (Table 7.1, Figure 7.2). This is mainly to give a brief insight into where the main fisheries are conducted, and the specific characteristics of the fishery for each region, including the current stock status. Each of these sea areas has separate and discrete fishing grounds, referred to as functional units (FUs) and assigned numbers. FUs are treated in more detail in Section 3.

Nephrops are found around the southern coast of Iceland (FU 1) with 10 discrete grounds identified at depths between 100 and 300 m (Eiriksson, 1999). There are no populations of *Nephrops* reported along the northern coast and this

Table 7.1 Functional units, sub-divisions and TAC areas for Norway lobster (*Nephrops norvegicus*)

Functional unit	Name	ICES sub-division	TAC area
1	Iceland south coast	Va	
2	Faroes	Vb	
3	Skagerrak	IIIa	IIIa; EC waters of IIIb
4	Kattegat	IIIa	IIIa; EC waters of IIIb
5	Botney Gut—Silver Pit	IVb,c	EC waters of IIa and IV
6	Farn Deeps	IVb	EC waters of IIa and IV
7	Fladen Ground	Iva	EC waters of IIa and IV and Norwegian waters of IV
8	Firth of Forth	IVb	EC waters of IIa and IV
9	Moray Firth	Iva	EC waters of IIa and IV
10	Noup	Iva	EC waters of IIa and IV
32	Norwegian Deep	Iva	Norwegian waters of IV
33	Off Horns Reef	IVb	EC waters of IIa and IV
34	Devil's Hole	IVb	EC waters of IIa and IV
11	North Minch	Via	VI; EC waters of Vb
12	South Minch	Via	VI; EC waters of Vb
13	Clyde	Via	VI; EC waters of Vb
14	Irish Sea East	VIIa	VII
15	Irish Sea West	VIIa	VII
16	Porcupine Bank	VIIb,c,j,k	VII
17	Aran Grounds	VIIb	VII
18	Ireland NW coast	VIIb	VII
19	Ireland SW and SE coast	VIIg,j	VII
20	NW Labadie	VIIg,j	VII
21	Baltimore	VIIg,j	VII
22	Galley	VIIg,j	VII

Table 7.1 Functional units, sub-divisions and TAC areas for Norway lobster (*Nephrops norvegicus*)—cont'd

Functional unit	Name	ICES sub-division	TAC area
23	Bay of Biscay North	VIIIa	VIIIa, VIIIb, VIIId and VIIIe
24	Bay of Biscay South	VIIIb	VIIIa, VIIIb, VIIId and VIIIe
25	North Galicia	VIIIc	VIIIc
31	Cantabrian Sea	VIIIc	VIIIc
26	West Galicia	IXa	IX and X; EC waters of CECAF[1]
27	North Portugal (N of Cape Espichel)	IXa	IX and X; EC waters of CECAF[1]
28	South-West Portugal (Alentejo)	IXa	IX and X; EC waters of CECAF[1]
29	South Portugal (Algarve)	IXa	IX and X; EC waters of CECAF[1]
30	Gulf of Cadiz	IXa	IX and X; EC waters of CECAF[1]

[1]Fishery Committee for the Eastern Central Atlantic.

division is thought to result from the difference in oceanic conditions. The south coast of Iceland is influenced by the warmer Atlantic Gulf Stream, whereas the northern coast is within the Arctic waters. Experimental fisheries for *Nephrops* started in 1939, but a targeted commercial fishery did not commence until 1951, which took another 7 years to develop fully. Until the extension of territorial waters excluded foreign vessels in the early 1970s, these grounds were subjected to significant fishing activity by other nationalities.

Faroe Islands (FU 2)—A limited creel fishery exists around Faroe Islands (FU 2). In the past 10 years, a single Faroese vessel has on one occasion landed 1.55 tonnes of *Nephrops* to Scotland from area Vb (Caroline Cowan, personal communication).

Skagerrak (FU 3) and Kattegat (FU 4)—The landings in Skagerrak and Kattegat for 2010 were taken by Danish (73%), Swedish (24%) and Norwegian fishers (2%). Danish fishers have the majority of the total allowable catch (TAC), which is 5200 tonnes for 2013. The Danish fishery is a trawl fishery, whereas an increasing, and now significant, part of 26% of the Swedish landings of 1386 tonnes in 2012 was taken by the creel sector (Figure 7.3). There is also a small creel fishery in the Hvaler area along the Norwegian Skagerrak coast. However, for the Skagerrak and Kattegat as a

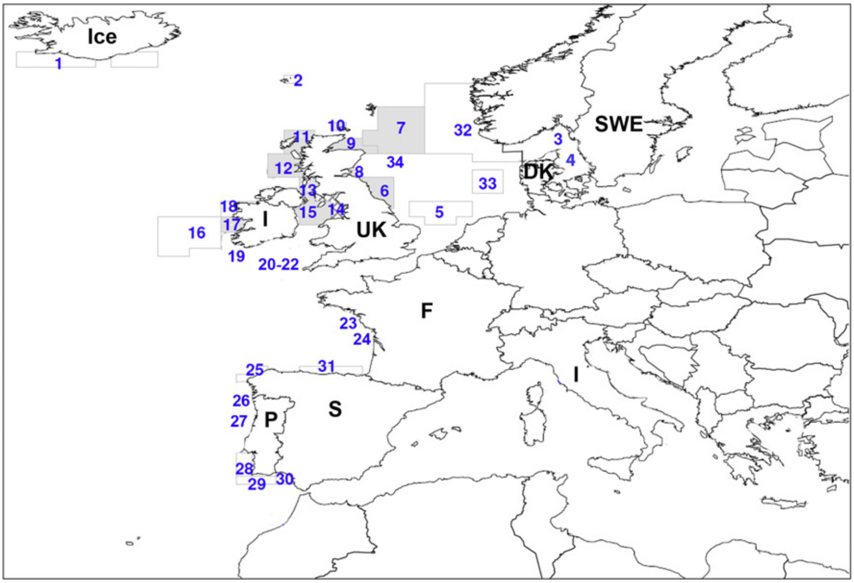


Figure 7.2 Map showing the geographical location of the 34 *Nephrops* functional units (1–34) in the North Sea (ICES sub-division IVa–c, IIIa), Western Scotland (ICES sub-division VIa), and in the Celtic Sea, Irish Sea and around Ireland (ICES sub-division VIIa–j), the Iberian Peninsula (sub-division VIIIa–c, IX) and in the northern area around Iceland and the Faroes (sub-division Va–b; see Table 7.1).

whole, only around 6% of the total landings (total landings were 8500 tonnes in 2010, ICES, 2012b; IIIa) is taken by creels. The Swedish creel fishery is described further in Section 1.6. The discard problem in *Nephrops* trawls and the decline of cod in the North Sea and not least in Kattegat led to the mandatory use of square-mesh panels (SMPs) in 2004, in line with the Cod Recovery Plan (EU regulation 423/2004). Further action was taken in 2009 when the centralised allocation of days at sea was changed to a kW-day system. This is discussed further in Section 3. Trawl selection improvements and the future of the region are discussed in Madsen and Valentinsson (2010).

1.1. North Sea

The main fisheries are Fladen Ground and Farn Deeps, and also Firth of Forth, Moray Firth, and, to a lesser extent, the Noup and Devil's Hole.

Fladen Ground (FU 7)—Within the Fladen Ground, substrates suitable for *Nephrops* burrows are distributed more or less continuously over a very large area (approximately 30,000 km^2). The distribution is slightly patchier

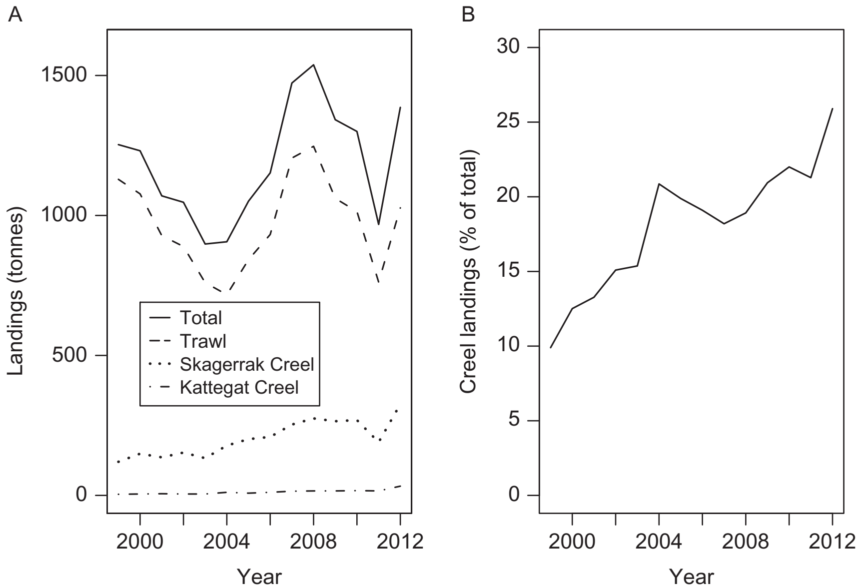


Figure 7.3 Swedish Norway lobster (*Nephrops norvegicus*) landings in 1999–2012. (A) Trawl in Skagerrak and Kattegat and creel landings (tonnes) in Skagerrak and Kattegat, respectively, within the ICES sub-division IIIa and (B) the proportion of creel to total landing (%) based on same data. *Data from SwAM, Fisheries statistics.*

towards the SW of the ground and sediments are patchy and coarse towards the North. The hydrographical conditions in this area are well suited to the retention of larvae due to a large-scale seasonal gyre that develops in the late spring over a dome of colder water. Because of the distance between fishing grounds and landing ports, the fishery in the Fladen is restricted to multi-day trips and is, therefore, fished by larger boats than the more inshore grounds. The fleet includes modern purpose-built boats from 12 up to 35 m, fishing mainly with 80-mm mesh size twin-rigs. Fishing trips are between 3 and 9 days, with the larger boats staying longer at sea. The Fladen fishery generally follows a similar pattern every year, with different areas producing good fishing at different times of the year. Abundance (according to the underwater television (UWTV) surveys) is generally higher on the soft and intermediate sediments located in the centre and south-east of the ground. Males consistently make the largest contribution to the landings although the sex ratio does vary. The Fladen is the largest unit in the North Sea and contributes just <50% of the overall TAC. The ICES advice for 2013 (ICES, 2012b) recommended that catches from the area should be no more than 10,000 tonnes, a reduction of

4100 tonnes from the 2012 advice. The more than significant reduction in the advised outtake from the area created a significant decrease in the overall TAC for the North Sea for 2013. As with all of the FUs within the northern North Sea, fishers are reporting increasing levels of predatory fish, such as cod, hake (*Merluccius merluccius*) and saithe (*Pollachius virens*) on the *Nephrops* grounds and are linking this with the decline in the abundance of *Nephrops*.

Farn Deeps (FU 6)—The Farn Deeps fishery is predominantly a winter trawl fishery (October–March), with only a small level of creel activity occurring in more isolated areas. The ground supports a fishery of 2000–3000 tonnes per year, taken principally by English trawlers, although visiting Scottish vessels account for between 20% and 30% of the landings (ICES, 2012b). The ground extends from Teesside up to around the Scottish border and ranges from around 50 to 110 m in depth. There has been an active *Nephrops* fishery off the North-East English coast since the end of the nineteenth century, albeit punctuated by the two World Wars. Prior to the First World War, landings peaked around 1911 at around 700 tonnes and did not reach these levels again until after 1960. It is hypothesised that the reduction in landings between these two periods is a result of lower effort, with many boats having been lost in the conflicts. The modern fishery comprises a wide range of vessel sizes with the local fleet typified by small vessels 15–20 m in length towing single-rig gears, a migrant fleet from Scotland towing single and twin rigs and one from Northern Ireland towing twin, triple and quadruple rigs. Since 2000, there has been an increase in the effort of vessels targeting *Nephrops* using multi-rig trawls. In 2004, they accounted for about 10% of the landings by weight and for about 20% by 2006. Since 1990, a moderate proportion (20–40%) of the landings from this fishery has been as tails (as opposed to whole). Until the mid-2000s, it was common practice to sort the catch while it was tied up in harbour and there are anecdotal reports of a population of *Nephrops* becoming established in the mouth of the river Tyne as a result of discarded animals. The major part of the sorting now takes place while the rig is steaming back to port. Fishing is usually limited to trips of 1 day with 2 hauls of 3–4 h being carried out. ICES (2012b) reports that the fishing effort is too high in the unit and that the biomass is, consequently, below the relevant reference point for a sustainable fishery.

Firth of Forth (FU 8)—The Firth of Forth ground is located close inshore to the Scottish coast and extends far up into the river estuary. The substrate composition is mainly muddy sand and sandy mud with only a small amount of the softest mud. In the late 1950s, the seine netters started to see big catches of *Nephrops* but discarded them as they were of no value.

This developed and by the early 1960s, the *Nephrops* were landed to be tailed for scampi. The fleet in the area targeted whitefish when it was abundant and *Nephrops* when it was less so. As the whitefish fishery developed further, and the use of the pair trawl became popular, the *Nephrops* fishery declined, until the mid-1990s, by which point the entire fleet was dependent on *Nephrops* alone. In the last 5 years, the fleet has decreased significantly and a number of vessels have started to pot for crab and lobster. During 2006/2007, the number of vessels regularly fishing in the Firth of Forth was estimated at 40 (23 under 10 m and 19 over 10 m), but in 2012, there were only 16 or 17 (Pittenweem, F.M.A., personal communication). The fishery provides income for many of the very small vessels working from the ports of the Firth of Forth, and many of them operate from the under-10 m pool quota, managed by the UK fisheries administrations, instead of the Producer Organisation allocations, which can sometimes restrict the fishing opportunities in the area. Some vessels, normally active in the Farn Deeps, come north from Eyemouth and South Shields, but, in turn, Firth boats sometimes move to other grounds when catch rates drop during the late spring moulting period. The area saw an influx of the larger trawlers from the North-East of Scotland in mid-2012 and this, unfortunately, coincided with significant quantities of fresh water going into the estuary, which may have influenced the reduced landings by the local fleet (Pittenweem, personal communication). Although the fleet has historically used single rigs and actively resisted the use of twin-rigged gear, a number of vessels have made the transition during 2012. There are very few, if any, *Nephrops* creelers in the area, but there are a significant number of crab and lobster pots and gear conflict has been reported. Landings have been variable throughout the time series (since 1981) and effort has reflected this, but it has been above F_{MSY} (the theoretical level of fishing effort that would result in a maximum sustainable yield) in the most part (ICES, 2012b). Despite this, the biomass of the stock is good and consistently well above B_{trig} (i.e. the biomass at which ICES recommends that further management action should be triggered to prevent further decline; ICES, 2012b), possibly as a result of larval recruitment from outside the area. The fishing pattern is highly seasonal with night fishing occurring predominantly during the summer and daylight fishing during the winter. The area is characterised by catches of smaller *Nephrops*, and discard rates are sometimes high.

