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Design of a Sampling Programme and Measurement of Contaminants in Food for Marine Strategy Framework Directive Descriptor 9

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Executive Summary

Descriptor 9 (contaminants in food) is one of eleven Marine Strategy Framework Directive (MSFD) qualitative Descriptors to be used in determining whether Good Environmental Status (GES) has been achieved for European regional seas (Directive EC/2008/56). For monitoring of compliance with GES for Descriptor 9, contaminant concentrations in fish and seafood should be compared against the EC regulatory levels. The fish and shellfish contaminant monitoring currently undertaken in Scotland was reviewed. Monitoring programmes include the UK Clean Seas Environment Monitoring Programme (CSEMP) undertaken by Marine Scotland Science (MSS) and Scottish Environment Protection Agency (SEPA), and the annual surveys of contaminants in shellfish from commercial harvesting areas undertaken by Food Standards Agency for Scotland (FSAS). The suitability of these activities in addressing the requirements of Descriptor 9 was assessed.

CSEMP is the main UK monitoring programme for contaminants in fish and, in Scotland, is undertaken by MSS. However, as most fish data are for liver tissue of small flatfish they are of limited use for assessing progress towards GES under Descriptor 9, as in the UK fish liver is not generally consumed. For CSEMP, trace metals are determined in fish muscle and liver, and PCBs in fish liver only. Regulatory levels are available for metals, dioxins and PCBs in fish muscle. However, only metals are analysed in fish muscle as part of UK CSEMP. PCBs and dioxins are not measured in fish muscle as this is not a requirement of the OSPAR Coordinated Environmental Monitoring Programme (CEMP) for the NE Atlantic. Monitoring of shellfish in Scotland is mainly undertaken by FSAS and SEPA. Mussel samples are collected by SEPA to assess compliance with the Water Framework Directive (WFD; 2000/60/EC) and its daughter Directive on Environmental Quality Standards (EQSD; 2008/105/EC) following the repeal of the Dangerous Substances Directive (DSD; 2006/11/EC) in December 2013; samples are analysed for PCBs, PAHs and trace metals, but not dioxins. FSAS undertake contaminant (includes trace metals, PAHs, PCBs and dioxins) monitoring in shellfish for the Shellfish Hygiene Directive (79/923/EEC). Both SEPA and FSAS shellfish contaminant data

could be used for Descriptor 9 assessments, although currently FSAS data is not submitted to the UK Marine Environment Monitoring and Assessment National database (MERMAN).

The available data from the above shellfish and fish monitoring programmes were obtained from the MERMAN database and from FSAS. Concentrations were mostly below the current available regulatory levels in both fish and shellfish. Although all contaminant groups with regulatory levels were analysed in mussels, dioxins are not routinely measured in fish muscle. However, it is possible to estimate dioxin toxic equivalent concentrations from PCB concentrations, using published models, for comparison with regulatory levels.

Due to the deficiencies of existing environmental monitoring programmes to address the requirements of MSFD Descriptor 9, particularly for fish, a sampling programme targeting appropriate fish species was designed. The designs were based around existing fish stock assessment research vessel surveys, with fish sampled from each trawling location with a probability proportional to the landings by the Scottish fishing fleet. Haddock, monk, and herring were selected based on their importance to the human diet (based on fish landings) and to represent different groups of fish (e.g. high trophic level, high fat content). The designs were implemented for each species for those parts of the North Sea and the Celtic Seas relevant to the Scottish fleet.

Introduction

The Marine Strategy Framework Directive (MSFD) took effect on 17 June 2008 (Directive EC/2008/56[i]) and was transposed into UK Law in July 2010 through the Marine Strategy Regulations 2010. The aim of the MSFD is to achieve Good Environmental Status (GES) for European seas by 2020; the MSFD does not apply to estuaries which are considered as transitional waters under the WFD. The Directive sets out eleven qualitative descriptors against which GES should be assessed. Descriptor 9 states that ***'contaminants in fish and other sea food for human consumption do not exceed levels established by Community legislation or other relevant standards***'. The Directive required an Initial Assessment of status by July 2012 and the identification of any measures required to achieve GES by 2014. The UK State of the Seas report, *Charting Progress 2*[1], and Scotland's Marine Atlas[2] were used as the basis for the Initial Assessment, which also includes an economic assessment[3]. A public consultation exercise on the UK Initial Assessment and the UK's Targets and Indicators for GES was recently undertaken by Defra; a report on the consultation exercise was produced by Defra

[i] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2008:164:0019: 0040:EN:PDF

and the Devolved Administrations and the Initial Assessment published[3]. Monitoring programmes for the assessment of environmental status should be in place by 2014, with the next status assessments due in 2018. However, currently there are a limited amount of Scottish contaminant data collected for monitoring programmes that may be suitable for the assessment of GES against Descriptor 9.

Task Groups were established by the European Commission's Joint Research Centre (JRC) for each of the Descriptors and reports produced for ten of the eleven descriptors (not Descriptor 7 - alterations of hydrographical conditions); the Commission's Joint Research Centre (JRC), produced advice on the scope of Descriptor 9[4]. In this document the term "contaminants" was interpreted as:

'hazardous substances present in fish as a result of environmental contamination for which regulatory levels have been set for human consumption or for which the presence in fish is relevant'.

Fish and other seafood are interpreted as:

'wild caught fish, crustaceans, molluscs, echinoderms, roe and seaweed harvested in the different (sub) regions, all destined for human consumption'.

Contaminant levels in finfish farmed in marine waters within WFD limits are not of relevance for assessing GES under MSFD, as their primary exposure is via a fed diet and so does not reflect local environmental conditions.

Levels established by Community legislation are considered to be:

'The regulatory levels set in community legislation for public health reasons.'

Contaminants found in the marine environment can be from either anthropogenic or natural sources. However, most contaminants are produced by anthropogenic activities. Direct or indirect releases to rivers, from industrial discharges and from sewage works discharges, are major sources of a range of contaminants. Furthermore, run-off from urban areas and atmospheric deposition continue to be diffuse sources of hazardous substances to the marine environment. Fish and other seafood are exposed to contaminants present in the water column and through their diet, which results in the bioaccumulation of contaminants and sometimes adverse biological effects. Substances accumulating in an organism are likely to bio-magnify up the food chain. The transfer of contaminants through marine food chains can result in bioaccumulation in commercial fishery resources and result in transfer to the human consumers of seafood.

MSFD Descriptor 9 Requirements: Targets and Indicators

Details of the criteria and indicators for GES for the eleven descriptors are provided in the European Commission decision document (Commission Decision 2010/477/EU) which Member States must use when implementing the Directive.

For Descriptor 9, the Commission Decision Document states that:

- Contaminants in fish and other seafood for human consumption do not exceed levels established by Community legislation or other relevant standards.
- In the different regions or sub-regions Member States need to monitor in edible tissues (muscle, liver, roe, flesh, soft parts as appropriate) of fish, crustaceans, molluscs and echinoderms, as well as seaweed, caught or harvested in the wild, the possible presence of substances for which maximum levels are established at European, regional or national level for products destined for human consumption.

The indicators listed for Descriptor 9 are:

- 9.1. Levels, number and frequency of contaminants:
- 9.1.1 Actual levels of contaminants that have been detected and number of contaminants which have exceeded maximum regulatory levels.
- 9.1.2 Frequency of regulatory levels being exceeded.

The UK Government and Devolved Administrations developed proposals for more detailed targets and indicators of Good Environmental Status for each of the eleven descriptors, through which we will measure progress towards achieving Good Environmental Status.

For Descriptor 9 (Levels, numbers and frequency of contaminants) the GES target and indicators proposed for contaminants in seafood by the UK is:

For contaminants where regulatory levels have been set, there should be a high rate of compliance based on relevant surveys and including samples originating from commercial fishing grounds in the greater North Sea and the Celtic Seas[3]*.*

Therefore, for monitoring compliance with GES, contaminant concentrations in fish and seafood should be compared against the regulatory levels. Descriptor 9 will cover those substances for which regulatory levels have been laid down. Commission Regulation EC/1881/2006 specifies Maximum Permitted Concentrations (MPCs) in food (including the muscle meat of fish, bivalve molluscs and crustaceans) for lead, cadmium, mercury, dioxins[ii], dioxin-like[iii] polychlorinated biphenyls (DL-PCBs) and benzo[*a*]pyrene (Table 1). Regulation EC/1259/2011 provides amended limits for dioxins and DL-PCBs plus additional limits for non DL-PCBs (ICES 6; CB28, 52, 101, 138, 153 and 180)[iv] (Table 1). Furthermore, MPCs are provided for dioxins (including DL-PCBs) and non DL-PCBs in fish liver and derived products. In 2012 MPCs for polycyclic aromatic hydrocarbons (PAHs) in fish were removed from regulation EC/1881/2006 and the MPC for bivalve molluscs was reduced. New levels are likely to be introduced for other contaminants such as three additional PAHs, polybrominated diphenyl ethers (PBDEs), and inorganic arsenic.

Monitoring should be undertaken in accordance with the sampling and analytical performance requirements defined in Commission Regulation EC/1883/2006. Information on the sampling location will also be required so contaminant data can be traced back to a (sub) regional level.

This report reviews the contaminants in fish and shellfish monitoring activities currently undertaken in Scotland and the suitability of these activities in addressing the requirements of Descriptor 9. Contaminant data currently available for biota were compared to regulatory levels. To fill identified gaps for assessing progress

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[ii] Dioxins (sum of polychlorinated dibenzo-para-dioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs), expressed as World Health Organisation (WHO) toxic equivalent using the WHO-toxic equivalency factors (WHO-TEFs).

[iii] Of the 209 PCB congeners, the most toxic are the so-called 'dioxin-like' PCBs (DL-PCBs). The DL- PCBs are the four non-*ortho* (CB77, 81, 126, and 169) and eight mono-*ortho* (CB105, 114, 118, 123, 156, 157, 167, and 189) congeners. DL-PCBs are stereo-chemically similar to 2,3,7,8-tetrachlorodibenzo-*p*-dioxin (TCDD) and, therefore, have similar toxic and biological responses to those of dioxins.

[iv] The seven ICES (International Council for the Exploration of the Sea) PCBs (CB28, 52, 101, 118, 153, 138, and 180) were recommended for monitoring by the European Union Community Bureau of Reference; these congeners were selected as indicators of wider PCB contamination due to their relatively high concentrations in technical mixtures and their wide chlorination range (3-7 chlorine atoms per molecule). The ICES 7 PCBs have been part of the OSPAR Co-ordinated Environmental Monitoring Programme (CEMP) since 1998. MPCs have been set for the ICES 6 (excludes CB118 which is classed as a DL-PCB).

towards GES for Descriptor 9, a sampling programme was designed targeting fish species important in the human diet (based on landings from each sub-region).

Table 1

Regulatory limits on the maximum permitted concentrations (wet weight) of certain environmental contaminants in edible portions of fish and shellfish (whole fish if appropriate). TEQ = Toxic Equivalent Concentration (summed concentrations of certain planar organic compounds based upon their relative toxicity[5]).

Regulation	Compound or element	Maximum permitted concentration	Species to which the limit applies
EC/1881/2006	Pb	0.3 mg kg^{-1}	Fish and shellfish with the main exceptions indicated below:
EC/1881/2006	Pb	0.5 mg kg^{-1}	Crustacea (excluding crab brown meat & head / thorax of lobster)
EC/1881/2006	Pb	1.0 mg kg^{-1}	Cephalopods (without viscera)
EC/1881/2006	Pb	1.5 mg kg^{-1}	Bivalve molluscs
EC/629/2008	Cd	0.05 mg kg^{-1}	Fish and shellfish with the exceptions indicated below:
EC/629/2008	Cd	0.1 mg kg^{-1}	Bonito, common two-banded seabream, eel, grey mullet, horse mackerel or scad (*Trachurus sp.*), louvar or luvar, sardine, sardinops, tuna, wedge sole.
EC/629/2008	Cd	0.2 mg kg^{-1}	Bullet tuna
EC/629/2008	Cd	0.3 mg kg^{-1}	Anchovy, swordfish
EC/629/2008	Cd	0.5 mg kg^{-1}	Crustacea (excluding crab brown meat & head / thorax of lobster and similar large crustaceans)
EC/629/2008	Cd	1.0 mg kg^{-1}	Cephalopods (without viscera), bivalve molluscs
EC/1881/2006	Hg	0.5 mg kg^{-1}	Fish and shellfish with the exceptions of crab brown meat, head / thorax meat of lobster (and similar spp.) and the species indicated below:
EC/629/2008	Hg	1.0 mg kg^{-1}	Anglerfish, Atlantic catfish, bonito, eel, emperor, orange roughy, rosy soldierfish, grenadier, halibut, kingklip, marlin, megrim, mullet, pink cusk eel, pike, plain bonito, poor cod, Portuguese dogfish, rays, redfish, sail fish, scabbard fish, seabream, pandora, shark (all species), snake mackerel or butterfish, sturgeon, swordfish, tuna.
EC/1881/2006	Benzo[*a*]Pyrene	5.0 µg kg^{-1}	Smoked fish and fishery products
EC/1881/2006	Benzo[*a*]Pyrene	5.0 µg kg^{-1}	Crustacea & cephalopods, other than smoked and excluding crab brown meat, head / thorax meat of lobster (and similar spp.)
EC/1881/2006	Benzo[*a*]Pyrene	5.0 µg kg^{-1}	Bivalve molluscs
EC/1259/2011	Dioxins & furans[1]	3.5 pg g^{-1} TEQ	Fish muscle and fishery products, excluding eel and freshwater fish
EC/1259/2011	Dioxins, furans & DL-PCBs[1]	6.5 pg g^{-1} TEQ	Fish muscle and fishery products, excluding eel and freshwater fish
EC/1259/2011	ICES 6 PCBs	75 µg kg^{-1}	Fish and fishery products, excluding eel and freshwater fish
EC/1259/2011	Dioxins & DL-PCBs	20 pg g^{-1} TEQ	Fish liver and derived products, with the exception of marine oils
EC/1259/2011	ICES 6 PCBs	200 µg kg^{-1}	Fish liver and derived products, with the exception of marine oils

[1]Individual compounds as listed in EC Regulation EC/1881/2006.

Current Scottish Monitoring of Contaminants in Biota

The Food Standards Agency for Scotland (FSAS), Scottish Environment Protection Agency (SEPA) and Marine Scotland Science (MSS) undertake contaminant monitoring in marine biota for a range of purposes. These include the UK Clean Seas Environment Monitoring Programme (CSEMP, including MSFD Descriptor 8) and the FSAS annual surveys of contaminants in shellfish from commercial harvesting areas. Fish and shellfish contaminant monitoring programmes are described below.