Moray Firth (FU 9)—The Moray Firth is a relatively sheltered inshore area that supports populations of juvenile pelagic fish and relatively high densities of squid at certain times. The Moray Firth borders the Fladen functional unit (FU 7) and there is some evidence of *Nephrops* populations lying across this boundary. The fishery occurs the year round, supporting a variety of vessels using both single and twin-rigged gear. The *Nephrops* fishery in the area commenced in earnest in the late 1960s/early 1970s and was predominantly prosecuted by relatively small (under 21 m) local vessels using single trawls that had previously been fishing for species such as cod and sprat in this inshore zone. *Nephrops* had previously been caught in the area by smaller vessels, mainly from Buckie, working up and down the Moray Firth coast in the inshore waters. The fishery gradually evolved to include the twin rig in the late 1980s/early 1990s. Today, the FU provides not only a year-round fishery for smaller local boats based in and around the Moray Firth coast, but also a refuge for the larger vessels when the weather is bad, restricting fishing in the Fladen area. The more nomadic and larger vessels are also known to visit the area when the fishing is particularly good. The local fleet does not generally have a particular discard issue, although it is known that some haddock (*Melanogrammus aeglefinus*) may be discarded in the summer months. There is very little, if any, creeling for *Nephrops* in the area, although some gear conflict issues have arisen between the *Nephrops* trawlers and the lobster and crab creelers. Landings throughout the lifetime of the fishery have been fairly stable but, as suggested previously, the effort in the area has been variable. That said, abundance has been healthy throughout the period for which information is available, indicating some resilience, particularly as the landings prior to 2007 are likely to have been under-reported. In recent years, a squid fishery has been seasonally important in the Moray Firth leading to a switch in the target fishery of the local fleet. The effort in the area increased in 2011 (ICES, 2012b) but may have decreased in 2012 due to a change in fishing patterns. Effort within the unit has been variable throughout the time series with biomass remaining relatively stable, although reducing more recently.

Botney Gut (FU 5)—A deep channel cutting east–west across the central North Sea, known as the Botney is actually a submerged river bed that has supported a moderate *Nephrops* fishery since the early 1970s with small landings reported from the late 1940s. The fishing area covers 1850 km^2 and spans both UK and Dutch territorial waters. This fishery is the most internationally diverse in the North Sea and has at times been used by vessels from Belgium, the Netherlands, Denmark, Germany and the United Kingdom. There is no creeling for *Nephrops* within the Botney Gut area.

Off Horns Reef (FU 33)—West of the Horns Reef lies a mid-sized *Nephrops* ground (5700 km^2). The landings from this FU were marginal for many years before a Danish fishery developed between 1993 and

2004, taking over 1000 tonnes. Since then, other countries have exploited the area and annual landings have been over 1400 tonnes. Relatively little is known regarding the distribution of muddy sediments in the area, which has not been surveyed by UWTV.

Norwegian Deeps (FU 32)—The spatial extent of commercial *Nephrops* activity within the Norwegian Deeps area is the largest in the North Atlantic at over 55,000 km^2 but is subjected to relatively little fishing activity, which has never taken more than 1200 tonnes. The fishery is commercially prosecuted by Swedish, Danish and Norwegian vessels and supports some recreational creeling as well. The commercial activity is based on trawl fisheries (both directed and mixed fisheries) as well as some by-catch in the northern shrimp (*Pandalus borealis*) fishery. North of 60 °N, the fishing activity is predominantly creeling.

Noup (FU 10)—The Noup fishery started at around the same time as the Moray Firth fishery and was primarily used by the same vessels but has since reduced in importance, as supported by the low, but variable, landings since 1997. As with the Moray Firth, the area was originally exploited by single-rigged trawlers, with a move to twin rigging late in the 1980s. At present, the fishery is prosecuted by around four vessels. The quantity landed from the area is now very small, accounting for $<1\%$ of the overall North Sea landings. There is very little information available on the stock, but it was thought to be relatively stable when the last survey was undertaken in 2007 and effort has reduced significantly since then (ICES, 2012b).

Devil's Hole (FU 34)—This unit was assessed individually for the first time in 2012 and the first UWTV survey was carried out in the same year. In advice before this date, the FU, although the largest of such, was thought of purely as part of the component of the stock that was outside of the defined FUs. The fishery started in the 1990s and was, arguably, opened up by vessels from Buckie. These vessels were relatively small in size and capacity and initially operated single-rigged gear, with some changing to twin rig later in the decade. The fishery currently supports 15–20 Scottish vessels with variable, relatively low, landings.

1.2. West of Scotland

On the west coast of Scotland, there are *Nephrops* fisheries in the North Minch (FU 11), South Minch (FU 12), the Firth of Clyde (FU 13) and, to a lesser extent, at Stanton Bank and in more offshore areas on the shelf edge. Small inshore trawlers targeting *Nephrops* take most of the catch, but some are caught by larger twin-rig vessels. Creel fishing accounted for 18% and 21%, respectively of landings in the North and South Minch in 2009 (including Loch Torridon, which is described in more detail in Section 1.6). Creel-caught *Nephrops* are generally larger and in better condition than those caught by trawling (Ridgway et al., 2006). They attract high prices in the live export market and provide an important source of income for small local boats. Creels are used mainly in inshore areas and sea lochs, where trawler access may be limited by the seabed or legislation. In some areas, both fishing methods are used and gear conflicts sometimes occur. Effort within the West of Scotland as a whole was anticipated to be increased during 2012 with an increased number of vessels working on the grounds.

North Minch (FU 11)—The North Minch extends from Kinlochbervie and covers most of the coast of Lewis and the northern part of Skye. As in many other areas, the seine vessels began catching *Nephrops* in the mid-1960s but either discarded them or, to a lesser extent, tailed them, as no real market was accessible. As the market began to develop, vessels from the east coast began fishing in the North Minch with trawl gear and were out-fishing the local vessels. As the west coast vessels began to change to trawling, significant fleets developed in towns such as Gairloch, Lochinver and Stornoway, with the numbers peaking in the early 1970s. In 2011, 79% of the landings from the North Minch were landed by trawlers, and quota was not restrictive. Effort restrictions operate in the area and until 2012 have not been restrictive. In 2012 and, to a lesser extent, 2011, significant numbers of east coast vessels fished in the area, leading to effort issues and the need for the Fisheries Administration to take action. Fishing mortality has fluctuated over time but does not appear to have had an adverse impact on the biomass. The ICES advice for 2012 recommends that landings should be restricted to 4200 tonnes, indicating that the fishery is exploited at sustainable levels. In recent years, fishermen have not reported the same high levels of predatory species as have been seen in the North Sea, but significant quantities of haddock were seen on the grounds in 2012. It is thought that this is due to vessels working with different fishing gear, rigged to catch a fish by-catch, and, to a lesser extent, increased abundance of haddock.

South Minch (FU 12)—The South Minch extends from the northern part of Skye and encompasses Muck and part of Jura at its southern end. The western extent encompasses Barra and South Uist and extends some way seaward from the west coast of South Uist. Fishing activity in the South Minch concentrated mainly on pelagic species and creeling until the 1960s when fishermen from the Clyde migrated north bringing their dedicated gear with them. The fishery has many characteristics in common with the North Minch, although the abundance appears to be a little more variable. Many vessels operating in the North Minch also operate in the south. Seventy eight percent of the landings in 2011 were made by trawlers, with the fishery being mainly Scottish, although very small landings are made by Northern Irish and, to a lesser extent, English vessels. ICES recommend catches of not more than 5800 tonnes for 2013, suggesting that the fishery is being exploited sustainably as the recommended number is well below the numbers of recent landings (ICES, 2012b).

Firth of Clyde (FU 13)—The Firth of Clyde (FU 13) is located off the west coast of Scotland near Ayrshire and is one of the three FUs in division VIa. FU 13 fishing grounds extend from Ayrshire westward into the Atlantic waters around Arran, Kintyre and Jura, stopping just south of Mull. The fishery has existed in these waters since the 1960s and can be split into two sub-areas, the first being the Firth of Clyde and the second, the Sound of Jura. These waters were used as fishing grounds for species such as herring until the 1980s when *Nephrops* became the dominant species (Combes and Lart, 2007). *Nephrops* are now considered to occur in high densities in both the Firth of Clyde and Sound of Jura (more than 0.8 burrowper m^2; ICES, 2012b). In 2011, fishing in FU 13 produced 6431 tonnes of *Nephrops* from these grounds. The catch was a combined effort from both trawls (accounting for 97% of the catch) and creels (accounting for 3% of the catch; ICES, 2012b), with vessels earning approximately £2000 per tonne of trawled *Nephrops* (Combes and Lart, 2007) with a minimum landing size (MLS) of 20-mm carapace length (CL; ICES, 2012b). Discards from trawls equated to 556 tonnes; while no data are available for discards from creels, the number is expected to be very low (ICES, 2012b). Approximately 92% of *Nephrops* landed in FU 13 are from Scottish vessels with the remaining 8% landed by other UK and Irish vessels. The area used to trawl for Nephrops is 3000 km^2 (Wieczorek et al., 1999) with the by-catch including cod, haddock and whiting (*Merlangius merlangus*). However, temporal and area bans that are enforced in FU 13 have led to a rise in the number of creel boats as trawlers are unable to fish over the weekend (ICES, 2012b). It is estimated that approximately one-third of the creel boats operate round the year. As a result of the findings and advice from ICES, it is suggested that landings should not exceed 5600 tonnes for the Firth of Clyde and 800 tonnes for the Sound of Jura (total of 6400 tonnes for FU 13). Anecdotally, the general size profile of Clyde landings decreased in 2012. This may have been purely due to localised increases in landings. Observations from early 2013 indicate that effort may again be high in the area as the visiting fleet appeared in January as opposed to the more normal March.

1.3. Celtic Sea, Irish Sea and West Ireland

Within the ICES sub-division VII (the fishing grounds around Ireland), 7 FUs are used to assess *Nephrops* stocks within three broader grounds, the Celtic Sea, the Irish Sea and West Ireland (ICES, 2012a). Trawling is the primary means of *Nephrops* fishing within these grounds, yet this may not be the most efficient method for landing. ICES (2012a) stated that *Nephrops* could be seen in grounds that were newly trawled, suggesting that at least some of these animals may be impervious to trawling efforts. This phenomenon of *Nephrops* grounds has been hinted at previously (Vergnon and Blanchard, 2006).

1.3.1 Celtic Sea FUs 20–22

The Celtic Sea is located to the south of Ireland. It is bordered in the north-east by St. George's Channel and in the east by the Bristol Channel and the English Channel and contains three FUs. Two small FUs (20 and 21, 'Labadie') are always considered together, and FU 22 Celtic Sea—the Smalls. Both single and twin trawlers are employed in FUs 20–21with the fishery dominated by French and Republic of Ireland vessels (98%). Although this fishery was thought to be stable, landings have decreased considerably over the past few years, with the French catch decreasing dramatically in this area from 90–95% to 45–50%. The FU 20–21 fleet in 2011 landed 1237 tonnes. Although discards were not calculated because of scarce observations, discards in the FU are thought to be high. Anecdotal evidence suggests that some of the Irish fleet are making the transition to multi-rigged gear, with the potential for increasing the overall pressure on the units in the Celtic Sea. The Irish fleet also saw a general increase in the amount of tails landed in 2012 as a whole, mainly as a result of the high price that the product was attracting.

FU 22—Smalls has existed as a fishery since the 1960s and is currently thought to be a relatively stable and productive stock. *Nephrops* landings in FU 22, an area covering 2881 km^2, are dominated by vessels from the Republic of Ireland (more than 95%) with a moderate density of *Nephrops* (around 0.5 burrows per m^2). In 2011, 617 tonnes of *Nephrops* were landed from these grounds, all of which were by otter trawls, with only 9% discards. Whiting and cod and occasionally haddock and hake dominate any by-catch. ICES advise that landings of *Nephrops* in FU 22 should not exceed 3100 tonnes in 2013 (ICES, 2012b).

1.3.2 Irish Sea

In the Irish Sea, *Nephrops* are exploited mainly in the waters to the west of the Isle of Man (FU 15—Irish Sea West) and most landings are by Northern Ireland (6000 tonnes per annum) and the Republic of Ireland (2000 tonnes). These landings give a combined first-sale annual value of about €14.7 million, which makes it the most valuable fishery in these waters with *Nephrops* occurring in very high densities (around 1.1 burrows per m^2), resulting in smaller sized animals (ICES, 2012b). However, among the Western Irish fisheries, there has been a prevalence of a dinoflagellate parasite, *Hematodinium* that has been present since 1994 with an estimated annual mean infection prevalence of 18% in 1996. Peak infection is believed to occur in April/May, with juveniles being more susceptible to the parasite. Significantly infected muscle tissue is reportedly bitter in taste, resulting in the meat being inedible (Briggs and McAliskey, 2002). A severe outbreak of the disease could have devastating consequences for one of the largest fisheries in the area in terms of stock recruitment and fishery revenue (Field et al., 1992). In 2011, FU 15 landed 10,162 tonnes and discarded a further 2700 using otter trawls from 5289 km^2 of fishing grounds. The trawls used are a combination of single and twin gears and 70–99 mm meshes, with an MLS of 20-mm CL. However, in order to reduce the by-catch (mainly juvenile whiting, cod and haddock), separator trawls and Swedish grids were used by approximately 45% of the Irish vessels (ICES, 2012b). Landings for the 2013 season should not exceed 9300 tonnes, similar to what the *Nephrops* stock in FU 15 has sustained for several years. However, within the domain of the Irish Sea, *Nephrops* are also fished off the West England coast from the north of Wales to the south-west border of Scotland (FU 14—Irish Sea East). This FU actually comprises two grounds and there is a small population fished in Wigtown Bay, just north of the main ground, although *Nephrops* in this area are in fairly low densities (around 0.3 burrows per m^2). In 2011, the *Nephrops* catch in FU 14, where the fishery operates mainly in spring and early summer and is male dominated, was 561 tonnes with around 28% discards, with the by-catch of this area comprising primarily plaice (*Pleuronectes platessa*), but cod and whiting as well. The number of vessels responsible for this catch numbered in the region of 60 vessels, with the fleet consisting of approximately 25 English and 35 Northern Irish vessels, using 70–99 mm meshes. The English used predominately single otter trawls, while over 70% of the Northern Irish vessels used multi-rig trawls (summary—38% twin: 62% single otter trawls; ICES, 2012b). Based on reports by ICES, landings within this FU should not exceed 880 tonnes in 2013. The Northern Irish fleet working in the Irish Sea reported a steady year in 2012, with 'good fishing, good prawns and good prices'. The good price reduced the overall landings and kept the overall quality to a high standard by reducing the economic pressure on fishermen to land inferior prawns or to fish harder. Effort may have increased in the Irish Sea in 2012 due to displacement of the Northern Irish fleet from VIa to VII.

1.3.3 West Ireland

The Western Ireland grounds comprise three FUs. The Porcupine Bank stock (FU 16) is located off the west of Ireland in the North Atlantic and the fishery operates mainly between April and July. *Nephrops* are taken by the Spanish fleet as by-catch in a multi-species trawl fishery together with demersal fish, comprising mainly hake, anglerfish (*Lophius piscatorius*) and megrim (*Lepidorhombus whiffiagonis*). However, *Nephrops* landings from Spanish trawlers fishing on this bank have decreased by about 90% in the last 25 years, from 3873 tonnes in 1982 to 483 tonnes in 2007. González-Herraiz et al. (2009) found a negative correlation with the NAO index with a time lag of 6.5 years. *Nephrops* density in this area is considered extremely low (<0.3 burrows per m^2). Although the stock size is thought to have increased over recent years, this may be only as a result of reduced fishing pressure since from 2010, FU 16 has employed a seasonal closed area during female emergence (first 3 years May–July but from 2013 only in May). This regulation has been adhered to well by the fleets allowing protection for a large area of the stock. In 2011, 1187 tonnes of *Nephrops* were landed in these waters using both single and twin rigs, with exploitation rates of females being lower than that of males. Discards are thought to be nominal, although the actual discard rates for 2011 are uncertain (ICES, 2012b). Landings in FU 16 should not exceed more than 1800 tonnes as advised by ICES, managed by a separate quota. This separation of quota has led to displacement of effort into other areas and has seen the larger offshore vessels typical of the FU 16 fishery on some of the more inshore grounds within divisions VI and VII. This is discussed further in Section 3.