Contaminants in Fish

Hazardous substances are measured in fish collected from Scottish sites for a number of studies. MSS monitor contaminants in fish at sites around Scotland for programmes such as the UK CSEMP and Clyde trend monitoring programme (Figure 1). Contaminants included on the OSPAR Coordinated Environmental Monitoring Programme (CEMP)[v] are analysed as part of the CSEMP[6]. Of the contaminants with EC regulatory levels (lead, cadmium, mercury, benzo[*a*]pyrene, dioxins, DL-PCBs and non DL-PCBs), dioxins and most DL-PCBs (only CB118 is monitored as one of ICES7 PCBs) are not monitored for the UK CSEMP. Dioxins and DL-PCBs are included on the OSPAR pre-CEMP and, therefore, analysis of these contaminant groups is not mandatory[6]. Furthermore, concentrations of DL-PCBs will be much lower than non DL-PCBs (ICES7 PCBs) and, therefore, the OSPAR pre-CEMP states that analysis in biota is only required if concentrations for the ICES7 PCBs are 100 times higher than the Background Assessment Concentration for these marker PCBs. Dioxin concentrations will also be much lower than concentrations of the ICES7 PCBs. To detect dioxins at such low levels the favoured technique for chemical analysis uses high-resolution mass spectrometry (HRMS). As neither MSS nor SEPA currently have access to high resolution mass spectrometry, this analysis would have to be outsourced at high cost. However, papers have been published looking at alternative methods to predict the total TEQs (for dioxins and 'dioxin-like' CBs) in fish tissue, using total or indicator PCB concentrations. These models have previously been applied to Marine Scotland PCB data

[v] Metals (cadmium, mercury and lead) in sediment and biota ; PAHs (anthracene, benz[*a*]anthracene, benzo[*ghi*]perylene, benzo[*a*]pyrene, chrysene, fluoranthene, indeno[1,2,3-*cd*]pyrene, pyrene and phenanthrene) in biota and sediment; PCBs (ICES7-CB28, 52, 101, 118, 138, 153 and 180) in biota and sediment; brominated flame retardants (hexabromocyclododecane (HCBD) and BDE28, 47, 66, 85, 99, 100, 153, 154 and 183 in biota and sediment, and BDE 209 in sediment).

for fish and have been described in detail elsewhere[7]. In summary, Bhavsar *et al.*[8] proposed that the total PCB (Aroclor equivalent) concentration could be used to estimate the total TEQ for dioxin and 'dioxin-like' PCBs. Lasrado *et al.*[9] looked at four models to predict TEQs using the US Environment Protection Agency fish tissue study. The authors concluded that the analysis of selected compounds or total PCBs could be used to estimate total TEQs and proposed models.

The main focus of the CSEMP has been to meet the temporal trend monitoring requirements of the OSPAR international agreement and in respect of compliance with EC Directives such as the Water Framework Directive (WFD) (EC/2000/60), Dangerous Substances Directive (DSD) (76/464/EEC) and Shellfish Waters Directive (79/923/EEC). The OSPAR CEMP requires the determination of lead, cadmium, PCB, and brominated flame retardant concentrations in fish liver, and mercury in fish muscle tissue; these plus PAHs and a wider range of trace metals are required to be monitored in mussels. For CSEMP, MSS monitor contaminants in plaice (*Pleuronectes platessa*), dab (*Limanda limanda*) or flounder *(Platichthys flesus*) from 10 sites annually. The use of modern analytical methodologies means that data for the three specified metals (and several others) are routinely obtained for both liver and muscle of fish. CSEMP contaminant data are submitted to the UK Marine Environment Monitoring and Assessment National database (MERMAN) and from there to international databases.

Organic contaminants (PCBs and polybrominated diphenyl ethers, PBDEs) have been measured in fish (plaice) liver from the Firth of Clyde as part of the MSS Clyde Trend Monitoring Programme. Seven fixed sites (five test sites (Skelmorlie, Hunterston, Irvine Bay, Holy Loch and Garroch Head) and two reference sites at Colonsay and Pladda) (Figure 1) have been monitored for organic contaminants annually. Fish liver has been analysed for PCBs since 1992 at Garroch Head and Pladda, and at all other sites since 1999. PBDEs have also been analysed in recent and historical plaice liver samples (dating back to 1997). Data from the Clyde trend monitoring programme is now also submitted to the MERMAN database.

Additional fish samples have been collected from sites on the east coast in recent years by MSS. Dab and haddock were sampled from offshore of the Firth of Forth in 2008 and flounder were collected from Alloa and Tancred Bank in the Forth estuary and from St Andrews Bay in 2008, 2010 and 2011 (Figure 1). PCBs were measured in fish liver and metals in liver and muscle and the data submitted to MERMAN.

The above environmental monitoring programmes existed pre-MSFD and generated data that were used in the UK's Initial Assessment for the MSFD. However, they were not designed for food monitoring and in producing the Initial Assessment, the authors noted gaps in the existing monitoring programmes with respect to their suitability for both environmental (Descriptor 8) and food (Descriptor 9) monitoring for the MSFD. Changes to the Scottish Descriptor 8 monitoring programme[10] were mostly to include geographical areas not previously considered, and hence gaps with respect to monitoring for Descriptor 9 remain.

The monitoring programmes described above focussed on fish species suitable for environmental monitoring (flatfish such as flounder, plaice, and dab), but these species only form a small proportion of Scottish landings, so are not the most suitable for food monitoring. For example, there were 304,400 tonnes of fish (pelagic and demersal) landed by Scottish vessels in 2013 with a value of £292 million, and plaice accounted for <1% of the total landings into Scotland[11]. Furthermore, the size ranges specified for fish sampling under the CSEMP means that most fish sampled are smaller than can be legally caught by commercial fisheries and, except for metals, contaminants are measured in fish liver rather than in the edible flesh.

Bioaccumulation of contaminants in fish is dependent on factors such as fat content, age and trophic level of the fish. Lipophilic contaminants, such as PAHs and PCBs, will accumulate more in fish tissue with a higher fat content. Due to the high lipid content of the liver, organic compounds (such as PCBs) will accumulate more in the liver than the muscle; therefore, these contaminants are measured in the liver for environmental monitoring programmes such as the CSEMP and the Clyde trend monitoring programme. In addition, many contaminants (including mercury) will bio-magnify, with fish higher up the food chain having higher concentrations of contaminants than fish of low trophic level. The fish species used for environmental monitoring are of relatively low trophic level (<3.5)[12], the size-ranges are smaller than commercially caught fish and most of the data are for liver, hence the on-going CSEMP and Descriptor 8 monitoring will produce contaminant data that will be of limited use for assessing progress towards GES under Descriptor 9.

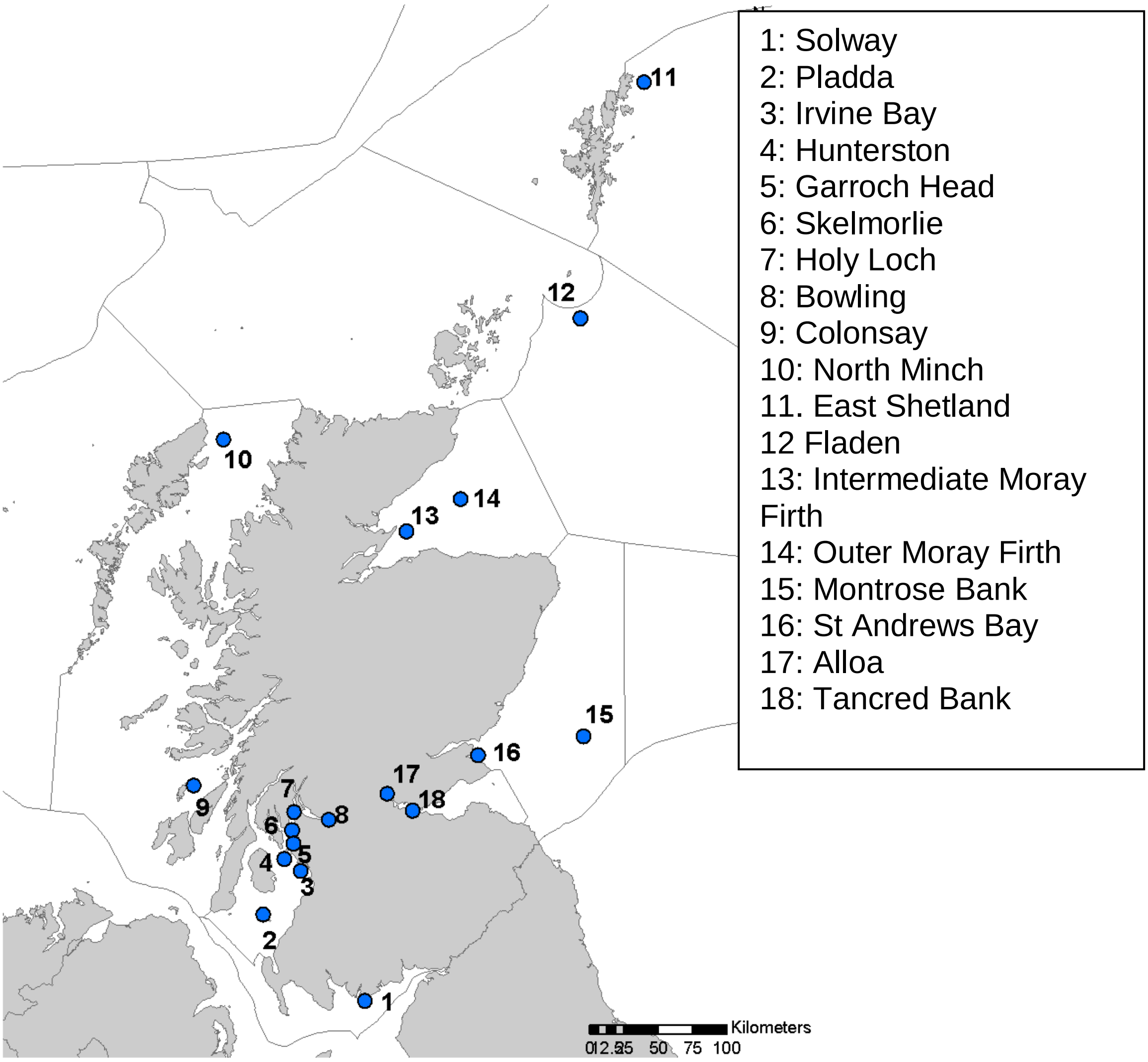

Figure 1: Scottish CSEMP fish monitoring sites regions, sampled annually for contaminant analysis. The grey lines show the Scottish sea areas[2].

In recent years there has been an increasing commercial interest in deep water fisheries. More than 130 deep water species are found in waters to the west of the UK, of which about 12 are fished commercially, including roundnose grenadier (*Coryphaenoides rupestris*), black scabbard (*Aphanopus carbo*) and black dogfish (*Centroscyllium fabricii*). Roundnose grenadier and black scabbard are targeted for the consumer market, whilst black dogfish are mainly caught as by-catch but are also used for fishmeal. The latest official information for deep water species landed into Scotland shows that total landings of black scabbard was 1,998 tonnes in 2012, accounting for 0.6% of all landings[13]. Halogenated persistent organic pollutants (PCBs and PBDEs) and total lipid were measured in the liver and muscle of three species of deep water fish (black scabbard, black dogfish (liver only) and roundnose grenadier) collected from the Rockall fishing area, to the west of Scotland, between 2006 and 2011[7]. Both contaminant groups were detected in the muscle and liver, with concentrations higher in the liver and PCB concentrations higher than PBDEs. Trace metal concentrations were also determined in the flesh and liver of deep water fish collected in September 2006[14]. The data were not submitted to the MERMAN database.

In addition to their annual shellfish monitoring programme (below), the FSAS has undertaken periodic surveys of contaminants (including PAHs, dioxins and PCBs) in food, including fish, since 1989[15-17]. The main purpose of these surveys is to allow the dietary intake of contaminants such as dioxins and DL-PCBs from processed fish and fish products to be estimated. Currently these data are not submitted to MERMAN.

Contaminants in Mussels

Under the UK CSEMP, SEPA monitor contaminants (trace metals, PCBs, PAHs and PBDEs) in native mussels collected from the intertidal zone from a range of sites across Scotland in January-March each year (Figure 2). Samples are collected to assess compliance with the Environmental Quality Standards (EQSD) daughter Directive of the WFD. In total, 56 shellfish sites around Scotland are monitored and data (metals, PCBs and PAH) submitted to the MERMAN database. MSS work with SEPA to undertake an integrated assessment of contaminants and their biological effects at approximately 6 sites per year. Many of these mussel sites are in remote areas (e.g. Shetland and the Western Isles) and so provide ‘background’ data. Following the repeal of the Dangerous Substances Directive (76/464/EEC) and the Shellfish Waters Directive (2006/113/EC), SEPA are currently reviewing the extent and frequency of their mussel monitoring programme, but data from their on-going monitoring could be of use for assessments under Descriptor 9, if from areas that may be harvested for human consumption.

Contaminants have also been measured in mussels as part of MSS’s Long Term Hazardous Substances Monitoring Programme. Farmed, rope grown mussels (Loch Etive and Loch Ewe) and wild mussels (Straad on the west coast and Shell Bay and Aberdeen Breakwater) have been collected monthly and analysed for hazardous substances with the aims of assessing the status of Scottish mussels with respect to concentrations of hazardous substances, and of investigating site and seasonal differences. Mussels from Loch Etive have been analysed for PAHs since 1999, and Loch Ewe, Straad, Aberdeen Breakwater and Shell Bay since 2005, when PCBs and

PBDEs were introduced to the programme. All data were submitted to MERMAN until the monitoring programme at all sites ended in 2012.

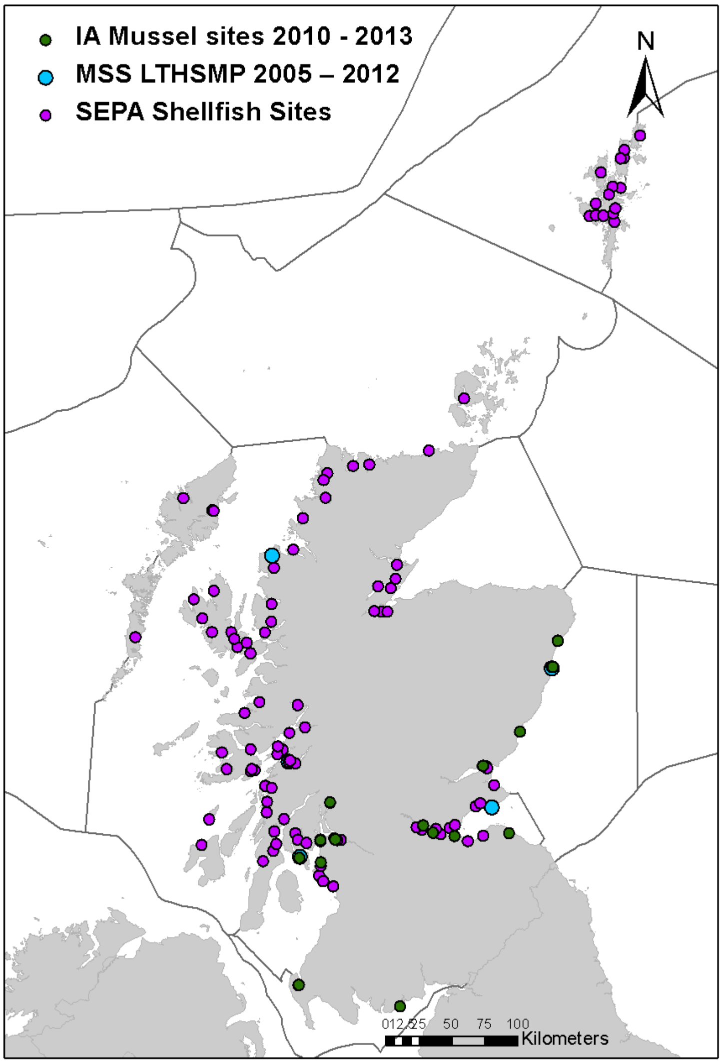

Figure 2: Scottish shellfish monitoring sites, including MSS's Long Term Hazardous Substances Monitoring Programme (LTHSMP) 2005-2012 sites, MSS integrated assessment sites and SEPA's Shellfish Water and Dangerous Substances Directive sites. Grey lines show the Scottish sea areas[2].

FSAS Shellfish Monitoring Programme

The Shellfish Hygiene Directive (79/923/EEC) includes the requirement to assess a range of elements of end product quality in shellfish offered for sale for human consumption. EU contaminants in foodstuffs regulations (EC/1881/2006, as amended) require that a range of contaminants do not exceed given MPCs in foodstuffs for sale for human consumption. The FSAS is the competent authority for this work. Therefore, as part of statutory monitoring (as detailed in Regulation (EC)

1881/2006) FSAS conducts annually monitoring of chemical contaminants in newly classified shellfish areas and/or shellfish areas which were subject to sanitary surveys. Directive monitoring only includes commercially harvested shellfish and, therefore, sampling does not include industrialised estuaries. This monitoring covers:

- Metals (chromium, manganese, cobalt, nickel, copper, zinc, arsenic, selenium, silver, cadmium, lead and mercury).
- PAHs.
- Dioxins and PCBs.
- Organochlorine pesticides.

These data are not currently submitted to the MERMAN database, but may be in future, and should be of use for Descriptor 9 assessments.

Comparison of data to Regulatory Levels

European regulatory levels (EC/1881/2006 and EC/1259/2011) are available for PAHs (benzo[*a*]pyrene), trace metals (Cd, Hg and Pb), dioxins, DL-PCBs and non DL-PCBs (ICES6 PCBs) in fish muscle, crustecea and bivalve molluscs and also for dioxins (including DL-PCBs) and non DL-PCBs in fish liver and derived products (Table 1). Dioxins and DL-PCBs (except for CB118 which is one of the ICES7 PCBs) are not currently monitored in Scotland for CSEMP purposes. However, there are now limits available for the ICES6 PCBs (CB28, 52, 101, 138, 153 and 180) in fish muscle and liver (EC/1259/2011; 75 µg kg^{-1} wet weight for fish muscle and 200 µg kg^{-1} wet weight for fish liver) which are routinely analysed as part of environmental monitoring programmes such as CSEMP. Additionally, maximum levels are likely to be set for three more PAHs and for inorganic arsenic (As) in the near future.

Recent (2007-2013) data was extracted from the MERMAN database for PAHs and metals in mussels, for metals in fish muscle and PCBs in mussels and fish liver sampled from Scottish sea areas. FSAS supplied MSS with data for dioxins, PCBs (including DL-PCBs), trace metals and PAHs in shellfish collected as part of their annual monitoring programme. All data (individual results) were compared to regulatory levels.

Fish

For fish muscle only trace metals data are available in the MERMAN database for Scottish sites. The muscle tissue from plaice, dab or flounder have been collected at

Scottish sites (CSEMP and Clyde trend monitoring) in eight Scottish sea areas (Solway Firth and North Channel, Clyde, Minches and Malin Sea, East Shetland, Fladen, East Scotland Coast, Moray Firth and Forth). To date there are 364 fish muscle samples with data for trace metals in MERMAN from the last seven years (2007-2013). Of these none exceeded the maximum level for Hg (0.5 mg kg^{-1} wet weight). Two samples exceeded the maximum level for Pb (0.3 mg kg^{-1} wet weight), one in the Moray Firth and one in the Fladen, and three for Cd (0.05 mg kg^{-1} wet weight), two in the East Scotland sea area (both from Montrose Bank in 2009) and one in the Solway Firth and North Channel (2007). PCBs data for fish liver (dab, plaice and flounder) are also held in MERMAN; non DL-PCB data are available for 434 fish liver samples (2007-2013). Forty-five samples exceeded the maximum level for the ICES6 PCBs in fish liver (200 µg kg^{-1} wet weight), all from the Clyde. Although dioxins and most DL-PCBs are not monitored in fish, concentrations will be much lower than for non DL-PCB concentrations. Dioxin toxic equivalent (TEQ) concentrations were estimated using published models[8,9] for the 434 samples (2007-2013) with PCB data in MERMAN. Nine samples (Lasrado model[9]) or twenty-six samples (Bhavsar model[8]), all from the Clyde (Loch Long, Holy Loch and Garroch Head), exceeded the total TEQ for liver of 20 pg g^{-1} wet weight. These samples also were above the MPC for the non DL-PCBs in fish liver.

PCBs were measured in deep water fish muscle as part of MSS deep sea research projects (2006-2012). Dioxin toxic equivalent (TEQ) concentrations, estimated from the PCB concentrations in fish muscle using published models[8,9], were below the EU MPC[7]. Furthermore, none of the fish muscle samples gave concentrations greater than 75 µg kg^{-1} wet weight for the sum of the ICES6 PCBs. Therefore, there is no risk to human health from consumption of these deep water fish. However, almost half of the 2009, 2011 and 2012 roundnose grenadier (21 out of 43) and black dogfish (10 out of 20) liver samples gave concentrations for the sum of the ICES6 PCBs above 200 µg kg^{-1} wet weight. Sixteen of these samples also gave an estimated dioxin TEQs above the MPC of 20 pg g^{-1} wet weight. The liver of both species have a very high lipid content (means of 51.8% - 74.7%) so are likely to accumulate higher concentrations of hydrophobic contaminants compared to species with a lower lipid content. The MPC is on a wet weight basis and, therefore, the high lipid content is not accounted for. Although food safety levels were exceeded it is unlikely that the liver of these species will be for the consumer market. Trace metal concentrations were also measured in fish collected in September 2006[14]. The concentrations of Hg and Pb were below the MPC, but Cd concentrations exceeded the MPC in 66% of round nose grenadier from the Rockall sea area. However, deep water fish represent less than 1% of total Scottish landings (e.g. black scabbard accounts for 0.6% of total Scottish landings[13]).

The FSA have also published contaminant data in fish from their food surveys. The most recent survey, in 2006, investigated dioxins and PCBs in 165 samples of processed fish and fish products purchased in the UK[15]. The samples analysed covered a wide range of fish and shellfish related products from supermarkets, independent retailers and specialist retailers. Fish analysed included cod, haddock, herring and mackerel. The concentrations of dioxins and DL-PCBs were below relevant EU regulatory limits in all of the samples. Total TEQ concentrations were in the range 0.01 - 3.17 pg g^{-1} wet weight, below the MPC of 6.5 pg g^{-1} wet weight for the total TEQ (dioxins plus DL-PCBs). Concentrations were generally higher in crab and in oily fish such as anchovies, herring, mackerel and salmon. In 2006 a survey of farmed and wild fish and shellfish was undertaken[16]. Samples were taken from retail outlets throughout the UK so there was no information on where samples were collected. Forty-seven composite samples, including mackerel, herring, wild and farmed salmon and farmed trout, were measured for PCBs and dioxins. Dioxins and PCBs were at low concentrations in nearly all of the samples. Total TEQ concentrations were in the range 0.02-28 pg g^{-1} wet weight, with the highest concentration in a sample of mackerel. One mackerel and one herring sample exceeded the MPC of 8 pg g^{-1} TEQ wet weight[vi] for the sum of dioxins and DL-PCBs.

In 2009 the FSAS undertook a survey of Scottish deep water fish, freshwater fish and non-commercial mussel beds for a range of contaminants including PCBs[17]. Thirty-two marine fish (muscle only) were analysed for PCBs, DL-PCBs, dioxins, PBDEs, PFCs, phthalates, brominated dioxins, chlorinated naphthalenes and trace metals. The contribution to the TEQ was higher for the DL-PCBs compared to the dioxins. Concentrations were lower in shellfish compared to fish and concentrations in marine fish were lower than freshwater fish. However, in all cases the total TEQs (dioxin and DL-PCBs) were lower than the MPC, with the highest concentration in a sample of roach (3.5 pg g^{-1} TEQ wet weight). Therefore, the concentrations were not of concern with respect to human health. For trace metals, nearly all fish samples were below the MPCs, with the mercury MPC exceeded in a couple of cases for ling and blue ling.

As it is possible to estimate the TEQ concentrations from the PCB concentrations using published models, and concentrations are likely be below the MPC in most Scottish sea areas, no additional monitoring of dioxins in fish is proposed for MSFD Descriptor 9.

[vi] This is the MPC from 1881/2006, this was amended to 6.5 pg g^{-1} TEQ wet weight in 1259/2011

Shellfish

PAH data for mussels collected at Scottish sites over the last seven years (2007 to 2013, inclusive) were extracted from the MERMAN database. Five hundred and twenty-seven mussel samples, collected from nine Scottish regions (Clyde, Minches and Malin Sea, Hebrides, North Scotland Coast, West Shetland, East Shetland, East Scotland Coast, Moray Firth and Forth) have been analysed for PAHs. Samples were collected as part of MSS's long term monitoring hazardous substances programme and by SEPA for the Dangerous Substances Directive and the Shellfish Waters Directive. Samples were mainly wild mussels, apart from MSS Loch Etive and Loch Ewe samples which are rope grown. Of the 527 mussel samples in MERMAN, 327 samples had data for benzo[*a*]pyrene of which 10 had concentrations greater than the MPC of 5 µg kg^{-1} wet weight. Eight of these were from sites in the Clyde region, one in the Forth and one in the Minches and Malin Sea (Tobermory).

PCB data for 422 mussel samples collected between 2007 and 2013 from nine regions (Clyde, Minches and Malin Sea, Hebrides, North Scotland Coast, West Shetland, East Shetland, East Scotland Coast, Moray Firth and Forth) were obtained from MERMAN. This extraction included both SEPA and MSS data. Only one sample, from the Tay estuary, exceeded the MPC of 75 µg kg^{-1} wet weight for the ICES6 PCBs in fish and fishery products.

Three-hundred and twenty-seven mussel samples, collected from nine Scottish regions (Clyde, Minches and Malin Sea, Hebrides, North Scotland Coast, West Shetland, East Shetland, East Scotland Coast, Moray Firth and Forth), have been analysed for trace metals over the last seven years (2007-2013) and data submitted to MERMAN. Data for Cd and Pb are available for all sites and for Hg for all but five sites. Most of these samples were collected and analysed by SEPA for the Dangerous Substances Directive and the Shellfish Waters Directive. Concentrations of Cd and Hg in all mussel samples were below the MPC of 1.0 mg kg^{-1} wet weight and 0.5 mg kg^{-1} wet weight, respectively. For Pb, seven samples exceeded the MPC of 1.5 mg kg^{-1} wet weight, three from the Clyde, two from the Forth, and two from Minches and Malin Sea.

Contaminants data (PAHs, PCBs, dioxins, trace metals) for the FSAS annual shellfish monitoring programme (2006-2011, inclusive) was provided to MSS. In total 139 shellfish samples (mussels, oysters, clams, razorfish, scallops and cockles) were analysed for PAHs. Benzo[*a*]pyrene was measured in all samples and all were below the regulatory level of 5 µg kg^{-1} wet weight for bivalve molluscs. Shellfish samples were also analysed for dioxins and PCBs (non DL-PCBs and DL-PCBs). In all cases the total TEQs (dioxin and DL-PCBs) and ICES6 PCB concentrations were lower than the EU regulatory limits of 6.5 pg g^{-1} TEQ wet weight and 75 µg kg^{-1} wet weight, respectively.

Between 2006 and 2011, 109 shellfish samples (mussels, oysters, clams, razorfish, scallops and cockles) were analysed for trace metals. All concentrations of Hg and Pb were below the regulatory level for bivalve molluscs. One sample exceeded the regulatory levels for Cd in bivalve molluscs, a scallop sample from Argyll and Bute in 2006.

Sampling Design for MSFD Descriptor 9

Objectives

Although existing contaminant data for fish and shellfish held by MSS, SEPA and FSAS suggests that concentrations are mainly below the regulatory levels, much of the fish data are unsuitable for use in assessments for Descriptor 9. Current environmental monitoring programmes are not designed to assess whether concentrations in fish for human consumption are of concern at the (sub) regional level. In particular, the programmes have limited spatial coverage and the species and matrix sampled are rarely those most relevant to human consumption. To surmount this, a sampling programme for fish should be designed for Descriptor 9 purposes. The design should target those species most destined for human consumption and ideally should sample fish in a way that is representative of the spatial and temporal distribution of the landings of the commercial fishery.

The GES target and indicators for contaminants in seafood proposed by the UK:

> *For contaminants where regulatory levels have been set, there should be a high rate of compliance based on relevant surveys and including samples originating from commercial fishing grounds in the greater North Sea and the Celtic Seas[3].*

is extremely vague. A ‘high rate of compliance’ is interpreted here as:

> The 95th quantile of the distribution of concentrations [of a contaminant] in the edible parts [muscle] of the landings [of a species] should be below the regulatory limit.

That is, the concentrations in 95% of landed fish should be below the regulatory limit. Adopting a precautionary approach, sampling will be designed so that, given current estimates of mean concentrations, there is a 90% power of demonstrating that the 95^{th} quantile is significantly below the regulatory limit based on a test at the 5% significance level.