The second of the West Ireland FUs, FU 17—Aran Grounds extend north from the South coast of County Clare to the North coast of County Galway and are approximately 909 km^2. These grounds are considered to have a fairly high density of small *Nephrops* (0.9 burrows per m^2), yet fluctuations have been observed in the stock size. In addition, the Aran Grounds have a catch sex ratio that varies greatly with a high percentage of males landed during the autumn. In previous years, FU 17 has been fished by French, English and the Republic of Ireland vessels; however, over the past few years, landings in these grounds have been solely by the Republic of Ireland. Currently, 90% of the fishery employs twin-rigged vessels with the total landings being 600 tonnes in 2011, all of which were from otter trawls. The by-catch of these grounds consists of hake, megrim and monkfish (ICES, 2012b). Recent surveys have shown the Aran Grounds stock in significant decline and harvest rates may be reconsidered. Data from 2004 to 2007 show that previously landings on these grounds had been restricted. ICES, 2012b has advised that *Nephrops* catch in the Aran Grounds should not exceed 590 tonnes in 2013.

FU 18—The *Nephrops* grounds to the northwest of Ireland have not been officially assessed, like the other FUs around Ireland, and ICES (2012b) states that there is currently no major *Nephrops* fishery in the area. Any *Nephrops* caught in this area are believed to be minimal in number and are not expected to exceed 200 tonnes. The recorded landings from 2011 are over 20 tonnes.

FU 19—Ireland SW and SE coast grounds extend along the entire Irish South coast from the north coast of County Kerry on the west to County Wexford on the east, spanning 1653.26 km^2. *Nephrops* in FU 19 are found to occur in moderate densities (around 0.5 burrows per m^2) with higher landing rates of males in comparison to females. In 2011, 608 tonnes of *Nephrops* were landed from these grounds. All landings were from otter trawls employing either single or twin rigs with 80–99 mm cod-end mesh size. The majority of vessels landing in these waters were from the Republic of Ireland (responsible for 96% of total landings), with a few French (3%) and English (1%) vessels. Discards were in the region of 18% with by-catch species including hake, megrim, anglerfish and monkfish (ICES, 2012b). Landings in FU 19 for 2013 should not exceed 820 tonnes, as advised by ICES.

1.4. Iberian Peninsula

The southern region of the North Atlantic distribution consists of nine FUs, namely, the Bay of Biscay (FUs 23–24); North and West Galicia (25–26); the Cantabrian Sea (FU 31); North, South and South-West Portugal (FUs 27–29) and the Gulf of Cadiz (FU 30). These southern *Nephrops* populations are distributed in much deeper waters than their northern counterparts (from about 80 to about 700 m) and here the distribution is patchy depending mainly on the sediment type. In the northern Bay of Biscay, this species occurs at depths ranging from 80 to 120 m (Conan et al., 1994); in Galicia, from 90 up to more than 600 m of depth (Fariña, 1996); and in South Portugal and the Gulf of Cadiz, between 200 and approximately 700 m (Figueiredo and Viriato, 1989; Ramos et al., 1996).

It is uncertain when *Nephrops* began to be exploited commercially in these southern areas, but De Buen (1916) refers to a commercial fishery for *Nephrops* in Spain and indicates its presence along the entire Iberian Peninsula coast. Since then, *Nephrops* fisheries have expanded considerably, in particular, over the last 50 years. During the past few decades, the trawling fleet have undergone considerable technological improvements (i.e. gear development, GPS) resulting in an increase in fishing effort. Landings of *Nephrops* in southern areas have been decreasing since the mid-1980s. Currently, the largest *Nephrops* catches are obtained in the Bay of Biscay with a total of 3398 tonnes in 2010, followed by the Iberian Atlantic coast with 275 tonnes, and the Cantabrian Sea and North Galicia division with 42 tonnes (Engelhard and Pinnegar, 2010). In this last division, the fishing effort is not specifically directed to *Nephrops* but to a mixed fishery that targets a number of different demersal species.

In the Bay of Biscay and the Iberian Peninsula Atlantic waters, *Nephrops* is mainly caught in a mixed bottom-trawling fishery and can be either a target species or a by-catch of finfish/crustacean trawlers. Mixed finfish trawlers target *Nephrops* together with hake, black anglerfish (*Lophius budegassa*), monkfish, megrim, horse mackerel (*Trachurus trachurus*), mackerel (*S. scombrus*) and blue whiting (*Micromesistius poutassou*). The crustacean fleet in the southwest and South Portugal targets, besides *Nephrops*, deep-water shrimps such as the rose shrimp (*Parapenaeus longirostris*) and also the red shrimp (*Aristeus antennatus*). During the last two decades, these vessels, traditionally targeting predominantly *Nephrops*, transferred most of their fishing effort towards the rose shrimp. Today, the latter species is the most important species for the crustacean trawling fleet in South Portugal. The decrease in *Nephrops* landings in the South-West/South Portuguese coast can also be related to this shift of fishing effort, but no specific studies exist that enable an assessment of effort changes. The same shift of effort happened in the Gulf of Cadiz where the rose shrimp also achieves a remarkably high first-sale price and where the fishing grounds are closer to the coast and easier to reach (90–380 m of depth).

Historically, *Nephrops* populations have been exploited along these coasts by trawling, but nowadays creels also account for a small proportion of the total landings. Creels were used locally on the west coast of Portugal, but only in areas unavailable to trawlers because of either legislative restrictions on access or unfavourable bathymetry. Although creels are very selective for *Nephrops* and proved to be financially profitable in the Portuguese west coast (mean first-sale price in 2007–2009 was €40 per kg), the expansion of this fishing gear is unlikely, mainly because of likely conflict with the trawling activity (Leocádio et al., 2012).

Nephrops represents a very valuable resource in these southern countries. One peculiar case is Portugal where, despite the relatively insignificant importance of landings in the context of global European figures, local first-sale values are considerably higher than elsewhere in Europe; it was €21.02 per kg in 2011, while the average prices per kilogram for the United Kingdom and France in 2011 were €5.60 and €9.25, respectively. These high prices achieved in Portugal are due to the quality of the product as *Nephrops* are sold fresh, refrigerated (from the trawling fleet) or alive (from the artisanal creeling fleet). The catch per unit effort (CPUE) in Portuguese waters has decreased from about 120 kg per day (per vessel) in 1989 to about 50 kg in 1995, and has remained more or less stable since then (ICES, 2004b). Based on the recommendations made by the WGNEPH, a zero TAC was set for 2003, 2004 and 2005 to let the stock recover.

1.5. The Mediterranean

1.5.1 Balearic Islands

The fishery in this part of the Mediterranean is operated by 40 trawlers working on the upper slope between 350 and 600 m depth with average annual catches of 10 tonnes (3.5 tonnes for females and 6.5 tonnes for males) between 2002 and 2009. Typical by-catch species in this fishing area are hake, megrim, blue whiting and anglerfish. The stock of *Nephrops* in this area is considered overexploited and for the period of 2002–2009, a pseudo cohort of 25,000 and a population biomass of 35 tonnes had been estimated (Guijarro, 2010).

1.5.2 Adriatic Sea (GSA 18)

In the Adriatic Sea, one-third of the total Italian landings are taken off the West coast and *Nephrops* ranks first among all the crustacean species exploited in terms of value. There have, however, been declines in catches since 1993 (Vrgoč et al., 2004). *Nephrops* can be found at depths of 30 m in the Northern Adriatic to 400 m in the southern area (Marano et al., 1998), with higher population densities in the north. Important fishing grounds for demersal trawlers are at 70 m depths off Ancona (Central Italy on the Adriatic coast) and at 220 m in the Pomo pit further off in the Middle Adriatic basin. The *Nephrops* fishery in Italy has been managed and regulated since 1980 by limited numbers of fishing licences, area limitations, mesh size restrictions, MLSs (EC 1967/06[1]) and seasonal fishing bans. The fishing effort and landings have declined since 2004 and annual landings have gone down from 1300 tonnes (2007) to 865 tonnes (2011) (Cardinale et al., 2012).

1.5.3 The Ligurian and Northern and Central Tyrrhenian Sea (GSA 9)

Nephrops in this area are targeted by bottom trawlers with a fleet of about 80–100 to date, fishing at 300–500 m depths along muddy slopes. Most trawlers targeting *Nephrops* also catch other commercial species (hake, deep-sea pink shrimp, horned octopus (*Eledone cirrhosa*), squids (*Todaropsis eblanae*)) and non-commercial ones. The *Nephrops* fishery in this area is the most valuable, with total annual landings between 248 tonnes in 2005 and 228 tonnes in 2008 (Cardinale et al., 2011).

1.6. Socio-economically interesting fishery regions

1.6.1 Loch Torridon

A creel fishery has existed for approximately 40 years on the North-West coast of Scotland, especially around Loch Torridon (FU 11, North Minch). In 1984, the Inshore Fisheries (Scotland) Act removed the ban on using mobile gear closer than three nautical miles from the shore. This resulted in an increased and intense conflict between trawlers and creelers. Creelers sought an exclusion zone where trawlers were banned and they could co-manage the fishery. In November 2000, this was recognised and legislated for (Bennett and Hough, 2007). At the same time, an exclusive trawl area of similar size was established solely for the use of trawlers. The creel fishermen in Loch Torridon set up a company, Shieldaig Export Ltd., to collectively supply the live *Nephrops* market. The *Nephrops* captured are mainly live-stored and exported to the Spanish market by air freight. Internal rules were also established for the closed area under the Torridon Management Plan (Bennett and Hough, 2007). The measures included a maximum number of creels for one (2×400) or two or more (2×800) fishermen per vessel, only one set of gear to be hauled per day, a maximum of 200 fishing days

[1] Council Regulation (EC) No. 1967/2006 of 21 December 2006 concerning management measures for the sustainable exploitation of fishery resources in the Mediterranean Sea, amending Regulation (EEC) No. 2847/93 and repealing Regulation (EC) No. 1626/94. Official Journal of the European Union, L409/11.

per year, berried females to be released and escape gaps to be of 22 mm allowing specimens up to 40-mm CL to escape, although the MLS is 20-mm CL. The Loch Torridon creelers take approximately 100–150 tonnes per year of a TAC for the management area C (FUs 11–13) of ca. 11,000 tonnes. The Loch Torridon creel fishery became the first *Nephrops* fishery to be eco-labelled under Marine Stewardship Council (MSC), underpinning the voluntary Loch Torridon Management Plan and otherwise sustainable fishery managed under TAC in management area C (FU 11; Mason et al., 2002). However, in 2011, the eco-label was withdrawn. The MSC eco-label, which has been under fire recently (Froese and Proelss, 2012), does not seem to have been missed by the creelers who suggested that it was of little value for marketing, although it is likely that this is because of the nature of the continental market rather than a general observation.

1.6.2 The Swedish coastal area

A creel fishery exists on the Swedish Skagerrak coast and 90% of the creel landing of 359 tonnes for Swedish *Nephrops* in 2012 came from here (Figure 7.3A). There is a smaller creel fishery prosecuted by Swedish fishermen in the Kattegat also. The creel fishery was introduced in the mid-1980s (Eggert and Ulmestrand, 1999) and the landings were 10–15% of the total in 1986–1999 (Swedish National Board of Fisheries, 2010). After the trawl border was moved out from 2 to 3–4 nautical miles, it gradually increased and has now reached 26% (Figure 7.3B). In 2006, borders for trawling and creeling were regulated further to give more space to the creelers, and from 2008, a permit for creeling was required to minimise the risk of overestablishment of creelers (Swedish National Board of Fisheries, 2006). Few new permits are currently given. For the year 2013, 109 vessels (102 skippers) have a permit to use creels in Sweden in vessels from 5 to 12.7 m, with most vessels 8–10 m in length (48%). The total TAC for Skagerrak and Kattegat in 2013 is 5200 tonnes, of which 1367 tonnes are for Swedish fishermen with 25% for creeling only. The first-hand sale value for the Swedish *Nephrops* landings in 2012 was €12.8 million, which ranked second in landings from the West coast after the northern shrimp (€14.0 million), and fourth in the country after herring (*Clupea harengus*; €17.0 million) and cod (€15.2 million). However, in Sweden, prices for *Nephrops* are between 8% and 23% (mean 18%) higher, about €3 per kg, for creel captured *Nephrops* compared to trawl caught (Swedish National Board of Fisheries, 2010). This is probably because creeled *Nephrops* are larger and deemed to be of higher quality. The *Nephrops* landing is sold shortly after landing mainly at the Gothenburg, Smögen or Strömstad fish auction, and then redistributed further. *Nephrops* are sold sorted or in different size categories. Swedish regulations state that *Nephrops* creels must be set in depths deeper than 30 m (SwAM, 2004:36), and the fishery often operates at 40–80 m depth. The fishers shoot 300–400 creels per day on average but only up to 800 creels (single fishermen) or 1400 (two or more fishers) are allowed (SwAM, 2004:36). It takes approximately 30 min to lift, empty, re-bait and shoot a fleet of 50 creels (Ungfors, A., personal observation). Soaking time for the gears is 2.5 days on average. The Swedish *Nephrops* creelers also target European lobster and brown crab (using lobster or crab pots).

2. CAPTURE METHODS

Trawling is the main gear used for capturing *Nephrops*. However, in some areas, particularly in Western Scotland and in the Swedish Skagerrak coastal region, the proportion caught by creeling is of significance and has increased markedly over the last 40 and 28 years of use, respectively. Nowadays, around 20% in the North and the South Minches and the Clyde, and 26% of the Swedish TAC are taken by creels, which means an even larger percentage in value terms. The length frequency differs in catches taken by trawls and creel captures (Jansson, 2008; Leocádio et al., 2012; Figure 7.4). The higher value of creel-caught animals means that a lower quantity can be landed to generate the same income (Table 7.2). The cost for fuel for creel fishers is also less. Ziegler and Valentinsson (2008) took a holistic view of the *Nephrops* industry using life-cycle analyses (LCA) and found that 2.2 l of diesel were used per kilogram of creel-captured *Nephrops* landed, which can be compared to selective trawl fishery using 4.3 l, mainly used by the fishing operations. Ziegler (2006) showed that the conventional trawl fishery uses 9.0 l of diesel per kilogram of *Nephrops* landed, the discrepancy due mainly to a cleaner catch composition (higher % of *Nephrops*) in the species-selective trawl compared to the conventional one.

Stocks with larger MLS where higher frequencies of the larger individuals are taken, are more suitable for creel capture. The highest MLS is in Skagerrak and Kattegat (40-mm CL), making this a promising area for creel fishers. The ecological foot print, for example, the benthic effect on the ecosystem using trawl versus creel has been evaluated and it is suggested that 1 h of trawling results in the same impacted area on the seafloor as during 1 year of the entire Swedish *Nephrops* creel fishery (Hornborg et al., 2012; Ziegler, 2006; Ziegler and Valentinsson, 2008). However, the consequences of

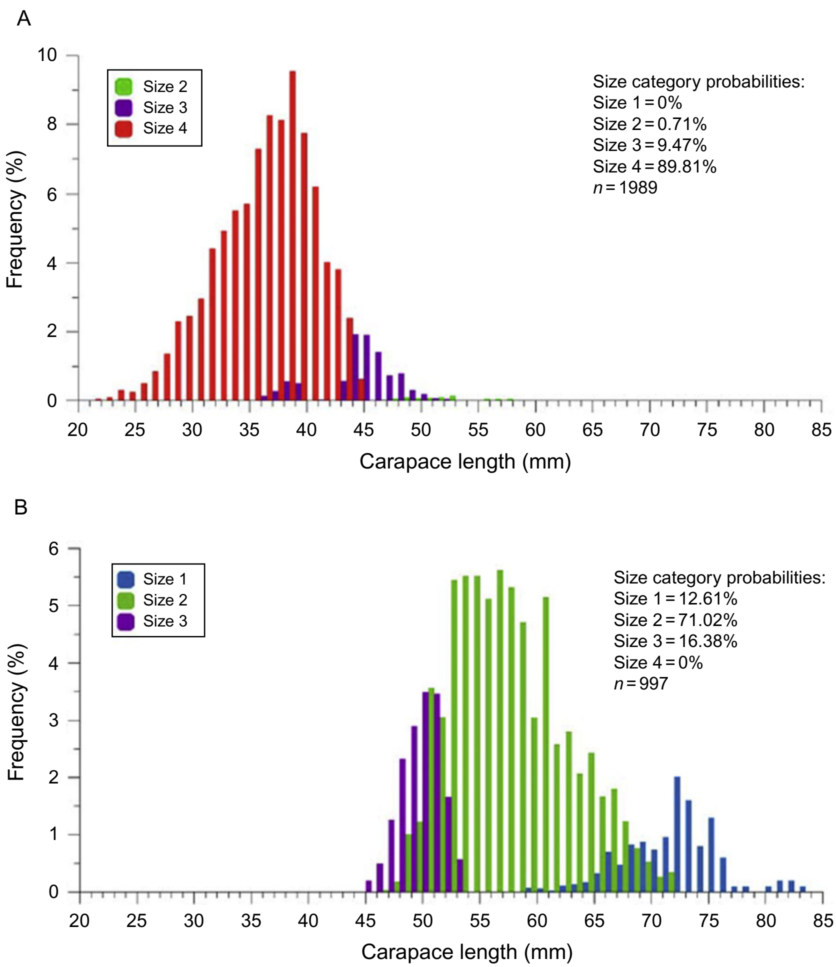


Figure 7.4 Size distribution in trawl (A) versus creel (B) catches shows that larger sizes are landed with creels for Norway lobster (*Nephrops norvegicus*). Size at first capture is larger and length distribution of the catch is greater in creels. Data are shown for the Portuguese coast (Leocádio et al., 2012).

Nephrops trawling activity on the sea bottom ecology are complex and there is scarcity of information on comparable control areas without a trawl fishery. Surveys using, for example, wreck areas as non-fished areas (Ball et al., 2000) or closures (Tuck et al., 1998) suggest that it is the fishing intensity *per se* that impacts the benthic ecology. Ball et al. (2000) found some indications of disturbance at the inshore trawling grounds used for less

Table 7.2 Examples of size-sorting categories in use for Norway lobster (*Nephrops norvegicus*) (up to four categories, XL-S, regional differences may occur), and the approximate first-hand sale value (€ per kg) for these in the three given areas

	Sorting category	Extra large (XL)	Large (L)	Medium (S)	Small (S)	Reference
UK waters	Numbers per kg	1–9	10–14	15–20	21–26	Don fishing company[a], Peterhead
	Approx. value (€ per kg)[a]	10	8	7	5	
Sweden (FUs 3 and 4)	Numbers per kg	1–5	6–10	11–15	16–20	
	Total length[b] (cm)		>16	14.5–16	13–14.5	
	Approx. value (€ per kg)	24.3–29.4–33.6	17.4–30	9.3–17.4	7–8.1	Gothenburg[b]
			7.0–15.5–39.1	5.9–10.9–27.8	5.7–8.6–25.5	Smögen[c]
			13.3	9.9		Strömstad[d]
Portuguese waters	CL (mm)	>60	47–72	36–53	>44	Leocádio et al. (2012)
	Approx. value (€ per kg)	47–130	23–67	7–24	2–10	

[a]Price to fishers.
[b]Gothenburg Fish auction mainly use two sorting categories, over 16 cm and 13–16 cm total length, but sell according to fishers' own sorting; main value changes during the year are given (lower spring-higher summer season).
[c]Smögen Fish auction use three to four sorting categories (min—average—max for year 2012 is given).
[d]Strömstad Fish auction use two sorting categories (over 16 cm and 13–16 cm, average for 2012 is given), the average value for creel captured in 2012 is 13.3 (no size sorting).
The size categories are affected by the minimum landing size (Figure 7.11 for more information). The first-hand sale is higher for the larger *Nephrops* (more than double), but the values differ during the year.

intensive fishing (e.g. the disappearance of echinoderm *Brissopsis lyrifera*) but that the trawling grounds still contained large molluscs, and the number of species did not differ significantly between untrawled and trawled areas. However, in deeper and more intensively trawled areas, there is a complete absence of large benthic infauna except *Nephrops*. In the Bay of Biscay, a community indicator (the ABC method—abundance–biomass comparison) has been used to evaluate trawling impacts on benthic invertebrates (Vergnon and Blanchard, 2006). In theory, disturbed habitats will have a lower average biomass than abundance compared to less disturbed areas where the biomass is larger (comparing curves for biomass and abundance for ranked species). The results of the ABC method were inconsistent with the theoretical expectation for these communities and the measured levels of fishing intensity, as the biomass of macro benthos (not least of *Nephrops* and *Liocarcinus* sp.) remained relatively high in the heavily trawled areas.

The sex ratio in the capture during the year differs, perhaps more in trawl landings than creeling. This is a result of the reproductive behaviour of *Nephrops*, where females are ovigerous for months during which time they are more prone to stay in their burrows. Males dominate trawl captures in the egg-bearing season. However, that egg-bearing females do not feed is apparently a 'truth with some modification'. Aguzzi et al. (2007) analysed the empty stomachs of both berried and non-berried females from captures taken at different times of the day and night. From this and laboratory studies in burrow emergence behaviour, they concluded that both berried and unberried females feed outside of their burrows (see Chapter 3). This can in fact be seen in creeling, and it can be regarded as a negative effect of creeling that a larger proportion of berried females are seeking food from the baited creel, which seems to attract even egg-bearing females into the cages. Aguzzi et al. (2007) hypothesise that the egg-bearing stage only modifies the range and duration of emergence. Although Jansson (2008) does not present data on berried versus non-berried females, the sex ratio in the Swedish creel fishery in 2 years of observations (64% males:36% females) is similar to the trawling data (65% males:35% females) from the region.

2.1. Net design

A commercial fishery for *Nephrops* was started in the late 1950s. Before this, the *Nephrops* was considered as an unwanted product caught as by-catch in finfish trawl fisheries. However, as the market demand increased, especially in the south of Europe, the fishing industry started to use seine nets of 55-mm mesh size and wooden otter doors to increase the opening width (ICES, 2004a). Eventually, a conventional trawl came into use, using mesh sizes of 70–80 mm with a rather low headline. This trawl evolved into a so-called scraper, also with a low headline but with wider wings and a heavier construction (ICES, 2004a). Initially, trawls were manufactured using natural fibres and used on muddy areas, but as harder grounds were explored, the net was protected using disc structures of rubber thread through lead rings.

Another improvement in the trawl was the development of the twin-rig trawl by Danish fishermen in the mid-1980s. This came from the tropical shrimp fisheries in the Gulf of New Mexico and was first used in European waters for *Pandalus* prawns but was quickly adopted for *Nephrops* across Europe. The net and, therefore, net drag are smaller in a twin rig compared to a single rig with a similar entrance width (Figure 7.5), with less engine effort required as a result, and the speed can be increased, leading to a dramatic increase in capture efficiency (Sangster and Breen, 1998). Eggert and Ulmestrand (1999) used a factor of 1.7:1 for conversion of twin-rig versus single-rig LPUE in their *Nephrops* economic modelling. There is some dispute within the fishing industry as to the environmental impact of the twin rig compared to the single rig as, in order to maximise contact with the seabed, a 'clump' of chain is positioned on the footrope between the two sets of gear. Single-rig fishers claim that the clump is causing a greater impact upon

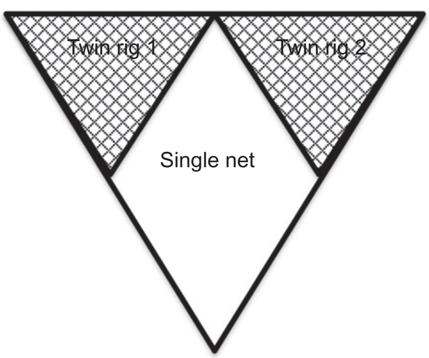


Figure 7.5 Twin-rig set-up reduces net drag. The trawl opening area (illustrated as the horizontal line) is theoretically similar for a single and a twin-rigged trawl, but advantage in reduced net drag is reached as the twin-rigged trawls are shorter why less water friction. *Modified from ICES (2004b).*

the seabed than their gear. To date, there has been no scientific evaluation of this claim.

The discarded portion of catches from *Nephrops* trawl fisheries is a widely recognised problem. The North-East Atlantic trawl fishery for *Nephrops* has the fifth highest discard ratio in the world (Catchpole et al., 2006a, 2008). The problematic high discard rates of under-sized *Nephrops* and by-catches of vulnerable finfishes (North Sea; Catchpole et al., 2005, 2008) have been the main driver for the many improvements in trawl design and the more stringent regulation. Reviews of trawl improvements and the resulting change in the selection pattern of *Nephrops* size and by-catch of other species have already been compiled (ICES, 2004a; Catchpole and Revill, 2008; Madsen and Valentinsson, 2010) and are not repeated herein. The approaches taken are square-mesh panels (SMPs) at various distances from the cod-end (Briggs, 2010; Catchpole et al., 2006b; Drewery et al., 2010; Krag et al., 2008), other 'windows' increasing the mesh size, often in the upper panel (Ingólfsson, 2011; Madsen et al., 2012), structures separating the trawl into horizontal layers using different species-specific escape behaviour within the trawl (Main and Sangster, 1981), and the use of a firm grid to physically sort out larger finfishes through an opening and let the smaller *Nephrops* be sieved in the cod-end (Catchpole et al., 2006b; Drewery et al., 2010; Valentinsson and Ulmestrand, 2008; Figure 7.6A and C). Due to the large amount of by-catch and discard of groundfish, especially cod, in the conventional *Nephrops* trawling (90-mm diamond mesh), the use of a species-selective grid, that is, trawls equipped with a Nordmøre-type firm sorting grid with a 35-mm bar distance and a 70-mm square mesh cod-end has become mandatory in Swedish national waters since 2004 (SwAM, 2004:36). The grid in the upper part of the trawl lets the fish escape through it, while the target species is retained on the bottom of the trawl.

The vulnerability of the *Nephrops* individuals to trawling is highly dependent on their emergence behaviour (Aguzzi and Sarda, 2008; Aguzzi et al., 2003, 2005). Their emergence behaviour from the burrow for feeding or mating is triggered at a specific light intensity, and impacted by depth, season and water parameters resulting in emergence patterns covering diurnal (deep-living stocks), nocturnal (shallow living) or crepuscular (medium depths), and is consistent with the idea that *Nephrops* is a visual feeder. Even within a specific region, the emergence pattern can vary following changes in light and oceanography, which has a profound impact on when the fishers trawl (see Chapter 3).

Figure 7.6 Different technical gear solutions to reduce discards (under-sized *Nephrops*) and by-catches (mainly gadoids) in *Nephrops* trawls. (A) A schematic trawl with the Nordmøre sorting grid device and escape window, (B) a schematic trawl with a square-mesh panel (SMP) in the cod-end and (C) photo of the Swedish species-selective trawl with the 35-mm Nordmøre sorting grid with 70-mm square mesh cod-end on a pier in Lysekil, Swedish West coast (photo by Therese Jansson). *Panels A and B from ICES (2004a), produced by FRS, Crown copyright.*

2.2. Creel types

Creel fisheries for *Nephrops* have now been established for three to four decades in regions such as Western Scotland and the Swedish Skagerrak with a few vessels also in the Kattegat. In the Faroe Islands, creeling for *Nephrops* is the only capture method as trawling is banned. A commercial and recreational creeling fishery occurs along the Norwegian coast, but the literature on these minor fisheries is scarce. Creeling also occurs in the north-eastern part of the Adriatic Sea and pilot creeling operations comparing trawl and creel-capture potentials have been performed for the Central Adriatic Sea (Morello et al., 2009) and the Portuguese coast (Leocádio et al., 2012). Creel trials have also been tested by fishers' organisations, for example, in Northern Ireland (ANIFPO, 2007). The typical creel design is either a one- or a two-chamber-type with a (1) half round transection (flat bottomed with a circular top, D-shaped, Figure 7.7A), which has advantages on board the vessel such as securing the creel pile while the fisher is standing on the deck between hauling and shooting, and staying put in strong currents as the drag is less, or is (2) square-shaped (box type, Figure 7.7B), increasing the inner volume. One or, most often,

Figure. 7.7 Photos of Norway lobster (*Nephrops norvegicus*) creel fishery in Skagerrak. (A) Top left, a single half round creel (D shaped), (B) top right square (box type) single creel, (C) below left, a double chamber square (parlour) creel and (D) below right, creel baited with salted herrings. Photo: Anette Ungfors.

two entrances with rings of 70–75 mm inner diameter lead towards the bait enclosed within the main chamber (Figure 7.7A and B). The size and air weight differs among the creels with weights ranging from 2.6 to 7.5 kg depending on the diameter of the steel frame (e.g. Carapax Ltd.). Scottish and Swedish creels have entrances on the longest sides, but creels in use in the Adriatic Sea (Croatian or Italian types) have entrances on the shorter side (Morello et al., 2009). Creels of the two-chambered type have an additional chamber at one end (or 'parlour', Figure 7.7C) where the *Nephrops* and by-catch such as crabs gather. A two-chambered creel increases the capture efficiency as seen, for example, for European lobster and brown crab (Lovewell et al., 1988), as the escape potential from the creel is reduced, which is of great value to the fishermen, especially when a longer soaking time, for example, owing to bad weather or weekends is needed. *In situ* filming of the American lobster (*Homarus americanus*) in and around a trap revealed that 94% escaped (Jury et al., 2001). Inter and intra-specific social interactions strongly affect captures. Effects of both sex and size have been demonstrated, that is, where the opposite sex is either attracted or reversed depending on the first individual entering the creel, and also that smaller sizes can be scared away when larger ones have already entered (Watson and Jury, 2013). By-catches of aggressive swimming crabs (*Liocarcinus* spp.), the spider crab (*Hyas araneus*) and the brown crab are often found in creels on the Swedish west coast (Jansson, 2008; Ungfors et al., in preparation), and can depress catches in specific areas or seasons so that fishers need to change area. Devices for decreasing the size of the entrance ring have been developed and are used seasonally.

Improvements for increasing the capture of *Nephrops* are ongoing as fishermen produce their own gears and gear manufacturers update their products. All are aiming to optimise the odour spread of the bait using thin mesh and minimal rope protection around the steel frames, while reducing the wear of the gear. Richardson (1996) found that blinding by high light intensities had no apparent effect on *Nephrops* responses to a baited creel and that catch rates were very low for blind and visually intact animals. Anecdotal knowledge of fishers indicates that the colour of the mesh may be of importance (Ungfors, A., unpublished data). The creel net is composed of a knotted polyamide diamond mesh. However, it is more likely that any colour effect is dependent on the contrast of the gear appearance, given the limited spectral sensitivity of *Nephrops* (see Chapter 4).