There are two types of design that would provide the data to estimate the 95^{th} quantile of concentrations in the landings and that might be achieved at acceptable cost by extending existing monitoring activities. The first is to sample fish landings at market throughout the year as part of the MSS market sampling programme. By timing sampling occasions correctly, the samples would be representative of the temporal distribution of landings. However, ensuring representative spatial coverage would be more difficult, as it is hard to predict where the fish on market will come from (at a finer resolution than the sub regional scale) before visiting the market. The logistics of organising such a programme would also be quite complex and would increase costs. Finally, there would be no control over the treatment of the fish between the time of capture and of sampling (i.e. when they are landed) so there is the possibility of additional contamination.

The alternative, which is developed further below, is to collect fish during the annual MSS research vessel surveys that provide indices of abundance for fish stock assessment. This is much simpler and would ensure representative spatial coverage by sampling from trawl locations with probability proportional to the commercial landings. However, it will only give a snap-shot of contaminant levels in fish for human consumption at the time of the survey. It is thus important to ensure that the survey is during a period when landings are relatively high and when contaminant levels are not unduly low due to seasonal variation.

Sampling Areas

The MSFD (Article 4) lists ten sub-regions for monitoring purposes and the report of the ICES/JRC Task Group for Descriptor 9 lists the most consumed species in each. The relevant sub-regions for the UK are:

- The Greater North Sea, including the Kattegat and the English Channel (OSPAR Region II).
- The Celtic Seas (OSPAR Region III).

Scottish waters fall within OSPAR Region II (includes the Scottish sea areas East Shetland, Fladen, Moray Firth, East Scotland Coast, Forties, and Forth) and OSPAR

Region III (includes the Scottish sea areas Solway Firth and North Channel, Clyde, Minches and Malin Sea, Hebrides, Rockall, Bailey, North Scotland Coast, Faroe-Shetland, West Shetland).

MSS conducts annual bottom trawl surveys in the North Sea (OSPAR Region II) in Quarter 1 (January-March) and Quarter 3 (July-September). These surveys provide data that are used in the assessment of fish stocks in ICES Area IV. The spatial extent of each survey differs slightly but, for Descriptor 9 purposes, both surveys can be used to sample Scottish waters in the North Sea as defined in Figure 3. There are also annual bottom trawl surveys to the West of Scotland (OSPAR Region III) in Quarter 1 and Quarter 4 (October-December) that provide abundance indices for ICES Division VIa (Figure 3). Division VIa extends beyond Scottish waters but, for simplicity, is regarded as the sampling area for Descriptor 9. For simplicity, we refer to these sampling areas as North Sea and West of Scotland.

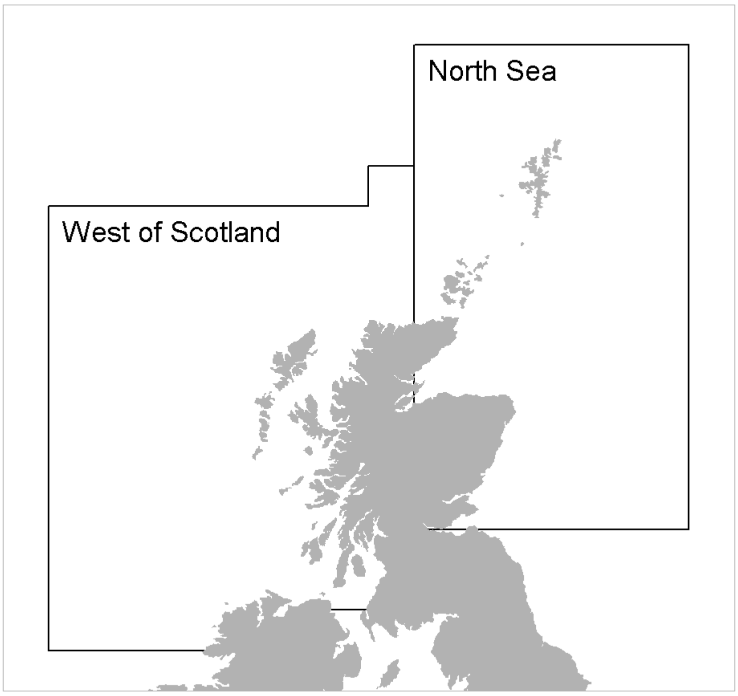

Figure 3 North Sea and West of Scotland D9 sampling areas.

Target Species

The ICES/JRC Task Group report for Descriptor 9[4] states that:

- In order to make monitoring results more comparable between (sub) regions, it would be advisable to select a limited number of target species from the most consumed species of fish and other seafood using the table in Annex II.

- General criteria for the selection of the species to be used for monitoring include species more prone to bio-magnify/bio-accumulate specific classes of contaminants, species representative of the different trophic levels or habitats, species representative for (sub) region.

Species for monitoring for Descriptor 9 should be selected using the list of most consumed species in OSPAR regions, presented in the ICES/JRC Task Group report[4]. Landings by Scottish vessels in the UK and abroad for 2012 have been reported[13] and are shown in Table 2 for species listed as being important in OSPAR Regions II and III.

The ability to accumulate contaminants should also be taken into account. Species with a higher lipid content and higher trophic status are likely to accumulate higher concentrations of contaminants. Trophic levels and the lipid content of the commercially relevant species are shown in Table 2. The lipid content can be classed as lean (0-2 %), medium fat (2-7%), fat (7-15%) and high fat (>15%)[18]. Factors such as migratory pattern and reproductive cycle can affect lipid content. In particular, fish have less lipid whilst spawning.

Table 2
Landings by Scottish vessels into the UK and abroad[13] and importance in OSPAR Regions II and III along with trophic level and lipid content class. The importance categories (+, ++ or +++) are taken from the ICES/JRC Descriptor 9 task Group report[4]. If the importance for Region 2 and 3 is different, then the Region 2 importance is shown first. Landings for the main species (total value landed > £2 million) are also shown by ICES areas (IVa and IVb - North Sea and VIa, VIb - West of Scotland)[13].

Common Name	Species	Importance in OSPAR regions II & III[4]	Scottish landings 2012 (tonnes)[13]		Trophic Level[12]	Lipid Content Class[a]
			North Sea	West of Scotland		
Herring	*Clupea harengus*	+++	33,640	8,369	3.2	fat
Cod	*Gadus morhua*	+++	10,565	146	4.4	lean
Hake	*Merluccius merluccius*	+++ (Region III only)	3,122	2,601	4.4	lean
Haddock	*Melanogramus aeglefinus*	+++ (Region III only)	25,528	4,661	4.1	lean
Monkfish	*Lophius spp*	+++ (Region III only)	4,637	2,074	4.5	lean
Megrims	*Lepidorhombus spp.*	+++ (Region III only)	1,378	675	4.2	lean
Whiting	*Merlangius merlangus*	+++ (Region III only)	8,717	203	4.4	lean
Mackerel	*Scomber scombrus*	+/+++	57,282	66,393	3.7	fat
Sole	*Solea solea*	+/+++			3.1	lean
Pollack	*Pollachius pollachius*	++ (Region III only)			4.2	lean
Sprat	*Sprattus sprattus*	+ /++			3.0	fat
Plaice	*Pleuronectes platessa*	+ /+++	2,845	39	3.3	medium fat
Saithe	*Pollachius virens*	+ /+++	5,485	4,541	4.4	lean

[a] lean, <2%; medium fat, 2-7%; fat, 7-15%; high fat, >15%[18].

Mackerel and herring, both pelagic species, are commonly found in OSPAR Regions II and III and have the highest landings by Scottish vessels (Table 2). Appendix 1 shows the spatial distribution of landings by vessels into Scotland during 2013. Herring are fished primarily to the north of Scotland whereas mackerel are fished over a wider area, reflecting their broader geographical distribution. For herring, landings are highest in the North Sea (33,640 tonnes in 2012) and for mackerel landings are similar in the North Sea (57,282 tonnes in 2012) and West of Scotland (66,393 tonnes in 2012). However, both species are migratory, mackerel more so than herring. Mackerel migrate from the spawning areas west of Ireland that they occupy from March through to July to the Viking bank area of the North Sea for the winter. Mackerel have the potential to move between the coast of northern Spain and the northern Norwegian Sea. Herring stocks are less mobile, but migrate within areas such as the west of Scotland or the North Sea. Although fish sampling for contaminant analysis should usually be outside the period of spawning, when fish are in a stable physiological state[19], this is not necessarily the case for Descriptor 9, particularly if the landings are greatest during the spawning season. Although herring can be found spawning in almost any month, around Scotland the majority spawn in the autumn, between August and October (North Sea and West Scotland). The lipid content of herring and mackerel muscle are in the range of 7-15%, and, therefore, they will have a higher potential to accumulate contaminants than lean species such as haddock and cod.

Of the demersal species, haddock and cod have the highest total landings by Scottish vessels, 30,189 and 10,711 tonnes respectively. For both species, landings from the North Sea are greater than from the West of Scotland[13]. Seasonal migrations of cod populations can take place, but in most areas feeding and spawning movements are limited. Similarly, haddock do not exhibit long migratory behaviour. Both cod and haddock muscle have a low lipid content (<2%). Monkfish have moderate landings by Scottish vessels and are found in both North Sea and West of Scotland grounds. They have a long spawning season, which takes place mainly during the first six months of the year, mostly in relatively deep water (150-1,000 metres).

Norway lobster (N*ephrops norvegicus*, also known as langoustine or Dublin Bay Prawn) is the most fished crustacean species, with Scotland having the largest *Nephrops* fishery in the world and the fishery being the second most valuable (at ca.£80 million p.a.) to Scotland after mackerel[20]. Adult *Nephrops* are non-migratory, spending most of their time in burrows in soft muddy sediment, except when feeding or to look for a mate. Due to the relationship between contaminant concentrations and sediment grain-size and organic carbon content, benthic organisms living in fine grained sediments may be more likely to accumulate contaminants than epibenthic or pelagic species. The largest Scottish fisheries in the North Sea are the Fladen Ground (~10,000 t p.a., ca.50% of North Sea catch), Firth of Forth and the Moray Firth; the North Minch, South Minch and Firth of Clyde on the West coast have similar sized fisheries (5-6000 t p.a.).

The target species for a Descriptor 9 sampling programme in both the North Sea and West of Scotland will, therefore, be haddock (high landings, high trophic level, limited migration, lean), herring (high landings, moderate trophic level, moderate migration, high lipid content), and monk (moderate landings, high trophic level, limited migration, lean). The individuals sampled should be of marketable size:

Haddock	≥30 cm (EC Regulation 850/98)
Herring:	≥20 cm (EC Regulation 850/98)
Monk:	≥500 g (EC Regulation 2406/96)
Nephrops:	≥25 mm carapace length (20 mm in the Clyde[21])

Stylized Sampling Design

This section describes the sampling design for a stylized fish survey in which the sampling area is sub-divided into S strata and there is a single haul in each stratum. Later sections then describe how the design was adapted and implemented for haddock, monk and herring, given the features of the bottom trawl surveys available.

Let L_s be the commercial landings (of a particular species) from stratum s, and let

$$p_s = \frac{L_s}{\sum_{s=1}^{S} L_s}$$

be the proportion of the total landings that came from stratum s. A representative sample of the landings is obtained by sampling from each stratum with probability proportional to p_s. This ensures that areas are sampled more frequently if they are more important to the fishery. The required number of fish from (the single haul in) each stratum is generated by simulating from a multinomial distribution

$$\mathrm{Mn}\,(n, p_1, p_2, \cdots, p_S)$$

where n is the total number of fish required (see below). Note that there is no unique allocation of fish to strata because the numbers are randomised: each simulation will generate a different design.

There are limited data on which to base the sample size n. Ten haddock, monkfish and herring were sampled on the Quarter 4 bottom trawl survey to the West of Scotland in 2012. The monkfish and herring were from a single haul and the haddock from five hauls, so there is no information about spatial variability in concentrations for the former two species, and only limited information for the latter.

The muscle of each fish was analysed for metals. There are regulatory levels for mercury (500 µg kg^{-1} for haddock and herring; 1000 µg kg^{-1} for monk), cadmium and lead (50 and 300 µg kg^{-1} respectively for all three species) (Table 1). All but one of the measured cadmium and lead concentrations were below the detection limits of 4.76 and 13.6 µg kg^{-1} respectively so, whilst reassuringly low, do not help much for design purposes. Assuming the mercury concentrations for each species are log-normally distributed, Table 3 shows the estimated median concentration, the standard deviation in log concentration, the 95^{th} quantile, and the upper 95% confidence limit on the 95^{th} quantile. The quantile and its upper confidence limit were estimated by maximum likelihood and profile likelihood methods respectively.

Table 3

Median mercury concentration (µg kg^{-1}), with standard deviation of log concentrations, 95^{th} quantile with upper 95% confidence limit, and regulatory limit.

		median	standard deviation	95^{th} quantile	confidence limit	regulatory level
Mercury	herring	61	0.68	186	350	500
	monkfish	139	0.55	344	578	1000
	haddock	107	0.31	177	236	500

For mercury, the 95^{th} quantiles are significantly below the regulatory level. This cannot be taken as proof of GES as the fish were taken from only a few locations (only one for herring and monkfish) but the estimates can be used to choose a sensible value of *n*. Table 4 shows the probability that the 95^{th} mercury quantile will be significantly below the regulatory level for different values of *n*, assuming the median concentration and standard deviation in Table 4. The table also shows the corresponding probabilities when the standard deviation is inflated by 1.5 as a pragmatic way of introducing some spatial variation. For the sample standard deviations estimated from the data, a sample size of n = 15 would give 90% power for all three species. If the standard deviations are inflated by 1.5, then 15 fish would still be adequate for haddock, but 50 monkfish would be needed and more than 100 herring. The cost of analysing these higher samples sizes would exceed the budget so, as a compromise, n = 20 fish of each species will be sampled. This gives acceptable power for the levels of variability observed in the data and a modicum of protection against additional spatial variation.