Creels are a passive gear in the sense that they are not mobile during the capture process. The creel, however, actively fishes by attracting *Nephrops* to potential food. Bait is sensed by the aesthetasc setae on the antennules, which are involved in chemo orientation (Hallberg and Skog, 2011), but other regions such as chemo-sensitive hairs on the pereopods as well as vision are involved (see Chapters 3 and 4). Bjordal (1986) filmed *Nephrops* creels in Norwegian fiords and found that only 6.1% (15 of 246) *Nephrops* entered the creel (Figure 7.8). The *Nephrops* approached the creel from downstream at angles up to 30° either side from the current. Of the *Nephrops* that approached the creel, 65% made physical contact. It appeared that it was hard for the *Nephrops* to find the entrance (they spent 1–40 min around the creel). Bjordal (1979) filmed various designs of creel and found that a trap with four entrances had better capture efficiency than one-entrance traps. Of 51 *Nephrops* that came into the creel vicinity, 6 entered, one of which escaped. Catching *Nephrops* by creels can be divided into different stages (Miller, 1990) where the attraction stage, which involves long-distance attraction by olfactory stimuli, and the gear stage, which operates in the proximity of the creel, are of importance. As larger male individuals spend a longer time out of their burrows (Briggs, 1988, 1995), they have a larger chance of encountering the odour plume of the bait and starting a search. Bjordal (1986) noted that smaller *Nephrops* were chased away from the creel by conspecifics or other species, or were frightened by the repellent gear, which resulted in a reduced time for finding the entrance. This may be why the creel is selective for larger individuals. A similar pattern of low

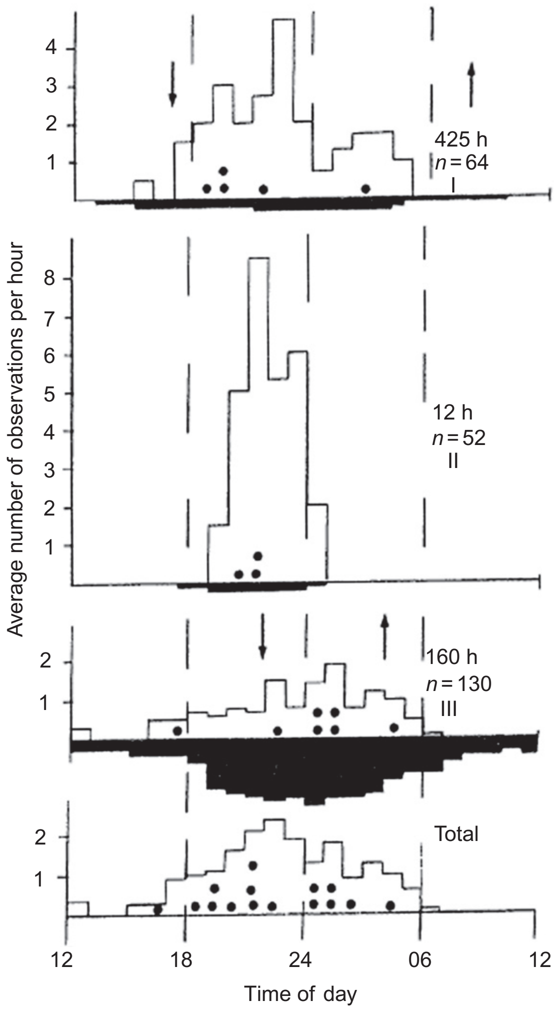


Figure 7.8 Summary of the behavioural responses to a baited creel. The capture efficiency for the creel is estimated based on UW-filming in Norway at three different locations (I Nyleia, II Nærøyfjorden, III Lysefjorden) and showed that 6.1% (15 of 246 approaches, summary below panel) entered the creel (Bjordal, 1986). Filled circles are catches of *Nephrops*, arrows indicate sunset and sunrise, and black field under the x-axis are the number of hours of observation (1–17 hrs).

capture efficiency (5%) was found for 300 h of filming around a creel in Western Scotland (Adey, 2007).

The CPUE (number or weight per trap) of crustacean increases with soak time, that is, the days the creels have been fishing at sea (Bennett and Brown, 1979; Miller, 1990).

In 2005–2006, an observer survey in the Swedish creel fishery (Jansson, 2008; more than 12,000 creels recorded for 26 vessels) found that on average 75% of the capture by weight consisted of the targeted *Nephrops*, 15% of under-sized *Nephrops* (under 40-mm CL) and 10% of fish such as cod and poor cod (*Trisopterus minutus*). This proportion is almost the opposite of the trawl fishery where the target *Nephrops* make up 30% in trawls using the Swedish 35-mm grid (and 70-mm square mesh) or only 15% in trawls without a grid (conventional 90-mm diamond mesh; Valentinsson and Ulmestrand, 2008; Ziegler, 2006). The creels capture larger individuals; the size at first catch is around 27 mm for the creels compared to at least 1 cm smaller CL for trawls. However, the Jansson (2008) creel study found the sex ratio to be equal to the trawl, 65 M:35 F.

Today, oily fishes such as herring or mackerel are mostly used as bait. In Sweden, the herring is salted before use (25 kg salt to 125 kg herring), either fresh or frozen, to allow for longer and easier use. In the Mediterranean, salted pilchard is used as bait (Morello et al., 2009). Smaller herring (50–100 g) are used whole, but larger ones are divided (Figure 7.7D). The herring bait is renewed at every hauling occasion, meaning every day or every second day, or occasionally at longer durations. Devices such as bait bags (Archdale and Kawamura, 2011) increase the length of time that the bait is attractive. This might be caused by the fact that the captured animal is unable to physically tear the bait apart and eat it, or that it reduces access for scavenging amphipods and isopods. In areas with a very high scavenger activity, such as the Adriatic Sea, up to 40% of bait can be consumed within 12 h and over 80% within 24 h (Morello et al., 2009). Bjordal (1979) evaluated different baits and found no statistical difference between the attractiveness of herring and mackerel, squid and trout pellet, or mackerel and trout pellet to *Nephrops*.

There have been several surveys and experiments examining which constituents of bait are the most attractive to crustaceans (Carr and Derby, 1986; Derby and Sorensen, 2008; Mackie, 1973). Some of the known and described feeding attractants in crustaceans are amines and certain amino acids (Levandowsky and Hodgson, 1965; Zimmer-Faust et al., 1984), with glycine and trimethylamine oxide being the most potent ones. Glycine is a free amino acid commonly found in invertebrate tissues and excretory products. Trimethylamine oxide is commonly found in plant and animal tissues. Other amino acids such as betaine have also been described to be an effective feeding stimulant (Hayden et al., 2007), and in some commercially available feeding attractants, a mix of up to nine different amino acids is used (Nunes et al., 2006). Other possible chemical attractants that could be used in bait would be sex pheromones, especially those that attract mating partners (Hardege et al., 2011), but besides the fact that they have not been tested for these purposes in the field yet, they would be seasonally restricted.

Presently, bait is one of the problems the creelers have to overcome, as the cost to buy it is around 5–10% of the value from the *Nephrops* first-hand sale. Around 1.1 kg of salted herring is used per kilogram of *Nephrops* landed (Ziegler, 2006). The herring is often caught by the fishermen themselves or bought from pelagic trawlers, and the baiting of creels with salted herring was estimated to be responsible for 10% of the total fuel use in the creel fishery (Ziegler, 2006). Artificial bait in pelleted, dried, or gelatinized form has been tried for other crustacean species such as brown crab (Dale et al., 2007), European lobster (Mackie et al., 1980), spiny lobster (*Panulirus interruptus*; Chanes-Miranda and Viana, 2000), and sand crab (*Ovalipes punctatus*; Archdale and Kawamura, 2011) to mention a few, and the preliminary results for *Nephrops* are promising (Ungfors et al., in preparation). Hancock (1974) reviewed the potential of using by-catch repellent bait ingredients to increase target captures. Baiting has also been suggested as potentially adding to the production of crustacean species, for example, to the American lobster in Maine (Grabowski et al., 2010; Saila et al., 2002) and the western rock lobster (*Panulirus cygnus*) in Western Australia (Waddington and Meeuwig, 2009). Bait has been calculated to contribute up to 13% of lobster food requirements over the whole ecosystem. This factor could contribute to the superior condition of *Nephrops* on creel bottoms compared to trawled ones as demonstrated (Eriksson, 2006).

Creel fishing has been shown to have no, or very little, disturbance effect on benthic fauna (Bergmann et al., 2002; Eno, et al., 2001). The survival of crustacean discard is also thought to be high (Bergmann and Moore, 2001), one reason why creeling has a light ecological footprint. Investigations into the stress of *Nephrops* experiencing reduced surface salinity during the trawling lift (or creeling) in the Kattegat have been carried out using exposure to 15 PSU water for 6 min and air exposure in different temperatures (5 or 15 °C; Harris and Ulmestrand, 2004), this resulting in increased mortality ranging between 25% and 42% compared to 0–8% for the control animals (full salinity treatment with or without air exposure). One negative aspect of creeling is the potential for ghost fishing. However, it has been found that the fishing potential for *Nephrops* creels was low after the bait had been consumed (Adey, et al., 2008). In addition, fishers state that it is seldom that they lose creels, and if they do, they can generally find them again.

The small size of *Nephrops* in the area and the intense activity of scavengers feeding on bait in the Central Adriatic Sea resulting in low capture rates has prevented the establishment of a creel fishery in this area (Morello et al., 2009; Panfili et al., 2007). In addition to this, the long distance to the fishing ground is not ideal for smaller creeling vessels (Morello et al., 2009).

3. FISHERY MANAGEMENT

There are several authorities in the North Atlantic that have jurisdiction over *Nephrops* fisheries. Norway, Iceland, and the Faroe Islands manage their fisheries independently, while the European Union manages *Nephrops* fisheries collectively under the TAC scheme within the Common Fisheries Policy (CFP). Input (i.e. effort control, closed seasons, minimum mesh size) and output measures (i.e. TAC quota, MLS, catch composition) are all used for Nephrops fishery management in a variety of combinations. It should be noted that the wording of 'total allowable catch' is generally misleading, as it is the landings that are the governing metric rather than the catch (which often contains individuals that cannot be landed due to size and/or sex limitations).

At its most basic, the purpose of fishery management should be to ensure that fishing activity does not induce permanent negative change to the stocks being targeted (or the habitat upon which they depend). The vast majority of commercially exploited stocks have at least one dispersive phase and, therefore, separation into distinct and meaningful stock units is often a subjective exercise. In the case of *Nephrops*, the post-settled individuals display a limited capacity for migration (Chapman and Rice, 1971) and the substrate requirements mean that there are fairly well-defined boundaries for the fishing grounds. Larval drift through successive generations may ensure that the genetic structure across a number of habitat patches is relatively uniform. Stock units can, therefore, be considered to be geographically large and it is likely that periodic local depletions are not necessarily disastrous. The timescale for fishery management, including the economic and social viability of fisheries, is typically 1–5 years and is decreasing with the increasing use of technology and co-management. Therefore for management purposes, the spatial scale of 'stock' identity should be reduced to match (Kraak et al., 2012).

For the purposes of fishery management and reporting, the Northern Atlantic is divided into a number of geographic zones. The International Council for the Exploration of the Seas (ICES, the umbrella scientific organisation on the eastern side of the North Atlantic) divides the sea into a grid of rectangles with dimensions of 1° longitude and half a degree latitude.

These rectangles are then grouped into nested classes of sub-divisions and divisions for the purposes of stock assessment and management.[2]

1. Iceland: Iceland sits within ICES sub-division Va and has independent control of waters out to 200 nautical miles. All *Nephrops* stocks in this sub-division are found within these territorial waters. The Icelandic management system is unique in Northern European waters in that there is a total ban on the landing of females. In addition to this, there is a quota system in force, which integrates the 10 identified grounds. TAC quotas are determined annually by the Icelandic Fisheries Ministry and they generally (but not always) are in line with the TAC recommended by the Marine Institute. Reported landings typically exceed the TAC.
2. Norway: There is relatively little restriction placed upon Norwegian fishers fishing in Norwegian waters for *Nephrops*, an MLS being the only quoted management measure (ICES, 2012a).
3. European Union: At the time of writing, *Nephrops* are the only crustacean fisheries to fall within the TAC regime of the European CFP. Seven management areas under EU jurisdiction are in force, with an additional allowance for landings by EU vessels operating in the Norwegian sector:
   a. EC waters of IIa and IV (essentially the EU zone of the North Sea),
   b. IIIa; EC waters of IIIb (EU zone of the Skagerrak and Kattegat),
   c. VI; EC waters of Vb (effectively the West coast of Scotland),
   d. VII (Irish Sea, Celtic Sea, and West coast of Ireland),
   e. VIIIabde (Bay of Biscay),
   f. VIIIc (Northern Spain),
   g. IX, X, CECAF 34.1.1(1) (essentially the Iberian Peninsula).

For each of the management areas, a landings quota would be agreed upon between the Member States, which would then be divided among the countries according to a fixed allocation key. The allocation keys, referred to as Relative Stability and enshrined within the Treaties establishing the European Union, were determined on the basis of the historical (1994–1996) track record of landings per species, country, and management area and were introduced in 1999. The use of a fixed key for national allocations has both benefits and drawbacks. It would be unfeasible, and arguably impossible, to re-negotiate national allocations for each species under

[2] The counterpart to ICES covering the North-West Atlantic is NAFO, but there are no stocks reported in these waters.

the TAC scheme on an annual basis and it provides a degree of stability in the fleet composition (by restricting the ability of new countries to enter a fishery). National fleet composition and their markets are not static and as a consequence of the TAC setting decisions, there would follow a series of negotiations at the national level to trade their quota allocations for other species or even different commodities.

Given the limited dispersal abilities of *Nephrops*, the ICES sub-division scale or quota setting often encompasses multiple *Nephrops* stock units. Fisheries scientists therefore undertake stock assessment at a finer scale and need to balance the geographical ranges of the non-migratory, post-settled population with the potential for larval distribution and the scale at which reliable data are available. The finest geographic scale at which fisheries statistics (i.e. landings and effort) are routinely recorded in European waters is, therefore, the ICES rectangle for assessment purposes, *Nephrops* stocks are defined as a collection of rectangles and known as FUs. As of 2012, there were 34 FUs defined in the North-East Atlantic, with a further 8 in the Mediterranean. Of the 34 North Atlantic FUs, 29 lie within EU waters (see Table 7.1). The units are distributed as follows: 11 FUs within the North Sea, 3 FUs on the Scottish West coast, 3 in the Celtic Sea, 4 west of Ireland, 2 in the Irish Sea, 1 FU each in Iceland and Faroe Island, 4 in the Bay of Biscay and 5 at the Iberian Peninsula (Table 7.3).

Table 7.3 Functional units and stock status for Norway lobster (*Nephrops norvegicus*)

Functional units (FUs) or groupings		**Stock status based on ICES assessment**
1	Iceland	
2	Faroe Islands	
3	Skagerrak	Units now are considered to be one stock. F decreasing and below F_{MSY}. Bmsy undefined, but all indices suggest the stock is exploited sustainably
4	Kattegat	
5	Botney Gut	No reference points defined. Data-limited approach has been applied, indicating that stock is exploited at a sustainable level
6	Farn Deeps	F above F_{MSY} and B below B_{trig}
7	Fladen Ground	F below F_{MSY} and B above B_{trig} for time series. Abundance does appear to be declining

Table 7.3 Functional units and stock status for Norway lobster (*Nephrops norvegicus*)—cont'd

Functional units (FUs) or groupings		**Stock status based on ICES assessment**
8	Firth of Forth	F above F_{MSY} and has fluctuated just above the level for a period of time. B above B_{trig} for the time series
9	Moray Firth	F above F_{MSY} for 2011 after a period at or below. B above trigger throughout time series. Stock slightly declining
10	Noup	No reference points defined. Data-limited approach has been applied, indicating that stock has been exploited slightly above the recommended level
32	Norwegian Deep	Reference points are not defined for this stock. Data-limited approach has been applied. F appears to be below possible reference points and B is stable. Landings appear to be at a sustainable level
33	Off Horns Reef	Reference points not defined. Data-limited approach has been applied indicating that landings are at or around desirable levels. B appears to be increasing although F is unknown
34	Devil's Hole	Reference points not defined. Data-limited approach has been applied, indicating that landings may be slightly above desirable levels. F is unknown, and B appears to be declining
11	North Minch	Fishery exploited sustainably. B above trigger for time series and F below target
12	South Minch	Fishery exploited sustainably. B above trigger for the time series and F below target
13	Firth of Clyde and Sound of Jura	F above sustainable yields but B well above trigger for the time series. Sound of Jura—F below F_{MSY} and B undefined due to short, patchy time series
14	Irish Sea East	F below F_{MSY}. B_{trig} undefined due to short time series. Stock is being exploited sustainably
15	Irish Sea West	F above $F_{MSY,}$ although it has fluctuated around it for the time series. B above trigger throughout time series

Continued

Table 7.3 Functional units and stock status for Norway lobster (*Nephrops norvegicus*)—cont'd

Functional units (FUs) or groupings		Stock status based on ICES assessment
16	Porcupine Bank	Advice revised in a year to account for first UWTV survey. F is thought to be below possible reference points, and B is increasing and is above the average of the time series
17	Aran Grounds	F below F_{MSY}. B_{trig} undefined, and B lowest in time series
19	Ireland SW and SE coast	F below F_{MSY}. B_{trig} undefined with no trend in B due to short time series
20+21	Celtic Sea—Labadie	Reference points not defined. Data-limited approach has been applied indicating that landings have been within sustainable levels in recent years. Trend indicates F is decreasing. Biomass is unknown, but LPUE has decreased in the last 2 years, suggesting declining abundance
22	Celtic Sea—The Smalls	F is below F_{MSY} after a period above. B_{trig} is not defined, but the trend indicates increasing B after a period of stability
23+24	Bay of Biscay	Data-limited approach has been applied. Qualitative evaluation suggests that F is above possible reference points with B increasing. Catch possibly slightly above sustainable levels (although precautionary)
25	North Galicia	No assessment for 2012. Qualitative evaluation suggests declining B with F unknown. Zero catch recommended. Recovery plan in place but not assessed by ICES
31	Cantabrian Sea	No assessment for 2012. Qualitative evaluation suggests declining B with F unknown. Zero catch recommended. Recovery plan in place but not assessed by ICES
26+27	West Galicia and North Portugal	No assessment for 2012. Qualitative evaluation suggests declining B with F unknown. Zero catch recommended. Recovery plan in place but not assessed by ICES

Table 7.3 Functional units and stock status for Norway lobster (*Nephrops norvegicus*)—cont'd

Functional units (FUs) or groupings		Stock status based on ICES assessment
28 + 29	South-west and South Portugal	Data-limited approach has been applied indicating that catch is at or about sustainable levels. Both F and B appear to be declining. Recovery plan in place but not assessed by ICES
30	Gulf of Cadiz	No assessment for 2012 although the data-limited approach has been applied and suggests that catch may be slightly above sustainable levels. Qualitative evaluation suggests declining B with F unknown. Recovery plan in place but not assessed by ICES

Data from ICES (2012b).

3.1. Management and policy making in the European Union

The ICES provides independent scientific advice to clients including the European Commission through the co-ordination of information from scientists from the 20 constituent nations. A schematic graph of the authorities and associated groups for *Nephrops* management within the EU is depicted in Figure 7.9. Members include those not within the European Union (e.g. Norway, Iceland, Faroes). The stock assessment advice for the major stocks of *Nephrops* is provided either on an annual or on a biannual basis with the most recent update provided in June 2012 (ICES, 2012b). The advice is timed to feed into the annual TAC and quota negotiations, with initial release in June and any required revisions between September and the beginning of December. In addition to this annual cycle, symposia and other workshops are organised throughout the calendar year.

Scientific advice submitted to the European Commission is subsequently reviewed by an internal group, the Scientific, Technical and Economic Committee for Fisheries (STECF). This body was established in 2002 (Council Regulation EC 2371/2002[3]), with an updated process in 2005 (Commission Decision 2005/629/EC[4]), and comprises 30–35 members who are experts in fisheries and marine biology from the member states. The annual

[3] Council Regulation (EC) No. 2371/2002 of 20 December 2002 on the conservation and sustainable exploitation of fisheries resources under the Common Fisheries Policy. Official Journal of the European Communities, L358/59.

[4] Commission Decision of 26 August 2005 establishing a Scientific Technical and Economic Committee for Fisheries (2005/629/EC). Official Journal of the European Union, L225/18.

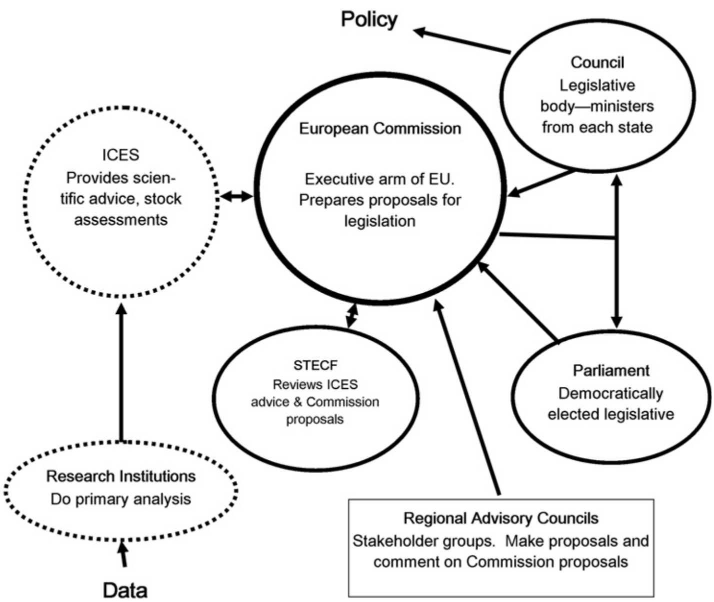


Figure 7.9 Flow chart depicting the process involved in developing fisheries legislation within the European Union.

report of STECF (e.g. STECF, 2012) containing recommendations for fishery management is passed on to the European Commission, which then generates proposals for the different geographic EU EEZ areas. Expert Working Groups with at least two of the STECF members can focus on different topics to prepare the recommendations. Both ICES and STECF comment on legislative proposals throughout the year, including long-term management plans (LTMPs).

The European Commission then takes the advice from ICES and STECF and makes proposals. The Commission is the executive arm of the European Union and has the sole responsibility of making proposals for legislation, a duty known as 'right of initiative'. The route that the legislation then takes is dependent on whether it is subject to a process known as co-decision or not. In the annual TAC and quota negotiations, normally held at the end of the calendar year and setting fishing opportunities for the following year, it is the Council of the European Union (formerly known as the Council of Ministers) that adopts the legislation. Other fisheries legislation, generally legislating for more than 1 year, must go through the process of co-decision where the European Parliament shares legislative power equally with the Council. If the two institutions cannot agree, the issue is passed on to a conciliation committee, comprising an equal number of members from both, to seek agreement. The process of co-decision, although more democratic, is somewhat unwieldy due to the number of people involved and the political nature of the Parliament. To date, the amount of time taken for legislation to pass through the process has been excessive, leading to some frustration among the stakeholders, particularly in relation to long-term management plans (LTMPs). That said, the opportunity for lobbying Members of the European Parliament has not been missed by some elements and some sectorally unpopular proposals have been withdrawn due to this.

The phraseology of ICES advice has evolved considerably in the last decade and there has not been consistent advice for a maximum biomass of landings. Phrases such as 'no increase in effort', 'reduce catches' and 'no increase in catches' have been used for FUs without a TV survey and it was left to the European Commission to convert this qualitative advice into the quantitative tonnages that the TAC system required. Even without these complications, the quota negotiations at the ministerial level means that changes in ICES advice do not necessarily translate into changes in TAC.

3.1.1 Regional Advisory Councils

Regional Advisory Councils (RACs) were established through a Council Decision as part of the CFP reforms in 2004 (European Union, 2004) and are, in the most part, geographically based. The RACs were intended to enable stakeholders to become more closely involved in the decision-making processes relating to fisheries by making recommendations and suggestions to the Commission and to national authorities. The RACs tend to form the main channel of consultation with stakeholders and are expected to have an expanded role under the 2013 CFP reform. The two RACs with the most significant interest in *Nephrops* are the North Sea RAC and the North-western Waters RAC.

3.1.2 North Sea Regional Advisory Council

The work of the North Sea Regional Advisory Council (NSRAC) is delivered by three working groups namely Demersal, Skagerrak and Kattegat, and Spatial Planning. These groups meet to discuss current and emerging topics and to develop advice and policy on behalf of the NSRAC membership. The working groups meet three–four times a year and enable a wide range of people to become involved in the NSRAC activities, including scientists, fishers, environmental specialists, economists and others. Each working group may be supported by a number of Focus Groups. Focus Groups are smaller groups, which are set up to address a specific topic. Focus Groups are flexible in their approach, drawing in representatives and experts from a number of sources. The *Nephrops* Focus Group (NFG) supports the Demersal Working Group and is developing an LTMP for the species.

3.1.3 Northwestern Waters Regional Advisory Council

The Northwestern Waters Regional Advisory Council (NWWRAC) also delivers policy advice through a number of working groups but on a subregional rather than thematic basis, namely, West of Scotland, West of Ireland and the Celtic Sea, the English Channel and the Irish Sea (NWWRAC, 2013). The working groups meet four times a year and are complemented by a Horizontal Working Group, covering issues of a more general nature, and subject-specific Focus Groups. The RAC does not currently have a specific NFG, but advice on the species is an active topic for informal groupings within the RAC and within the working groups.

3.1.4 The LTMP and the rebuilding plans

Although still under development, the NSRAC NFG has been working on the construction of an LTMP for the species since 2009. The group, comprising industry representatives from a number of North Sea nations and supported by CEFAS and Marine Scotland, agreed that the plan needed to be more than a harvest control rule and that it should take into account the differences in the national and sub-national fleets and the characteristics of their fishing grounds. The ability to protect discrete FUs on an individual basis is at the heart of the plan, but FU TACs or effort management are not considered to be the only means of delivery. In order to deliver management measures appropriate for the individual FUs, the plan consists of overarching objectives complemented by area-specific rebuilding of fishing plans that are designed to be implemented when required but can be revoked when any threat to the FU is deemed to have diminished sufficiently. The implementation of measures in each plan would be initiated at the point when the biomass or fishing mortality breaches a trigger that buffers the relevant reference points and promotes a flexible and proactive form of fisheries management.

The measures included in the plan were initially identified through the Focus Group but have since undergone significant stakeholder consultation to assess their acceptability, in terms of both efficiency and acceptability to the fleet. The latter point is important as fisher buy-in or, to a certain extent, ownership of measures increases the likelihood of compliance (Eggert and Ellegard, 2003; Gutiérrez et al., 2011), enhancing their efficacy and reducing the cost of enforcement. The first round of consultation was undertaken in the summer of 2010 and was general in its approach, taking account of a number of events throughout the North Sea coast of Scotland and North-East England. The results from the events were varied, depending on the fishing area and, more importantly, the characteristics of the consultees. As is usually the case (Johnson and Prime, 2009), the preferences of the more artisanal fishers varied significantly from those of the more nomadic or larger vessels. The second round, initiated in summer 2012 (Bailey et al., 2012), is in progress and has been more focussed on the specific management measures applicable to each area. These include, although are not limited to, gear restrictions, horsepower restrictions and the use of 'of which no more than' quotas.

3.2. Regulation of the *Nephrops* fishery in the European Union

The institutions and basic processes of the high-level policy making for the management of *Nephrops* in the European Union have been described in a previous section (3.1). Of the regulations that come from the process, there are a variety that are applied to *Nephrops* fisheries, some of which are specifically designed to manage the *Nephrops* fisheries and others that manage the stocks associated with them. Other regulations aim to set general rules for fisheries of specific types, often described by mesh size. These regulations are transposed into Member State legislation and are often complemented by bespoke domestic legislation, some examples of which are described here.

The basic conditions of any fishery within European waters are described within Council Regulation, 850/98 and its subsequent amendments.[5] Council Regulation, 850/98 describes fisheries by area of capture, target species and mesh size and defines the minimum quantity of the target species that should be retained by a vessel. Further, the regulation determines the species and the quantities of the species that can be landed alongside the target. These principles are intended to prevent larger fish species being targeted by smaller mesh fisheries and to ensure the protection of juveniles. This regulation should have been repealed and replaced during 2012, but the

[5] Council Regulation (EC) No. 850/98 for the conservation of fishery resources through technical measures for the protection of juveniles of marine organisms (europa.eu, ID number LEX-FAOC018268).

co-decision process has delayed agreement with the new regulation. The regulations also define specific characteristics of the fishing gear, such as twine thickness and positioning of SMPs, technical specifications that affect the selectivity of the gear in terms of both *Nephrops* and by-catch species. In many cases, Member States enhance these regulations with complementary use of domestic legislation, such as Statutory Instruments (UK and IRE). One example of such use is in Scotland where instruments, applicable to all UK vessels in Scottish waters and all Scottish vessels in UK waters, are used to legislate for a variety of measures including provisions increasing the selectivity of the gear (SSI 165/2009[6]) and legislating against multi-rigged gear (SSI 13/2007[7]).