Table 4

Probability (%) that the 95th mercury quantile will be significantly below the regulatory level for different sample sizes *n* and standard deviations. Probabilities greater than 90% are in bold.

n	Herring sd = 0.68	sd = 1.02	Monk sd = 0.55	sd = 0.83	Haddock sd = 0.31	sd = 0.46
10	82	26	**94**	44	**100**	89
15	**93**	32	**99**	55	**100**	**97**
20	**98**	35	**100**	63	**100**	**99**
25	**99**	40	**100**	71	**100**	**100**
30	**100**	43	**100**	77	**100**	**100**
40	**100**	51	**100**	87	**100**	**100**
50	**100**	59	**100**	**93**	**100**	**100**
100	**100**	84	**100**	**100**	**100**	**100**

D9 Sampling in the North Sea

Figure 4 shows the planned haul locations for the 2014 bottom trawl surveys in the North Sea in Q1 and Q3. The sampling area is divided into ICES rectangles with usually one haul in each rectangle. The strata for the D9 survey are, therefore, taken to be the ICES rectangles, with suitable modifications when there are no hauls in a rectangle. Since concentrations would be expected to be positively correlated spatially, rectangles with no hauls were combined with adjacent rectangles until each stratum had at least one haul (see Figure 4). In the tables of D9 sampling designs that follow, each stratum is indexed by the rectangle within it that has a haul.

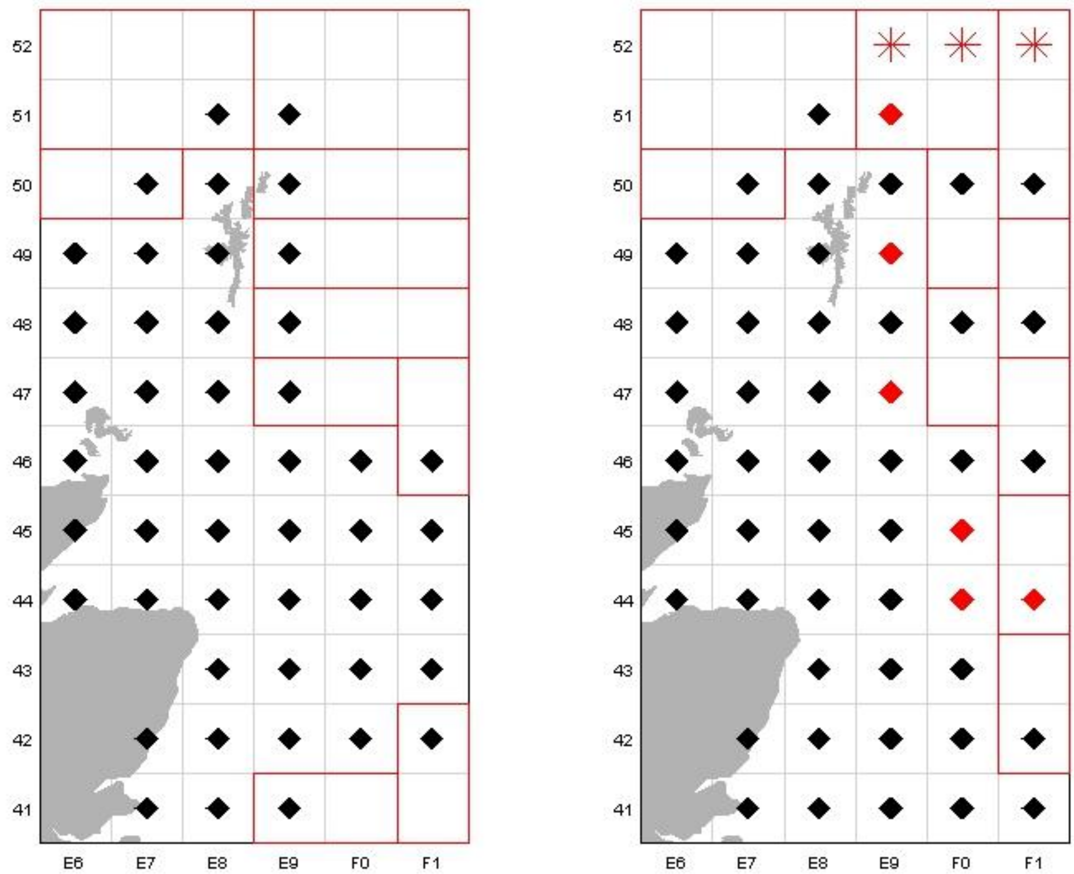

Figure 4: Planned bottom trawl surveys in ICES Area IV in Quarter 1 (left) and Quarter 3 (right) of 2014. Diamonds indicate haul locations and the thin black lines show ICES rectangles. When designing the D9 sampling, the Q3 haul locations shown in red had not been confirmed, with the red stars indicating possible alternatives. The red lines show where rectangles have been combined into larger strata to ensure that there is at least one haul in each stratum.

Haddock

North Sea haddock landings were fairly consistent across months in each of the years 2010-2013 apart from a dip in April (Figure 5). Therefore, either the Q1 or Q3 survey could be used to sample haddock for D9 purposes, since landings are likely to reasonably large at the time of both surveys. The spatial distribution of landings was also reasonably consistent across years with the greatest landings tending to be in the central part of the survey area (Figure 5) where both surveys will trawl all rectangles. A D9 sampling design (i.e. number of haddock from each stratum) was generated for the Q1 survey based on the spatial distribution of the landings in 2013 (Table 5). The Q1 survey was used because, if insufficient haddock were caught, sampling could be repeated during the Q3 survey. It is impossible to ensure that there will be sufficient fish caught on each haul to meet the D9 sampling requirements. To provide some protection against this, a second ‘contingency’ design was generated. Where possible, these extra fish should also be sampled and used to make up any shortfall in numbers in the primary design.

Table 5

D9 sampling design for North Sea haddock using the Q1 survey and 2013 landings. The total number of fish is the combined number from the primary and contingency design.

Statistical rectangle	Landings (tonnes)	Sampling probability	D9 sample size	Total Fish
E9 48	2325	0.10	3	7
E9 49	1819	0.07	3	7
F0 44	827	0.03	2	5
E9 44	1428	0.06	2	3
E8 44	1309	0.05	2	3
E8 46	1440	0.06	1	2
E8 49	843	0.03	1	2
E7 45	565	0.02	1	2
E7 44	796	0.03	0	2
E8 48	1473	0.06	1	1
E8 47	1276	0.05	1	1
E6 48	529	0.02	1	1
E8 50	244	0.01	1	1
E7 50	222	0.01	1	1
E9 43	1441	0.06	0	1
E6 49	118	<0.01	0	1

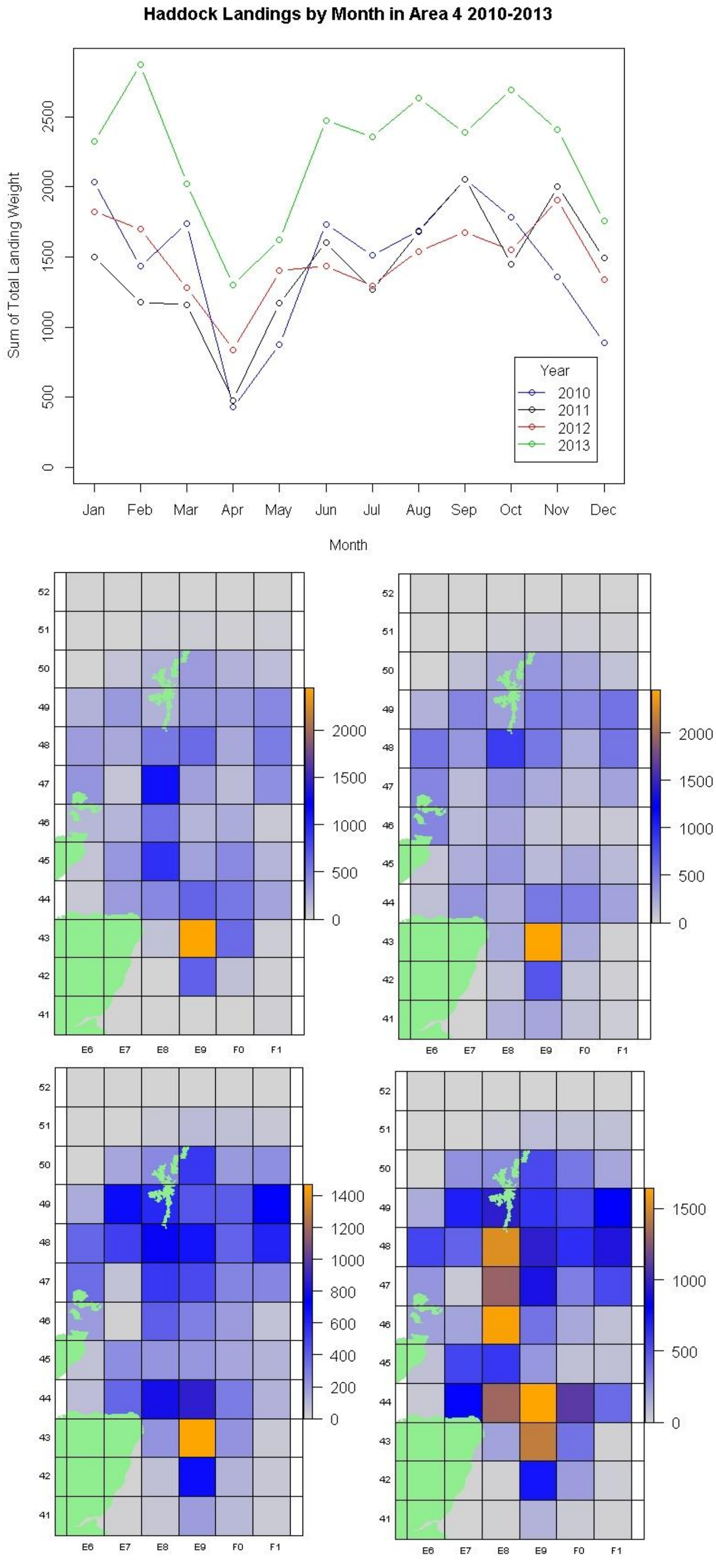

Figure 5: Haddock landings (tonnes) by Scottish vessels into Scotland from ICES Area IV for 2010-13. Top: monthly landings. Bottom: spatial distribution in the D9 sampling area (2010-2013 from top left).

Monkfish

North Sea monkfish landings within the North Sea were reasonable consistent across months for each of the years 2010-2013, although landings were generally highest in Q2 (Figure 6). For this reason, both surveys would be suitable for D9 sampling. The spatial distribution of landings was also reasonably consistent across years with the greatest landings in the north west of the survey area (Figure 6). A D9 sampling design was generated for the Q1 survey based on the spatial distribution of the landings in 2013, but only six of the required 20 fish were caught, despite having some contingency sampling. A new design was, therefore, generated for the Q3 survey (Table 6). Due to potential changes in haul locations during the Q3 survey some statistical rectangles selected in the D9 design may not be trawled. To cover for this, any samples generated for rectangles that may not be trawled were duplicated in a nearby rectangle that will be trawled.

Table 6

D9 sampling design for North Sea monkfish using the Q3 survey and 2013 landings.

Statistical rectangle	Landings (tonnes)	Sampling probability	D9 sample size	Total fish
E6 49	560	0.14	1	8
E6 48	332	0.08	4	5
F0 48	150	0.04	3	4
E9 50	168	0.04	3	3
E9 52	77	0.02	1	3
F0 46	77	0.02	1	3
E8 51	123	0.03	2	2
E8 50	124	0.03	0	2
F0 50	343	0.08	0	2
E7 49	185	0.05	1	1
E7 50	194	0.05	1	1
E9 48	86	0.02	1	1
E9 51	180	0.04	1	1
F1 44	26	0.01	1	1
E7 48	18	0.01	0	1
E9 45	106	0.03	0	1
F0 44	65	0.02	0	1

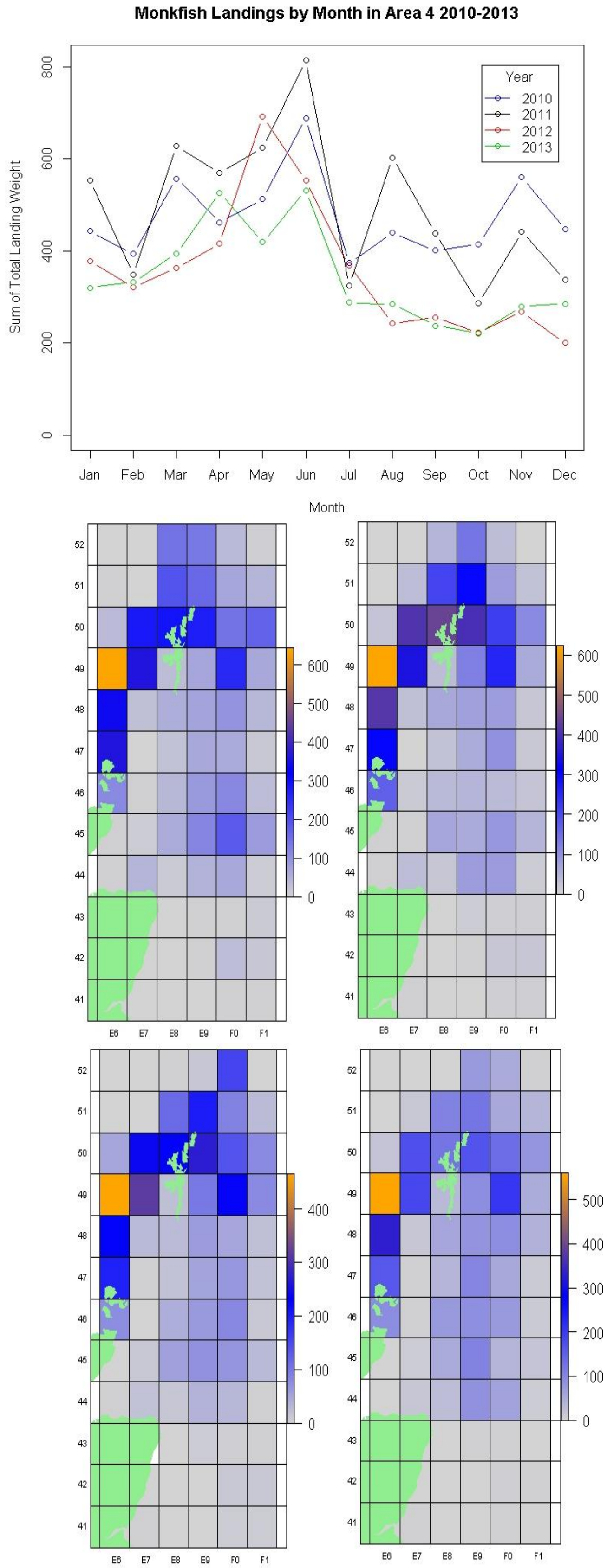

Figure 6: Monkfish landings (tonnes) by Scottish vessels into Scotland from ICES Area IV for 2010-13. Top: monthly landings. Bottom: spatial distribution in the D9 sampling area (2010-2013 clockwise from top left).