Management and recovery plans also have the potential to affect the *Nephrops* fishery. Currently, there are no management plans applicable to the species, although the draft LTMP for North Sea *Nephrops* is discussed earlier in this chapter. There are, however, two recovery plans that impinge on the regulation of *Nephrops* fisheries. Council Regulation 2166/2005 amends 850/98 to legislate for the recovery of *Nephrops* in the Cantabrian Sea and the Western Iberian Peninsula.[8] The plan assumes a direct relationship between fishing effort and the level at which the TAC is set and aims to return the stocks to safe biological limits within 10 years by reducing the fishing mortality by 10% year on year. Effort restrictions, *per se*, are not in place but are effected by appropriate reductions in the available TAC. ICES have not evaluated the plan. The Cod Recovery Plan (Council Regulation 1342/2008, 2008[9]) applies to fisheries in European Union waters of ICES sub-divisions III, IV, VI and VIIa. The plan does not relate directly to *Nephrops* but is applied to fisheries that encounter cod as a by-catch and includes many of the *Nephrops* fisheries on that basis. The plan assumes a 1:1 relationship between fishing effort and cod mortality and, as a result, restricts the fishing effort available to sections of the fleet in a move to increase the biomass of cod to above B_{trig}. The regulation, replacing Council

[6] SSI 2009 No. 165, The Sea Fish (Specified Sea Areas; Regulation of Nets and Other Fishing Gear; Scotland) Amendment Order 2009. www.scotland.gov.uk

[7] SSI 2007 No. 13, The Prohibition of Fishing with Multiple Trawls (No. 2; Scotland) Amendment Order 2007. www.scotland.gov.uk

[8] Council Regulation (EC) No. 2166/2005 establishing measures for the recovery of the Southern hake and Norway lobster stocks in the Cantabrian Sea and Western Iberian Peninsula and amending Regulation (EC) No. 850/98 for the conservation of fishery resources through technical measures for the protection of juveniles of marine organisms. (europa.eu, ID Number LEX-FAOC061052)

[9] Council Regulation (EC) No. 1342/2008 establishing a long-term plan for cod stocks and the fisheries exploiting those stocks and repealing Regulation (EC) No. 423/2004. (europa.eu, ID number LEX-FAOC084627)

Regulation 423/2004,[10] made it possible for the Member States to manage the effort allocated to its fleets (as opposed to management at EU level), and it is this ability that has influenced the *Nephrops* fleets in III, IV, VI and VIIa, and their legislators more than anything else in recent history. The Swedish fleet in the Skagerrak and Kattegat are awarded for using a species-selective trawl equipped with a 35-mm grid in combination with a square mesh cod-end. These incentives, and also the potential trawl area, were reduced for Swedish fishers not using the improved trawl. In Sweden, around 100 over 10-m vessels have permits for trawling. There are 94 permits for trawling with the grid and 100 for trawling without it. Under 10-m vessels are currently exempt from CRP effort restrictions. In 2010, incentives became similar for the Danish fishers to use an SMP device in the cod-end (SELTRA 300; Madsen et al., 2012). Since 2007, Danish fishers have had a vessel quota system where each fisher is allocated an annual share of the Danish quota (ICES, 2012b; IIIa). The Scottish Conservation Credits Scheme requires additional selectivity measures in return for additional days at sea (Marine Scotland, 2012). The Scottish fleet in 2012 was required to operate highly selective gear for the entire year in return for a maximum of 200 days at sea. Many other Member States are operating similar schemes.

The selectivity measures outlined in the previous paragraph are mainly in response to the CRP, but, as a general rule, there is a move to discard reduction of other species as well and all commercial fisheries within the EU will be subject to a discard ban by 2019. This means that fisheries using relatively small mesh to catch a target species will have to make changes in their gears to significantly reduce the incidental by-catch of species that fishers cannot legally land or for which they cannot source quota.

As mentioned previously, *Nephrops* is currently the only crustacean subject to the TAC regime. The overall TAC is agreed on an annual basis, generally at the December Council of Ministers, and is not subject to co-decision. The TAC for each area is then distributed to Member States on the basis of Relative Stability. Member States have a variety of quota management mechanisms. Some, such as Denmark and the United Kingdom, use versions of individual quotas and allocate the quota to individual vessels through Producer Organisations. Others, such as the Republic of Ireland, use a pool system with monthly allocations that are the same for each vessel within a certain group.

[10] Council Regulation (EC) No. 423/2004 establishing measures for the recovery of cod stocks. (europa.eu, ID Number LEX-FAOC041519)

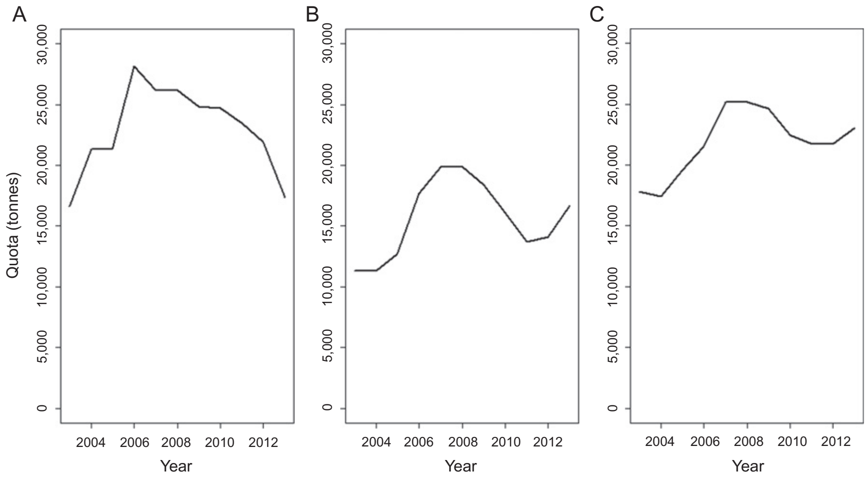


Figure 7.10 Overall TAC for Norway lobster *Nephrops* in ICES subdivision (A) IV, (B) VI and (C) VII.

The TAC for *Nephrops* can be variable and, as noted previously, is managed at an ICES sub-area level. This means that a significant shift in the abundance of one of the larger FUs can have a significant impact on the overall quota and, therefore, the management of the quota. Figure 7.10 shows the changes in TAC in Area IV for the years 1983–2013. As the figure shows, the Area IV TAC (encompassing all FUs) has declined in recent years, broadly following the declines in abundance, as measured by the UWTV surveys, that have been observed in FUs 7, 8 and 9 over the preceding four years. The largest FU within the North Sea is the Fladen area (FU 7), and the ICES advice for this unit drives much of the overall TAC set for the North Sea by the European Union. ICES advice for 2013, published in 2012, stated that catches from FU 7 should be no more than 10,000 tonnes, a reduction of 4100 tonnes from the 2012 advice, considerably impacting the fishing opportunities available to the North Sea fishermen. The overall TAC changes for the 10 year period are also illustrated for Areas VI and VII (Figure 7.10).

The issue of FU management of *Nephrops* has been touched upon in several parts of this chapter. The developments within this area will undoubtedly significantly influence the *Nephrops* fisheries in the EU as a whole. The only real example of individual FU management is in FU 16, the Porcupine Bank in Area VII. FU 16 is subject to additional regulation in the form of the use of a separate 'of which no more than' quota and a seasonal closure.

In 2010, the area was considered to be in decline and an annual closed area was introduced from 1 May to 31 July at the request of industry through NWWRAC. In 2011, a separate quota, an 'of which no more than' quota, was introduced to further protect the area. The individual TAC was unpopular but, combined with the closure, was deemed to have the potential to demonstrate a real move towards the proactive management of individual fisheries, provided it had the same principles as those underlying the work of the NSRAC LTMP, including flexibility. This type of regulation needs to be flexible and to be revoked when the stock no longer needs the level of protection. NWWRAC (2012) proposed a rule to enhance the efficacy of the closed area, associated with the available recruitment and abundance indices, to be applied to determine the length of the closure. As recruitment and abundance are fairly good, the closure was reduced to 1 month's duration for 2013. The RAC proposed a similar rule for the use of the 'of which no more than quota' which, although not adopted at the 2012 December Council of Ministers, is hoped to be implemented in the near future.

3.3. Mixed fishery issues

There are limits to the extent to which demersal trawl gear can be made to target specific species, and *Nephrops* trawls are no exception. A wide range of finfish species co-occur on the muddy substrates inhabited by *Nephrops*, and a wide range of commercially important species are observed in the catches including whiting, dab (*Limanda limanda*), haddock, plaice, cod, hake and other crustacean species. Discards of blue whiting and horse mackerel can be significant in the Bay of Biscay (ICES, 2012b). In South Portugal, the crustacean fleet also generates high discard rates, which can reach over 70% per weight (Monteiro et al., 2001). Most of the discarded species have little or no commercial value (e.g. the blue whiting and boarfish *Capros aper*). In addition to the commercially landed species, there are a large number of other species that have appeared in trawls targeting *Nephrops*: the English observer scheme has recorded 119 different species in *Nephrops* fisheries across the North and Irish Seas. Species subject to quota management will only be landed where the vessel has available quota, and where the sizes are above the MLS regulations. Non-quota species will only be landed where there is a sufficient market.

The mixed nature of these fisheries has been a mixed blessing, with some fishers regarding a whitefish by-catch as an economically vital part of their operations. In some sectors, however, this was offset by the imposition of by-catch limits and restrictions to the number of days at sea, as noted in previous sections. One of the major influences on the activities of the trawl-based *Nephrops* fleets in the North and Irish Seas in the last decade has been the state of the cod fisheries in those regions. The problem was compounded by the effort regulations for different mesh size categories. *Nephrops* trawl fisheries predominantly use mesh sizes between 80 and 90 mm; however, this size mesh will also retain finfish down to quite small (and therefore young) sizes. There was a period between 2002 and 2004 during which effort was transferring out of the larger meshed (over 120 mm) trawl fisheries into the 80–99 mm categories as the 'days at sea' effort restriction was less prescriptive for this sector. As a measure for protecting the cod stock, this was obviously counter-productive, due to the higher catch rates of under-sized individuals by this smaller mesh size and the effort transfer was halted. In 2010, ICES started producing mixed fishery forecasts, in which the catch composition of the various fleet components were analysed and future catches predicted based upon historical catch patterns and the various management objectives for the species complexes. For example, if the availability of cod quota was the most limiting factor and fisheries were required to stop all activities once the quota was exhausted, then the fleets catching the most cod would be required to cease activity ahead of the fleet sectors with little or no cod catch. Alternatively, if fishing activity was to continue until all quotas were exhausted, then the model could look at the potential for changes to discarding practice resulting from management restrictions on landings (ICES, 2012b; WGMIXFISH).

3.4. Minimum landing size

The MLS for *Nephrops* is, in general, 25-mm CL; or 85-mm total length, (TL), except for the sub-division VIa (FUs 11–13), VIIa (FUs 14–15), VIII (Bay of Biscay) and IX (Iberian Peninsula), which has an MLS of 20-mm CL (70-mm TL). Also, the MLS is different for Skagerrak and Kattegat, it being 40-mm CL (130-mm TL; Council regulation (EC), 850/98; Table 7.1, Figures 7.2 and 7.11). Variations in SOM between FUs may have important implications for fisheries management, particularly if mesh sizes are set to avoid the capture of immature individuals. There are different methods and techniques for investigating the maturity in female and male *Nephrops*. The histological approach in female *Nephrops* uses the presence/absence of spermatophores to confirm that individuals have mated, or the maturity stage of the ovaries (where stage 3 and above are considered as mature),

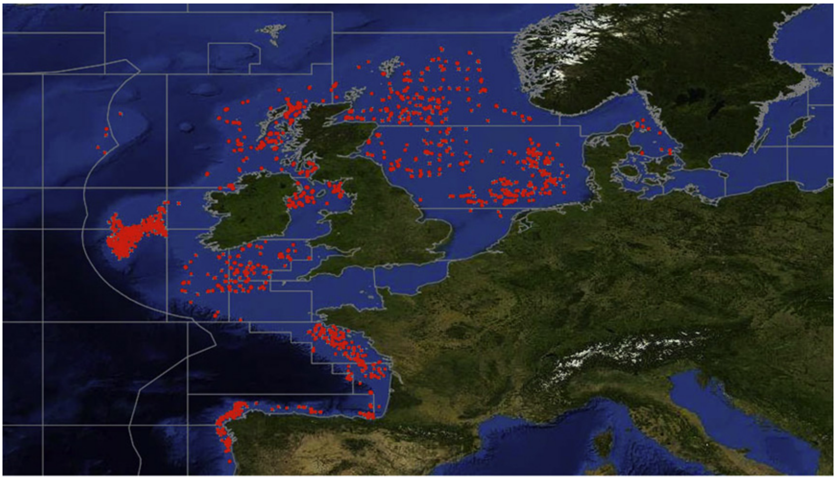


Figure 7.11 Minimum landing sizes (MLS) for Norway lobster (*Nephrops norvegicus*) can be checked with a specific gauge. The MLS for the regions are 25-mm CL (or over 85-mm total length) in the North Sea (IV, FUs 5–10), around Ireland (FUs 16–22) and the Norwegian Deep (FU 32), and 20-mm CL (or over 70-mm total length) on the West coast (VIa, FUs 11–13), the Irish Sea (VIIa, FUs 14–15) and the Bay of Biscay (VIII), and the Iberian Peninsula (IX); for Sweden, and Skagerrak and Kattegat (FUs 3 and 4), it is 40-mm CL (>13 cm total length). Photo of a Carapax gauge: Anette Ungfors.

which is an indication of the physiological maturation. Maturity diagnostics for male *Nephrops* investigate the presence/absence of spermatophores in the vas deferentia, showing the grade of physiological maturation. The morphological approach determines maturity in female *Nephrops* using the abdomen width as an indicator of maturity, while in male *Nephrops*, the appendix masculina or the claw propodus length are used (McQuaid et al., 2006).

The results of the ICES (2006) SOM analyses showed differences in the female size at maturity for different stocks, although there also appeared to be some variability within stocks, especially between years (Figure 7.12, Table 7.4). SOM values are often given as different proportions of the stock being mature based on different characters (see later), and often the length is given where 50% of the individuals (L_{50}) have reached a mature stage. In particular, the southern Iberian stocks show a much higher size at maturity (L_{50} 28–38 mm CL), re-emphasising the idea that the biological characteristics of these deep-water stocks more closely resemble those of the Mediterranean stocks rather than those of the other North Atlantic stocks. L_{50} for the North Sea, western waters and the Bay of Biscay (FUs 5–24) are of a similar size with no specific geographical pattern (L_{50} 21.7–25.5 mm CL),

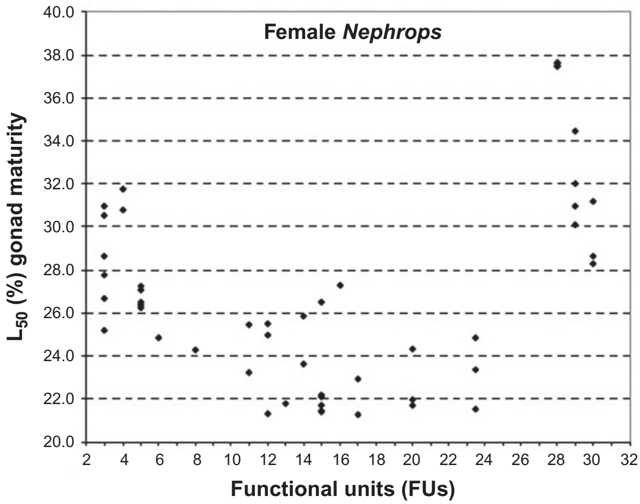


Figure 7.12 Overview of the size at onset of sexual maturity (SOM) for female Norway lobster (*Nephrops norvegicus*). The carapace length where 50% of the stock is mature (L_{50}), based on gonad maturity staging. In general, females from FUs 3–4 (Skagerrak and Kattegat) and FUs 25–30 (Iberian Peninsula) become mature at a larger size than females from the North Sea, Western Scotland, Celtic Sea, Irish Sea and around Ireland—Bay of Biscay. *Redrawn from ICES (2006).*

Table 7.4 Female Norway lobster (*Nephrops norvegicus*) size at onset of sexual maturity (SOM) based on the biological characters in use from different geographical areas

Area	Character	L_{50} or inflexion point (mm CL)	References
Histological character			
Skagerrak	Ovary maturation stage (>III)	28.5	Eggert and Ulmestrand (1999)
Firth of Clyde	Ovary maturation stage (>III)	22.6–33.5	Tuck et al. (2000)
Irish Sea	Ovary maturation stage (>III)	22.9	McQuaid et al. (2006)
Skagerrak	Ovary maturation stage (>III)	30.5	ICES (2006)
Scotland		23.3–25.5	
England		24.8	
Ireland		21.7–24.3	
France		21.5–24.8	

Table 7.4 Female Norway lobster (*Nephrops norvegicus*) size at onset of sexual maturity (SOM) based on the biological characters in use from different geographical areas—cont'd

Area	Character	L_{50} or inflexion point (mm CL)	References
Portugal		37.6	
Spain		28.6–31.2	
Strait of Sicily	Ovary maturation stage (>III)	30.9	Bianchini et al. (1998)
Algarve	Ovary maturation stage (>III)	30	Relini et al. (1998)
Alboran		36	
Catalan		30	
Ligurian		32	
Tyrrhenian		32	
Adriatic		30	
Euboikos		33	
Irish Sea	Spermatheca	21.5	McQuaid et al. (2006)
Morphological character			
Irish Sea	Abdomen width	23.2–27.6	McQuaid et al. (2006)
Firth of Clyde	Abdomen width	21.4–34.6	Tuck et al. (2000)
Functional maturity			
Firth of Clyde	Ovigerous, smallest	22–32	Tuck et al. (2000)
Off Portuguese coast	Ovigerous, smallest	36	Ayza et al. (2011)

but the SOM at adjacent Skagerrak and Kattegat (FUs 3 and 4) is higher (L_{50} 30.8–31.7 mm CL). In the Irish Sea, the lowest estimate for SOM in females was at 21-mm CL, and in males at 15-mm CL, based on histological examinations (McQuaid et al., 2006). Morphology-based estimations showed a bigger variation in size at SOM; in females, it ranged from 23.2 to 27.6 mm CL. Differences in SOM for males, as estimated from the break point in the growth rate of the appendix masculina (situated on the second pleopod), are judged to be noisy and biased due to methodological problems, mainly caused by the problems in consistency in measurement of the appendix masculina, as even different hauls within same FUs gave the same variation as for the whole FU data set (ICES, 2006). The difference in break points for the males between the FUs is therefore not believed to be caused by genuine regional differences. The break point is most often found around 30-mm CL, which indicates the size of sexual maturity (functional maturity).

4. STOCK ASSESSMENT

There are many methods to assess or estimate crustacean population abundance (e.g. Smith and Addison, 2003). CPUE, length cohort analysis (LCA), virtual population analysis (VPA) and, more recently, UWTV surveys are commonly used methods of assessment for *Nephrops* population estimates. The former three are of limited reliability, in comparison with the UWTV, due to bias in fisheries dependent data and internal model assumptions. LCA/VPA analyses investigate the fishery mortality of males and females per year and the result from the analyses has traditionally been compared to CPUE trends from the commercial log books or survey data, to 'tune' the analyses. However, as fishermen visit the grounds with the highest abundance, for example, observed with UWTV on Farn Deep in the winter fishery 2002/2003 (Bell et al., 2005), declines in stocks from CPUE may be masked. Fishermen report the captures per statistical rectangle, 1° of longitude and 0.5° of latitude, ca. 56 × 65 km, and Bell et al. (2005) state that CPUE should be aggregated on a finer geographical scale of 10–20 km, to be able to detect density declines. Surveys are undertaken nationally to collect data (data collection regulation); ICES Fishmap shows the Fish trawl survey stations for which data on *Nephrops* have been collected, for all the ICES states in 1993–2012 (Figure 7.13).

4.1. VPA (including multi-species)

VPA uses catch data (fishery-dependent data collection) to determine the past stock size using mortality rates (Jennings et al., 2001). It uses fishing mortality (number landed) and natural mortality (estimated) to discern the number in the stock for the previous time period (i.e. the previous year/month) and survivors. This data can then be compared to real-time data across set number or repetitions (ICES, 2006; Sardá and Aguzzi, 2012)

Figure 7.13 ICES Fishmap showing *Nephrops* surveys (fish trawl surveys) for all years 1993–2012. ICES FishMap. 'Norway lobster, *Nephrops norvegicus*'. http://www.ices.dk/marineworld/fishmap/ices/ (accessed 28 December 2012).

and modified to analyse other factors such as reproduction potential and recruitment (Relini et al., 1998).

VPA uses age-based data for population dynamic modelling to describe the influence of fishing pressure upon the stock size. However, as with crustaceans generally, identifying the age of *Nephrops* is problematic because there are no easy or relatively cheap methods to identify age, any calcified markings being lost with the old outer exoskeleton (Ulmestrand and Eggert, 2001). To overcome this problem, the von Bertalanffy growth parameters are used to convert length data into age classes, referred to as 'slicing' of the data (ICES, 2004a,b). However, this method has come under scrutiny because of the lack of assumed variability in growth, and other external influences such as sampling and capture methodology. Thus, there is a strong reason for scientists to use VPA-derived models with caution (ICES, 2006; Sardá and Aguzzi, 2012; Tuck et al., 1997; Ulmestrand and Eggert, 2001). Most parameters can be found in the literature, such as regional fishing effort and technology, natural mortality rates, for example, from stomach analysis, SOM and size–weight relationships (Sardá and Aguzzi, 2012; Sparre, 1991; ICES, 2012a). The demand for developments within the VPA models for estimating growth from age–size and tagging studies is increasing to reduce the bias set in using estimated or fitted growth functions (Walters and Martell, 2004). There are, however, several methods that have been used for determining the age of individuals. Indirect age measurement using pigment aggregation in the eyestalk or neural areas over time has been evaluated for different species, for example, the European lobster (O'Donovan and Tully, 1996; Sheehy et al., 1999) and the brown crab (Sheehy and Prior, 2008), as well as for *Nephrops* (Belchier et al., 1994). This technique requires calibration for each species and environment using specimens of known age (Vogt, 2012). Lipofuscin analyses using spectrophotometric methods have also been evaluated for, for example, the blue crab *Callinectes sapidus* (Ju et al., 2001). Recently, a new direct technique has been presented where cuticle growth bands are observed on the eyestalk or gastric mill stones for commercial crustaceans such as the American lobster and snow crab (Kilada et al., 2012).

There are, however, a number of alternative models that can incorporate data derived from *Nephrops* fisheries without the need for aging techniques. These include Stock Synthesis and GADGET modelling frameworks that allow for *Nephrops*-specific variation in capture. This variation could be in the form of density-dependent growth and maturity rates, and reduced female emergence patterns that typically reduce the availability of other models or assessments to be used. There are several VPA methods used for *Nephrops* population assessments that differ in the way the data are presented and calculated. ADAPT and XSA are a few methods, which use catch data affiliated with survey data, that are becoming increasingly popular.

Multi-species VPA (MSVPA) differs from the single population model as variation in mortality and growth can be influenced in each time period due to interactions with other species (Magnusson, 1995; FAO). In standard VPA, natural mortality (M) is considered constant, whereas MSVPA assumes that M is iterative for each time period and age. Predation is also included and influences the mortality within the model. There have been few attempts with this method as it seems both complex and time consuming regarding the broadness of scope in the model in determining the predator–prey relationship within the fishery (Molina and Livingston, 2004).

Overall, it seems that VPA and Length Cohort Analysis provide the most realistic and reliable estimate of populations as they use direct data from the individuals caught (Sardá and Aguzzi, 2012). A note of caution with these approaches is that absolute biomass estimates are dependent upon the landings being reliably reported. Prior to 2006, there was widespread under-reporting of a large number of species including *Nephrops*. The introduction of 'Buyers and Sellers' legislation in the United Kingdom appears to have significantly improved the reporting of landings. Under this legislation, it is required that the purchases of fish be registered. Most assessment studies are now using VPA/LCA in conjunction with other assessment methods, which have been similar in their findings, such as CPUE and UWTV monitoring. The Western Irish Sea FU is interesting in terms of *Nephrops* population assessment as it has long-term capture data and survey data and is developing techniques for UWTV that are suitable for exploring several assessment methods in an integrated approach for advising management.

4.2. UWTV surveys

Fishery-independent abundance-estimating methods are therefore important as a tool for managers. UWTV surveys for counting *Nephrops* burrows as a fishery-independent assessment have been conducted for research purposes since the 1980s (Bailey et al., 1993; Chapman, 1985), as assessment guidance since 1994 for Scottish waters, refined in EU projects (Marrs et al., 1996; Tuck et al., 1997), and for absolute indices of density since 2009 (ICES, 2012b). Sarda and Aguzzi (2012) review the burrow counting method as an alternative to traditional assessment methods, such as VPA modelling. This method is independent of the fishery and therefore reduces the associated bias; however, the method is not without analytical bias (ICES, 2009, 2012b), as discussed later. Decision on the use of fishery-independent methods such as UWTV was made following difficulties associated with assessing non-aged species and bias in reporting of commercial data affecting VPA/LCA and CPUE trend analyses.

The seabed is monitored using TV cameras fastened on a sledge towed after a vessel at a speed of 0.5–0.7 knot (e.g. Campbell et al., 2009b). The area covered is calculated from the known width of the visual frame of the camera corrected for the distance above bottom (recently laser points have been used as frame marks) and the distance covered over the filming based either on vessel GPS tracks or odometer. Burrow systems (rather than individual entrances) are counted. This means that the individual counter has to assess how many entrances are likely to be associated with a specific burrow using visual cues such as burrow entrance shape, orientation, and distance from other entrances. It is also important for the counter to ignore the burrows associated with other burrowing fauna. The assumption behind the method is that each burrow system is inhabited by one adult (larger than 17 mm) *Nephrops*, that is, occupancy is assumed to be 100%. Burrows not occupied are thought to infill quickly and it is suspected that unoccupied burrows are not counted during surveys.

Uncertainties concerning the resulting abundance have been debated and are summarised (Uncertainties table, ICES, 2007), and burrow occupancy and burrow system morphology are an important focus of research. Improvements in methodology since the WKNEPHTV 2007 (ICES, 2007) are given in ICES (2009, 2012c) and methodological modellings to answer the critics have been made (Campbell et al., 2009a). Edge-effect uncertainty may overestimate the population as burrow systems not totally within frames are counted and extrapolation to a total substrate area yields a higher density than in reality and is corrected for in estimations in the Adriatic Sea (Morello et al., 2007). Investigations on whether the burrow system is inhabited by one or more individuals have mostly been performed in shallow lochs accessible by SCUBA and need to be done in other habitats (depth, areas). The time taken for the collapse of an uninhabited burrow is dependent on the bottom (from days to weeks to years) where trawling frequency, current and bioturbidation of other species have an impact, and a better idea of collapse time is needed. The shape and extension of a burrow also needs more attention, for example, using ROVs to inject coloured dye into the burrow to learn about the burrow system. The identification of the species inhabiting a burrow (shape of the entrance and other signs) can be a problem, especially at the edges of the frame, where light and quality of picture are not so good. Other burrowing species inhabiting soft areas that can lead to overestimation of the density are the thalassinid shrimp (*Calocaris macandreae*), angular crab (*Goneplax rhomboides*) and the fish Fries' goby (*Lesueurigobius friesii*). However, experienced readers can discriminate between burrows and a conservative attitude is taken, that is, not including those burrows where there are reasonable uncertainties.

There are two main types of design for investigating burrow densities: the use of a randomised grid and the pseudo-randomised stratified-type. One analytical issue of UWTV is how many stations per strata are necessary to give a fair picture of the real abundance with a given precision, that is, a variance in burrow density needs to be stated and aimed for (ICES, 2007). For the randomised method where a station can be placed anywhere within the strata, the co-efficient of variation (CV, relative standard error) is used to precisely determine the average burrow density and is decreased with the number of stations. On the other hand, variation of the grid design method may be estimated from probability calculations and comparison with earlier data from the strata (Thompson, 2002). This gives an indication of how sampling effort can be adjusted in relation to the relative error. This serves as a proxy for the relative standard errors used in the confidence intervals calculation. The CV from randomised strata locations is mostly below 20%, whereas grid locations have an estimate of variation of below 5%

(ICES, 2012b). The Study Group on *Nephrops* Surveys (SGNEPS) has an important role, that of international coordination of UWTV efforts, and is focussing on planning, protocols, quality control, design and issues regarding survey development (ICES, 2012c). SGNEPS recommend that a CV (or relative standard error) of <20% is an acceptable precision level for UWTV survey estimates of abundance. The lowest survey densities are on the Fladen ground with 2.5 stations per 1000 km^2, while the highest densities are on the Aran Grounds with 79.9 stations per 1000 km^2. Currently, a randomised fixed grid design is used for all UWTV surveys operated under the Marine Institute, except for the Aran Grounds. For some grounds, such as the Aran Grounds, fewer stations using longer distances between stations are recommended.

4.2.1 Reference point determination

The ability to determine a standing biomass and a harvest rate is only part of establishing how a fishery is performing. It is important to understand what the exploitation limits (in terms of long-term sustainability) of any harvesting regime are. The evolution of the wording of ICES advice over the last decade has been in response to changes in philosophy, moving from MBAL (minimum biological acceptable limits), to the Precautionary Approach and, most recently to MSY (maximum sustainable yield), the latter in response to the European Union's 'Marine Strategy Framework Directive' (MSFD, EC regulation 2008/56/EC[11]). Within the MSFD, there are 11 separate descriptors of what Good Environmental Status (GES) should be (including food-webs, marine litter, hydrodynamics and contaminants), and there is a specific section for commercially exploited fish and shellfish species. Under this, descriptor stocks shall (1) be exploited sustainably consistent with high long-term yields, (2) have full reproductive capacity in order to maintain stock biomass, and (3) the proportion of older and larger fish/shellfish should be maintained (or increased). The time scale for this commitment is that GES should be achieved by 2016 or 2020 at the latest. GES for commercial species has been interpreted by ICES as a requirement for stocks to be exploited at MSY. Analytical determination of MSY requires a parameterised functional relationship between the size of spawning stock and the number of recruits, which, for the majority of *Nephrops* stocks, is not possible given the lack of a fully age-based assessment. Proxies for

[11] Directive 2008/56/EC of the European Parliament and of the Council of 17 June 2008. Establishing a framework for community action in the field of marine environmental policy (Marine Strategy Framework Directive) Official Journal of the European Union L164/19.

harvesting strategies, which are likely to generate MSY, are therefore used and the three candidates for F_{MSY} are $F_{0.1}$, $F_{35\%SPR}$, and F_{max}. These proxies are determined using processes similar to the Jones Length Cohort Analysis (Jones, 1984). As LCA assumes that the input length frequency comes from a population at equilibrium, a 3-year average length frequency is used. Anything that might change the shape of the length frequency (e.g. gear selection pattern, discarding patterns, stock–recruitment changes) will therefore induce a change in the associated reference points; so, regular updating of these reference points is required.

There may be strong differences in relative exploitation rates between the sexes in many stocks. To account for this, values for the candidates have been determined for males, females, and the two sexes combined. The F_{MSY} candidate considered to be most appropriate has been selected for each FU independently according to the perception of stock resilience, factors affecting recruitment, population density, knowledge of biological parameters, and the nature of the fishery (relative exploitation of the sexes and historical harvest rate vs. stock status). A formalised decision-making framework was developed for the selection of preliminary stock-specific F_{MSY} proxies (ICES, 2012a). These proxies may be modified following further data exploration and analysis. The combined-sex F_{MSY} proxy is considered appropriate if the resulting percentage of virgin spawner per recruit for males or females does not fall below 20%. When this does happen, a more conservative sex-specific F_{MSY} proxy is selected instead of the combined proxy.

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