Herring

North Sea herring landings peak in August each year, with high landings between July and September (Figure 7), so only the Q3 survey is suitable for D9 purposes. The spatial distribution of herring landings for herring varied considerably between years (Figure 7), presumably due to schooling and the short period of peak fishing activity, with the greatest landings typically somewhere in the north western part of the survey area. To get a more robust prediction of 2014 landings, the D9 survey design was based on the average landings in each rectangle between 2010 and 2013. The sampling requirements are given in Table 7. Due to potential changes in sampling locations during the Q3 surveys (see Figure 4) some statistical rectangles selected may not be sampled. To account for this, any samples generated for rectangles that may not be sampled were duplicated in a nearby rectangle that will remain in the IBTS survey design for contingency.

Table 7

D9 sampling design for North Sea herring using the Q3 survey and averaged 2010-2013 landings.

Statistical rectangle	Landings (tonnes)	Sampling Probability	D9 sample size	Total fish
E8 47	3230	0.11	4	8
E8 48	1480	0.05	2	5
E7 46	817	0.03	3	3
E9 47	1250	0.04	1	3
E9 49	1070	0.04	1	3
E9 50	1060	0.04	0	3
E8 46	603	0.02	2	2
F0 43	383	0.01	1	2
F0 46	1230	0.04	0	2
E8 49	134	0.00	0	2
F0 44	991	0.03	1	1
E9 46	898	0.03	1	1
F1 46	529	0.02	1	1
E7 47	2050	0.07	1	1
F0 48	2200	0.08	1	1
E7 49	376	0.01	1	1
E8 44	402	0.01	0	1
F1 44	1020	0.04	0	1
E9 45	323	0.01	0	1
E6 46	575	0.02	0	1
E6 48	380	0.01	0	1
E7 48	2250	0.08	0	1
F0 50	222	0.01	0	1
F1 50	997	0.04	0	1

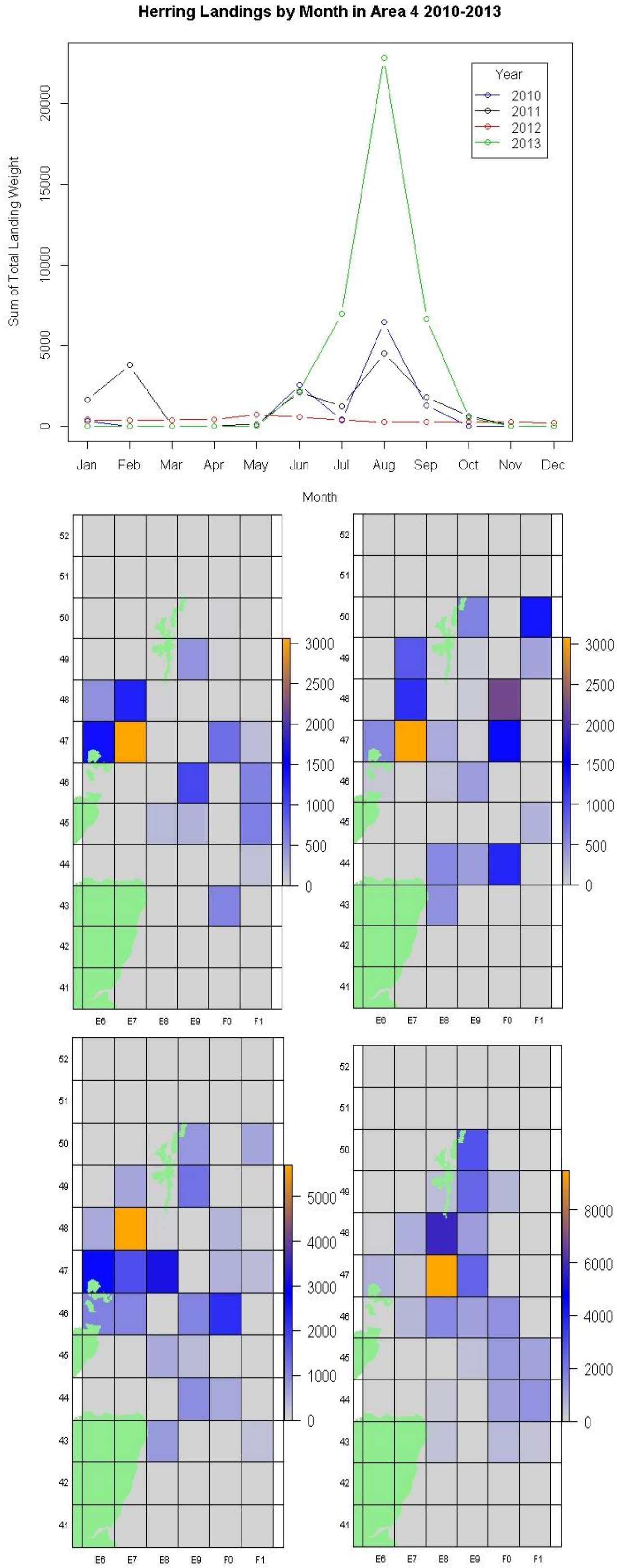

Figure 7: Herring landings (tonnes) by Scottish vessels into Scotland from ICES Area IV for 2010-2013. Top: monthly landings. Bottom: spatial distribution in Scottish waters (2010-2013 clockwise from top left).

D9 sampling to the West of Scotland

Figure 9 shows the strata used in the 2013 Q4 and 2014 Q1 bottom trawl surveys on the West Coast. The stratification is based on fish densities from previous surveys (denoted by different colours) further stratified into contiguous areas (see labels on Q4 survey). There is no sampling in the white areas (unfishable) or in the west of the survey area, but this is not a problem as landings from these areas are negligible. There are several hauls in each stratum, the number depending on the area of the stratum and the variation in fish densities within it. For D9 monitoring, the landings in each stratum are estimated by assigning the reported landings from each ICES rectangle to the stratum with which it shares the greatest area; for example the landings from rectangle 40E2 are assigned to stratum G3 in the Q4 survey. The target numbers of fish in each stratum are then generated from the proportions of the total landings in each stratum (as before). In theory, the fish from each stratum should be randomly chosen from the hauls in that stratum. In practice, a sensible number of fish are retained from each haul (to ensure that the target number is met) and then the fish are randomly chosen from these.

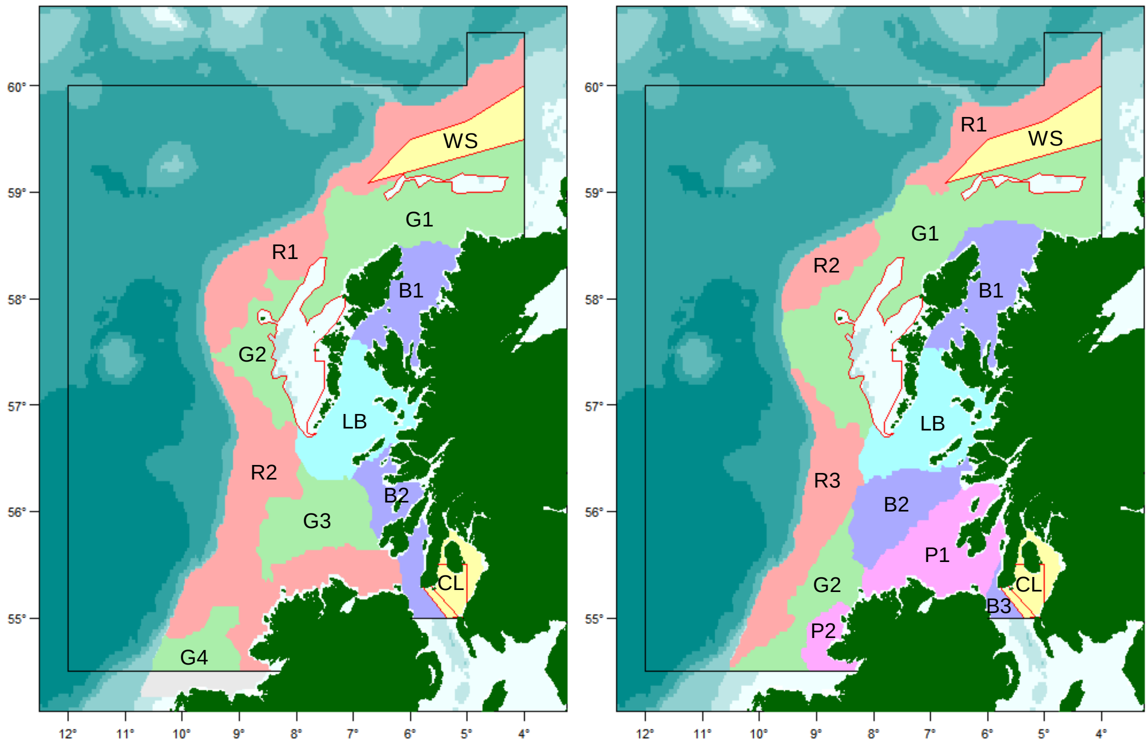

Figure 9: Strata used for the 2013 Quarter 4 (left) and 2014 Quarter 1 (right) bottom trawls surveys of ICES Division VIa (black line). White areas are unfishable areas. No samples are taken in the west of the area (essentially beyond the 200 m contour) as this is not suitable habitat for the target species (cod, haddock, whiting, saithe and hake).

Haddock

The monthly pattern of West of Scotland haddock landings varied considerably over years (Figure 10). The landings were relatively high and had the greatest consistency in Q1 and the Q1 survey is the obvious choice for D9 purposes. However, at the time of designing the survey (Oct 2013), only the 2012 and provisional 2013 landings had been considered and these suggested the Q4 survey was also a reasonable choice. Haddock landings are mostly from the north-east of the area (Figure 10). A D9 sampling design was generated for the Q4 survey using provisional 2013 landings but, due to bad weather, only part of the survey area was covered, and only some of the required haddock were caught. A revised sampling design was, therefore, generated for the Q1 survey using revised 2013 landings (Table 8). To avoid unnecessary sampling, those fish that had been caught on the Q4 survey were regarded as having come from the Q1 survey and used where possible.

Table 8

D9 sampling design for West of Scotland haddock using the Q1 survey and 2013 landings. The last column gives the number of fish per haul required to provide a reasonable chance of sampling sufficient fish overall.

Stratum	Landings (tonnes)	Sampling Probability	D9 sample size	Fish per haul
R1	155	0.04	2	1
R2	61	0.02	0	0
G1	2998	0.85	16	3
B1	107	0.03	0	0
LB	156	0.04	1	1
R3	45	0.01	1	1

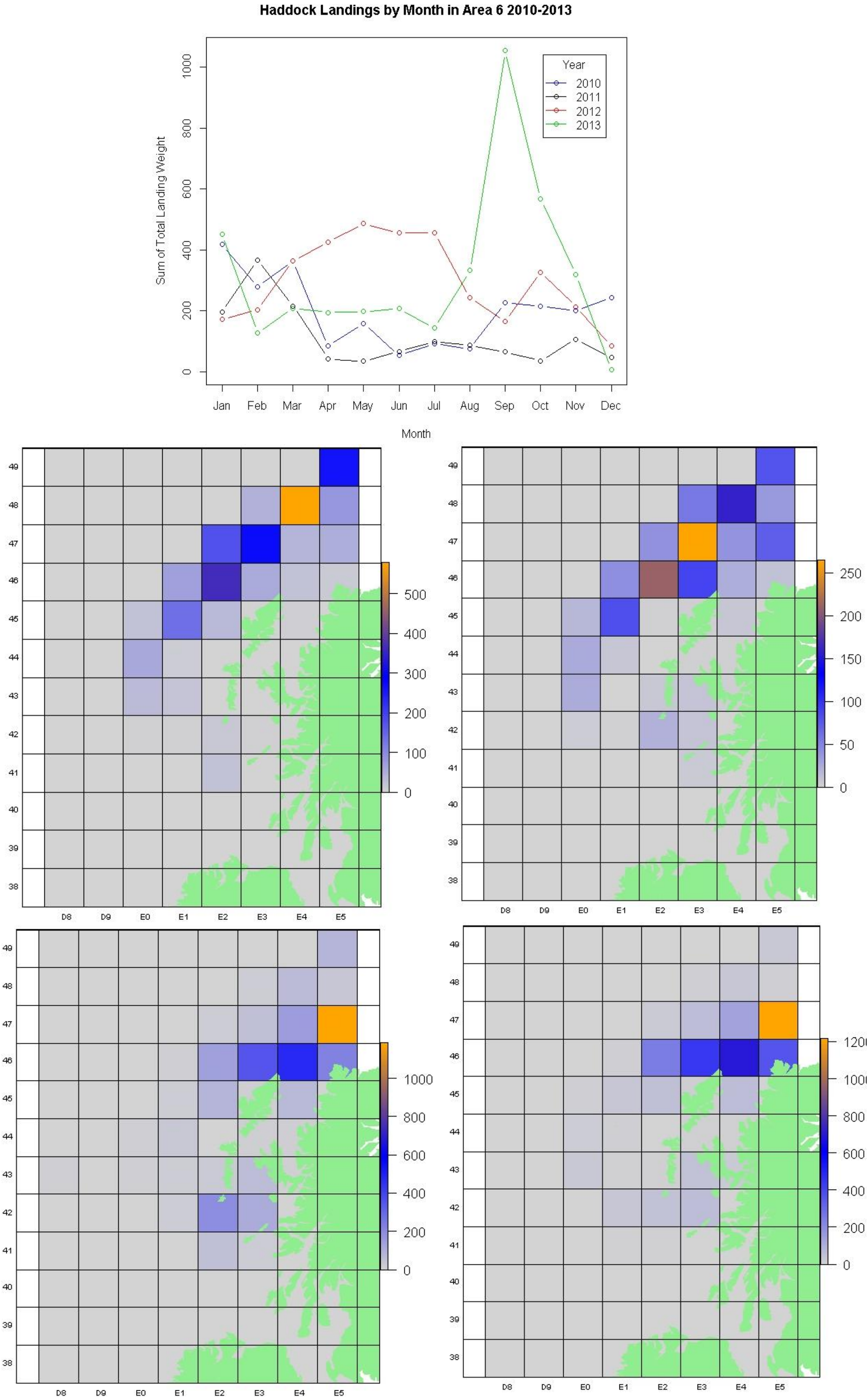

Figure 10: Haddock landings (tonnes) by Scottish vessels into Scotland from ICES Division VIa 2010-13. Top: monthly landings. Bottom: spatial distribution (2010-2013 clockwise from top left).

Monkfish

The monthly pattern of West Coast monkfish landings was consistent over years (Figure 11). Landings were relatively high throughout Q1 and usually high again in December. On this basis, the Q1 survey is a robust choice for D9 purposes. The spatial distribution of landings is consistent across years (Figure 11) with landings mostly from close to the shelf edge (the 200 m controur). A D9 sampling design was generated for the Q1 survey using 2013 landings (Table 9).

Table 9

D9 sampling design for West of Scotland monkfish using the Q1 survey and 2013 landings. The last column gives the number of fish per haul required to provide a reasonable chance of sampling sufficient fish overall.

Stratum	Landings (tonnes)	Sampling Probability	D9 sample size	Fish per haul
R1	226	0.25	4	3
R2	168	0.19	3	3
G1	414	0.46	11	2
LB	56	0.06	2	2

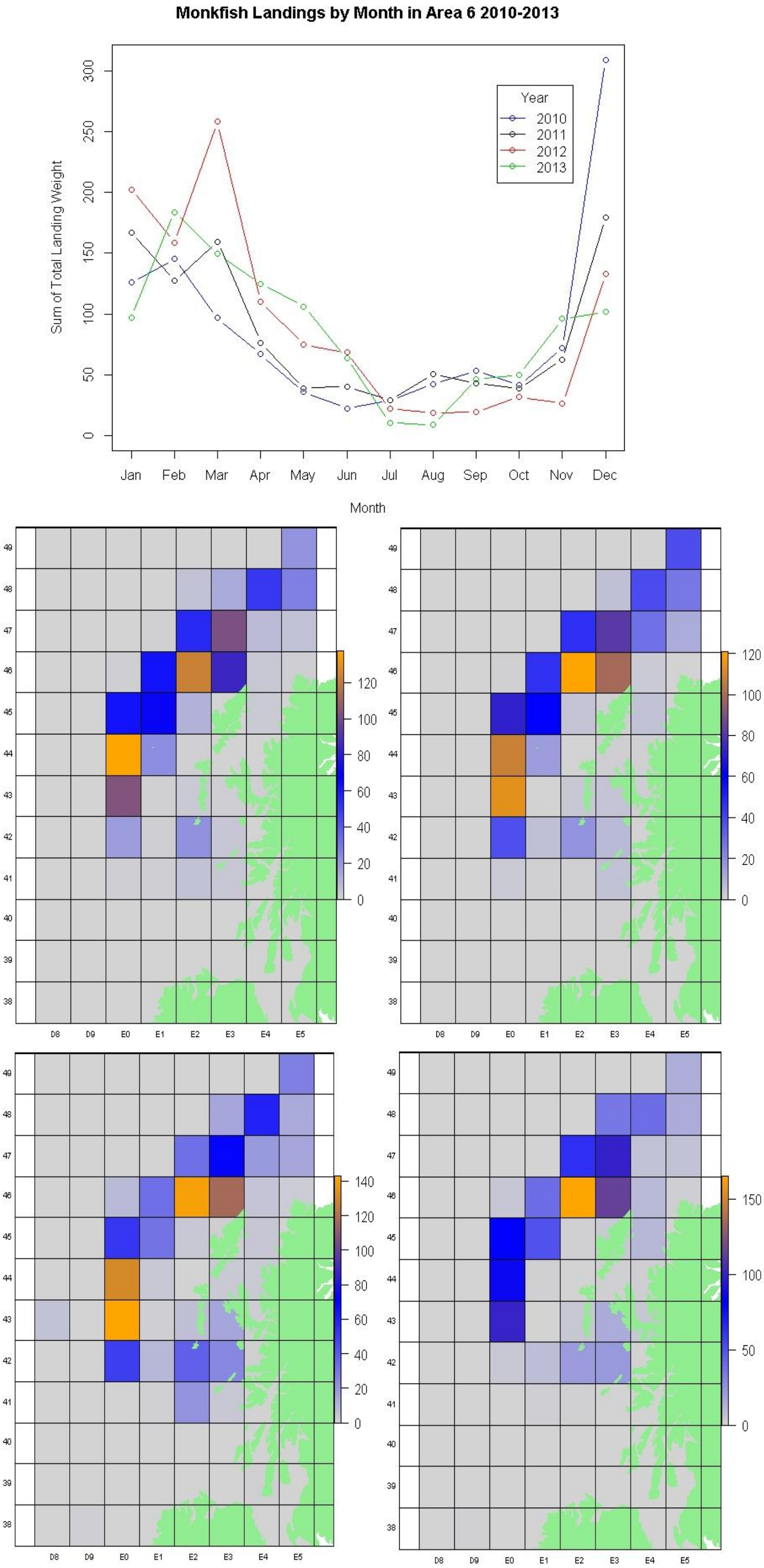

Figure 11 Monkfish landings (tonnes) by Scottish vessels into Scotland from ICES Division VIa 2010-13. Top: monthly landings. Bottom: spatial distribution (2010-2013 clockwise from top left).

Herring

Herring landings usually peak in August, with virtually all landings between July and September (Figure 12). As the herring acoustic survey (HERAS) is the only survey of the West of Scotland area in Quarter 3, this survey was used to collect herring samples for D9 purposes. Across years, herring landings have been consistently high in the north east of the area and low elsewhere (Figure 12). HERAS has a predetermined route, which includes the part of the West of Scotland area with high herring landings. However, HERAS only trawls for fish to ground-truth acoustic readings. During the last three HERAS surveys, at least four statistical rectangles were trawled (Figure 12). These rectangles varied between years, but the rectangle with the highest landings in 2013 was trawled every year and nearby rectangles were also trawled. Since trawling locations are unknown before the survey, a D9 design based on landings could not be generated. Instead, given that every year at least four statistical squares are trawled, five fish will be required from each trawled rectangle to meet the minimum requirement of 20 fish. This was doubled to ten fish from each trawled rectangle for contingency. The choice of fish for analysis will then be based on a post-hoc randomisation of the sampled fish based on the herring landings in 2014.

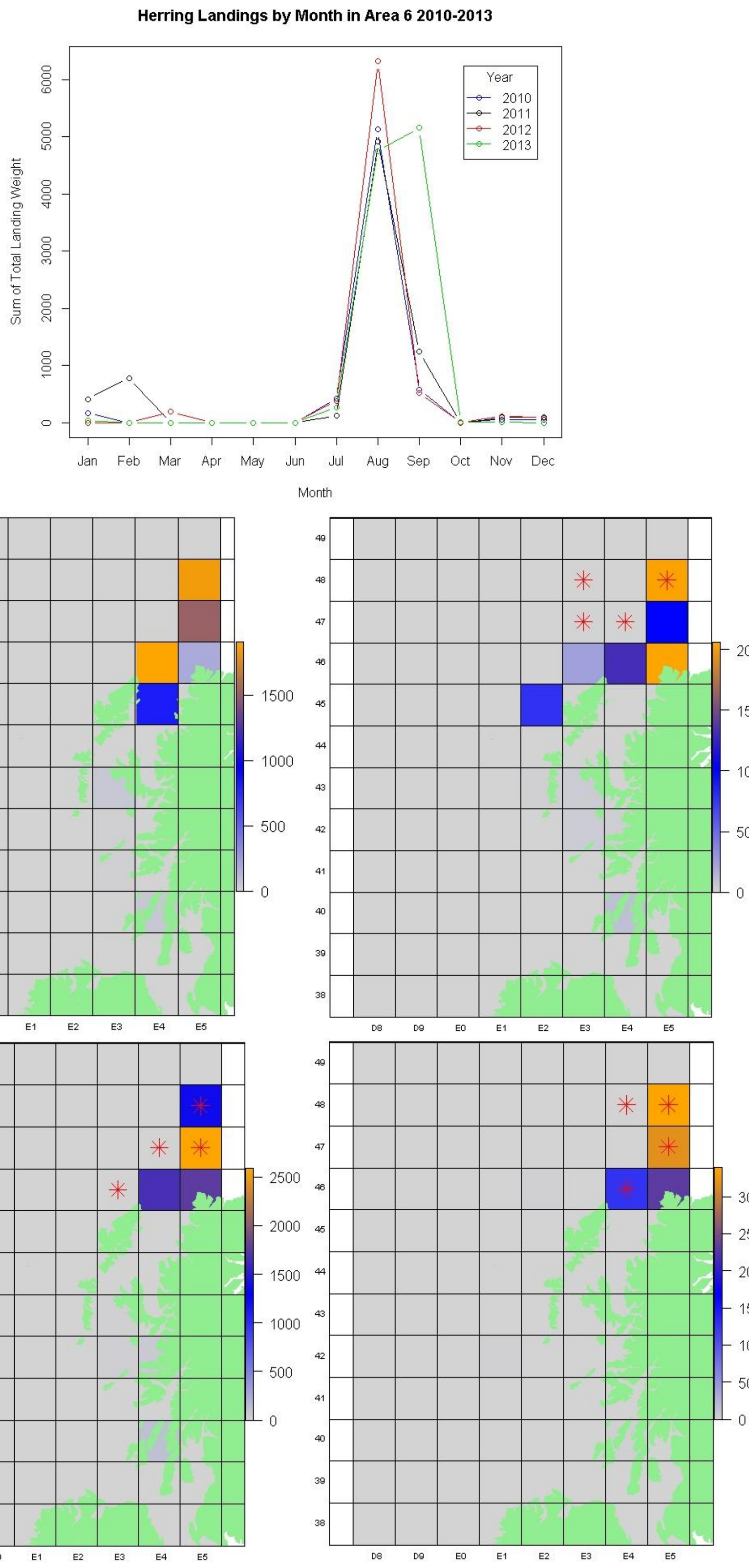

Figure 12: Herring landings (tonnes) by Scottish vessels into Scotland from ICES Division VIa 2010-13. Top: monthly landings. Bottom: spatial distribution (2010-2013 clockwise from top left). Red stars indicated herring acoustic survey (HERAS) locations (only data from 2011-2013 used).

Conclusions

1. The Marine Strategy Framework Directive's Descriptor 9 states that ***'contaminants in fish and other sea food for human consumption do not exceed levels established by Community legislation or other relevant standards***'. Therefore, for Descriptor 9 assessment, contaminant concentrations in fish and seafood should be compared against the EC regulatory levels.

2. European regulatory levels are available for trace metals (Cd, Hg and Pb), dioxins, DL-PCBs and non DL-PCBs (ICES6, CB28, 52, 101, 138, 153 and 180) in fish muscle, crustacea and bivalve molluscs, for PAHs (benzo[*a*]pyrene), in crustacean and bivalves and for dioxins (including DL-PCBs) and non DL-PCBs in fish liver (EC/1881/2006 and EC/1259/2011).

3. Current Scottish monitoring programmes for contaminants in shellfish undertaken by SEPA and FSAS will be of use for Descriptor 9 assessments. SEPA monitor 56 shellfish sites around Scotland for metals (including Cd, Hg and Pb), PCBs (ICES7, CB28, 52, 101, 118, 138, 153 and 180) and PAHs (including benzo[*a*]pyrene], this data is submitted to the MERMAN database. As part of statutory monitoring, FSAS conducts annual monitoring of chemical contaminants (metals, PAHs, PCBs, dioxins and organochlorine pesticides) in newly classified shellfish areas and/or shellfish areas which were subject to sanitary surveys. These data are not currently submitted to the MERMAN database, but may be in future, and could be of use for Descriptor 9 assessments. This may require amendments to MERMAN which will require additional resource.

4. MSS monitor contaminants (including Cd, Hg, Pb and ICES6 PCBs) in fish at sites around Scotland for programmes such as the UK Clean Seas Environment Monitoring Programme (CSEMP) and Clyde trend monitoring programme. Most of these data will be of little use for Descriptor 9 assessments as commercially exploited fish species/size-ranges are not targeted and, with the exception of metals, contaminants are measured in fish liver rather than in the edible flesh.

5. Dioxins and DL-PCBs in fish muscle or liver are not an OSPAR CEMP requirement and, therefore, are not routinely monitored for UK CSEMP. Due to the very low concentrations of dioxins found in the environment, the chemical analysis requires high-resolution mass spectrometry. MSS and

SEPA do not have the capability to measure dioxins, so this analysis would have to be contracted out at significant cost. However, dioxin TEQs may be estimated from the PCB concentrations using published models and could be used to demonstrate if dioxin TEQs are likely to exceed the MPC. Therefore, no additional monitoring of dioxins and DL-PCBs is proposed for Descriptor 9.

6. Available data obtained from FSAS and from the MERMAN database indicates that GES is likely to be achieved for Descriptor 9. Shellfish data in the MERMAN database (trace metals, PCBs and PAHs) and from FSAS (trace metals, PAHs, PCBs and dioxins) shows that concentrations are below the available maximum permitted concentrations (MPCs) in nearly all samples. Although there is very little data on the concentration of dioxins, particularly for fish, the available data indicates that concentrations are not of concern. The FSAS has carried out a number of surveys on dioxins in fish and fishery products. Concentrations were generally below MPCs.

7. Recent data are not available on the concentrations of contaminants in *Nephrops*, although this is the most fished crustacean species. *Nephrops* burrow in fine sediment, which will contain higher concentrations of contaminants than coarse sediments. A statistical sampling design has not been undertaken, but samples will be taken from commercially important fishing grounds (the Clyde and the Moray Firth) close to potential sources of contaminants.

8. Although there are monitoring programmes in place for the analysis of contaminants in biota (such as FSAS surveys and the UK CSEMP), they do not fully meet the requirements of MSFD Descriptor 9, particularly for fish. Therefore, a fish sampling programme for Descriptor 9 was designed. Haddock, monkfish and herring were selected based on their importance to the human diet (based on landings data) and their ability to accumulate contaminants. Sampling was based around existing research vessel surveys for obtaining indices of abundance for use in fish stock assessments. Fish were sampled on these surveys from haul locations with probabilities proportional to landings.

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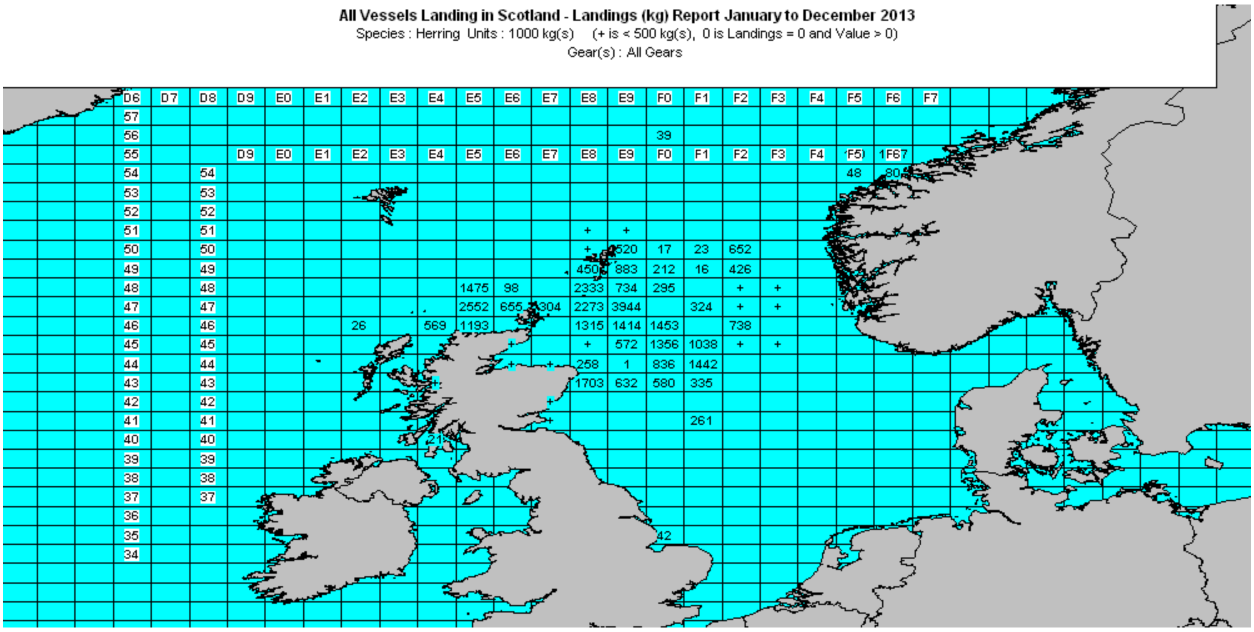
Appendix 1

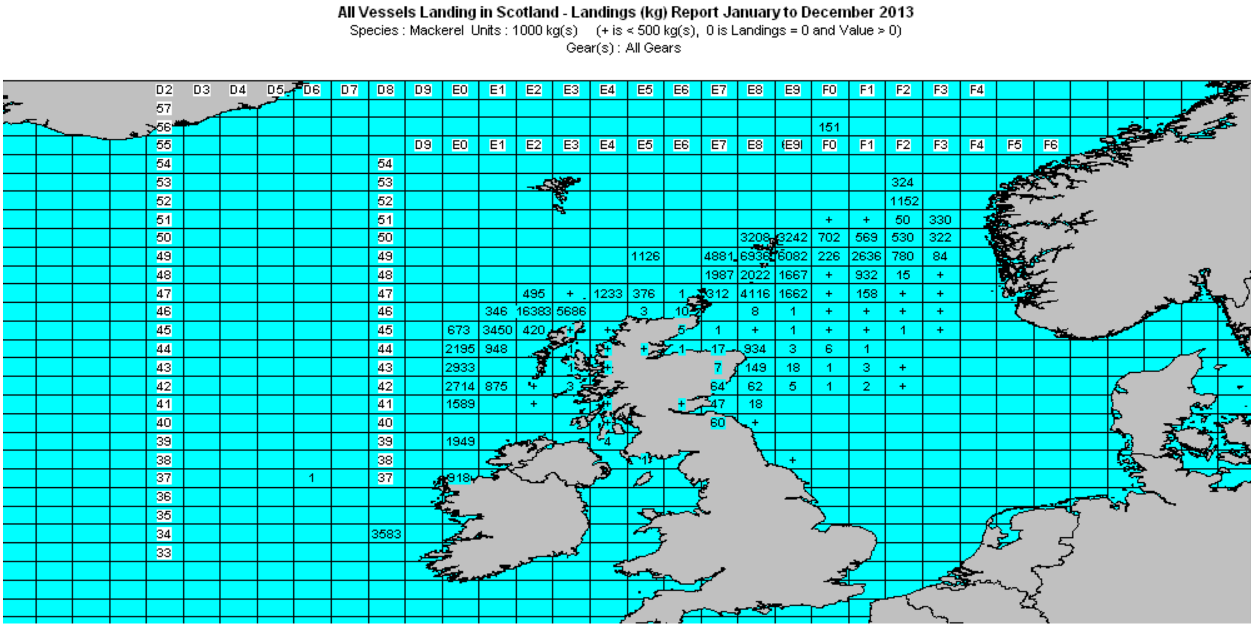
Maps showing the landings in Scotland, by ICES stat Squares, in 2013 for Herring, Mackerel, Haddock, Cod, Monkfish (Angler) and Norway Lobster.

Units: 1000 kg

Herring

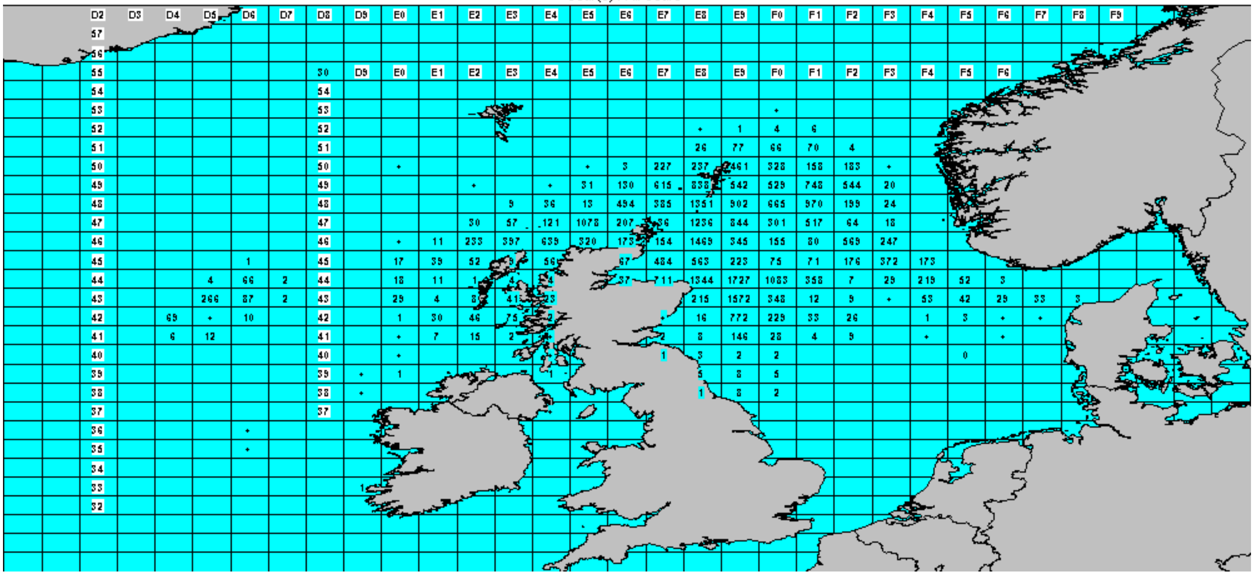


Mackerel



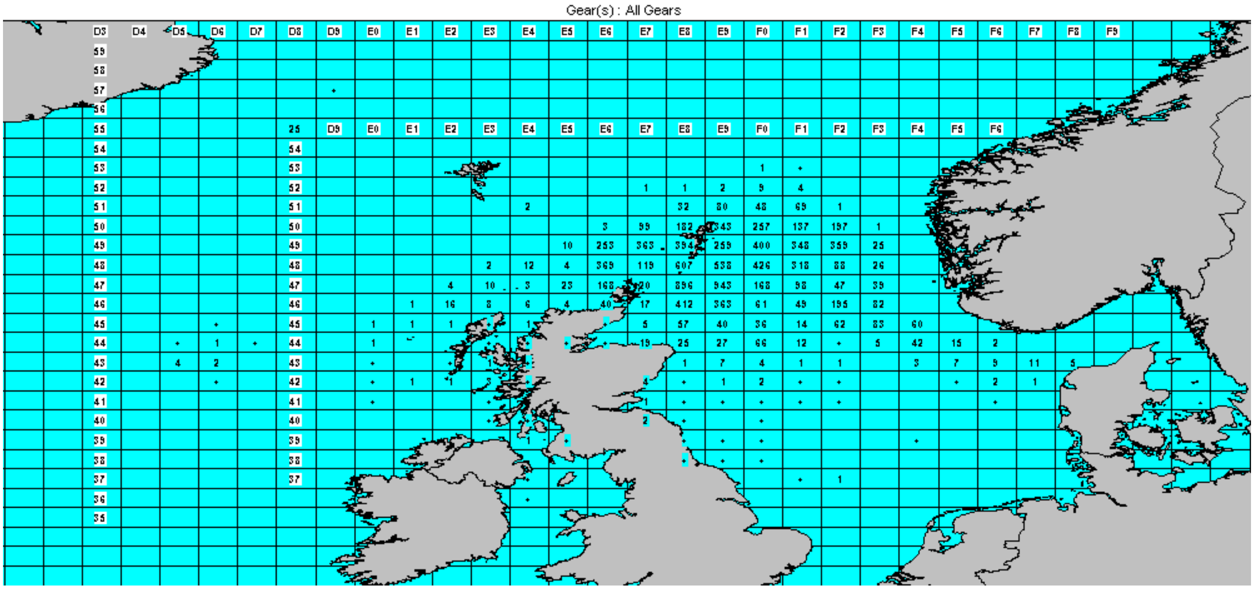
Haddock

All Vessels Landing in Scotland - Landings (kg) Report January to December 2013
Species : Haddock Units : 1000 kg(s) (+ is < 500 kg(s), 0 is Landings = 0 and Value > 0)
Gear(s) : All Gears



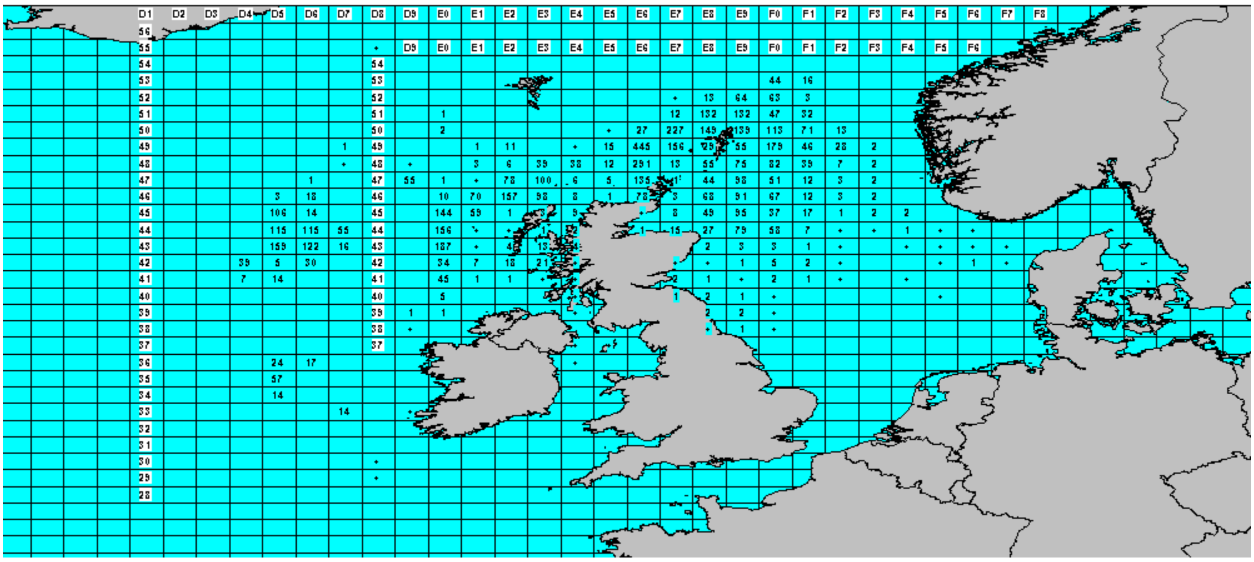
Cod

All Vessels Landing in Scotland - Landings (kg) Report January to December 2013
Species : Cod Units : 1000 kg(s) (+ is < 500 kg(s), 0 is Landings = 0 and Value > 0)
Gear(s) : All Gears



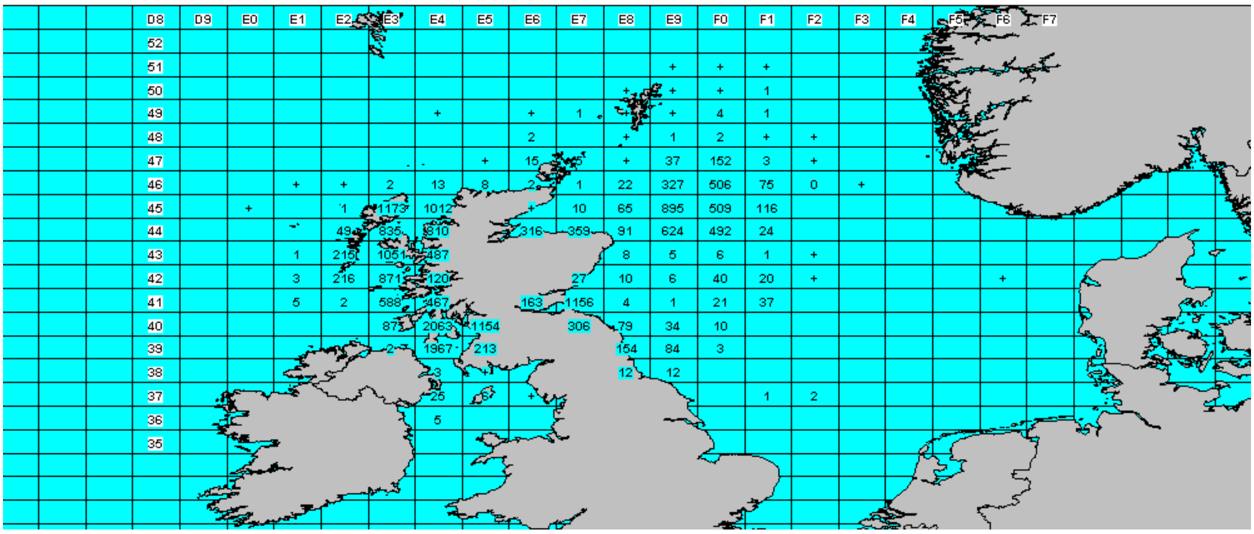
Monkfish

All Vessels Landing in Scotland - Landings (kg) Report January to December 2013
Species : Angler fishes (unidentified) Units : 1000 kg(s) (+ is < 500 kg(s), 0 is Landings = 0 and Value > 0)
Gear(s) : All Gears



Nephrops

All Vessels Landing in Scotland - Landings (kg) Report January to December 2013
Species : Norway Lobster Units : 1000 kg(s) (+ is < 500 kg(s), 0 is Landings = 0 and Value > 0)
Gear(s) : All Gears



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