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**Clyde Ecosystem Review**

**F McIntyre, P G Fernandes and W R Turrell**

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# CLYDE ECOSYSTEM REVIEW

McIntyre, F., Fernandes, P.G. and W. R. Turrell

## Contents

1. EXECUTIVE SUMMARY .....	4
1.1 Introduction .....	4
1.2 Literature Review - Environment .....	5
1.3 Literature Review - Biodiversity .....	6
1.4 Literature Review – Non-Fishing Human Impacts .....	8
1.5 Literature Review - Fishing (Pelagic and Shelfish) .....	9
1.6 Heath and Speirs (2011) .....	13
1.7 A Management Data Tool .....	17
1.8 Suggestions for Future Work.....	19
1.8.1 Clyde Hydrodynamic Model .....	19
1.8.2 Clyde Ecosystem Model .....	20
1.8.3 Clyde Inshore Benthic Survey .....	20
1.8.4 Clyde – an MSFD Development Area? .....	20
1.8.5 Clyde Pelagic Fish Stock Acoustic Survey .....	20
1.8.6 Clyde Demersal Fish Survey.....	20
1.8.7 Improving the Clyde Management Evaluation Model .....	21
2. INTRODUCTION .....	22
2.1.1 An Ecological Desert - Thurston and Roberts (2010) .....	22
2.1.2 A Changed Ecosystem - Heath and Speirs (2011) .....	22
2.1.3 This Report .....	23
3. THE ENVIRONMENT OF THE CLYDE SEA.....	25
3.1 Definition of the Clyde Sea.....	25
3.2 Geological History of the Clyde .....	25
3.3 Bathymetry and Sedimentology .....	26
3.4 Hydrography .....	28
3.4.1 An Annual Cycle in the Clyde.....	29
3.4.2 Warming Sea Temperatures .....	32
3.5 Plankton.....	32
3.5.1 Phytoplankton .....	33
3.5.2 Zooplankton .....	35
3.6 Concluding Remarks.....	35
3.7 Suggestions for Further Work .....	35
4. BIODIVERSITY .....	37
4.1 Background.....	37
4.2 Benthic Fauna.....	38
4.3 Maerl beds .....	39
4.4 Seabirds .....	40
4.5 Megafauna.....	41
4.6 Threats to Biodiversity.....	42
4.6.1 Invasive species .....	42
4.6.2 Climate change.....	42
4.7 Protection of Biodiversity.....	42
4.8 Suggestion for Further Work .....	43
5. HUMAN IMPACTS (OTHER THAN FISHING) .....	46
5.1 Background.....	46
5.2 Assessment of Pollution .....	47
5.3 Marine Litter .....	52
5.4 Shipping.....	52

5.5	Aquaculture.....	53
5.6	Scotland's Marine Atlas – Overall Assessment .....	54
5.6.1	Activities and Pressures.....	54
5.6.2	Clean and Safe.....	55
5.6.3	Healthy and Biologically Diverse.....	55
5.6.4	Response / Forward Look.....	55
5.7	Concluding Remark .....	56
6.	HUMAN IMPACTS - FISHERIES .....	57
6.1	Introduction.....	57
6.2	Legislation.....	57
6.3	Stock Assessment .....	59
6.4	Pelagic Fisheries.....	59
6.4.1	Herring.....	59
6.5	Demersal Fisheries.....	61
6.5.1	Cod.....	63
6.5.2	Hake .....	64
6.5.3	Saithe .....	65
6.6	Shellfish fisheries.....	65
6.6.1	Nephrops.....	65
6.6.2	Scallops.....	68
6.6.3	Other Shellfish .....	70
6.7	Sea Angling .....	70
6.8	Environmental Effects of Fishing.....	71
6.8.1	Trawling.....	71
6.8.2	Dredging.....	72
6.8.3	Discards.....	72
6.9	Suggestion for further work.....	73
7.	THE CURRENT STATUS OF THE CLYDE DEMERSAL FISH COMMUNITY .....	74
7.1	Summary of Demersal Clyde Landings .....	74
7.2	A Climatic Effect ?.....	75
7.3	Limitations of Landings Data.....	76
7.4	Research Vessel Survey Data .....	76
7.4.1	Constructing the Time-Series.....	76
7.4.2	The Basic Fish Data.....	77
7.4.3	Demersal Fish – Changes in Biomass .....	78
7.4.4	The Mix of Demersal Fish Species in the Clyde .....	82
7.5	Concluding Remarks.....	86
7.6	Suggestions for Further Work .....	87
8.	ECOSYSTEM COMPARISONS.....	88
8.1	Black Sea.....	88
8.2	Gulf of St Lawrence .....	88
8.3	Mediterranean.....	89
9.	CLYDE MANAGEMENT EVALUATION MODEL (CMEM) .....	90
9.1	Introduction .....	90
9.2	Methodology and Model Data Layers.....	90
9.2.1	Create grid.....	90
9.2.2	Masks .....	91
9.2.3	Bathymetry .....	92
9.2.4	Areas and Volumes.....	92
9.2.5	Habitat Type .....	92
9.2.6	Fishing Activity Data (VMS) .....	93
9.3	Results.....	95
9.3.1	Bathymetry .....	95
9.3.2	Depth Distribution .....	95
9.3.3	Spatial Limit Masks .....	97

9.3.4	Areas and Volumes of the Clyde Spatial Domains .....	97
9.3.5	Sediment Distribution.....	98
9.3.6	Fishing Activity – Raw VMS .....	100
9.3.7	Fishing Activity – Interpolated Maps.....	101
9.3.8	Concluding Remarks.....	103
9.3.9	Suggested Further Work.....	103
10.	Bibliography .....	105
10.1.1	Proceedings of the Royal Society of Edinburgh B, Volume 90, 1986.....	116
11.	Annex – Species list for the Clyde from Heath and Speirs (2011).....	118

## 1. EXECUTIVE SUMMARY

### 1.1 Introduction

In July 2010 a scientific paper authored by researchers from York University was published, entitled “Ecological Meltdown in the Firth of Clyde, Scotland, Two Centuries of Change in a Coastal Marine Ecosystem” (Thurston and Roberts, 2010).

This stimulated immediate media interest (Glasgow Herald and Sunday Times articles, Radio 5 live) and a BBC Panorama programme in August.

Subsequently, Marine Scotland Science (MSS) commenced work which led to this review of the Clyde Ecosystem.

Independently from the process underway within Marine Scotland, the University of Strathclyde also commenced work on the issue of the ecological status of the Clyde.

While Thurston and Roberts (2010) relied entirely on landings data, the University of Strathclyde study used research vessel survey data obtained from MSS.

As a result of a detailed and well-founded analysis, in July 2011 Professor Heath published a definitive analysis of the present state of the Clyde Sea demersal fish community in his paper, with Dr Doug Speirs, entitled “Changes in species diversity and size composition in the Firth of Clyde demersal fish community (1927-2009)” (Heath and Speirs, 2011).

The conclusions of Heath and Speirs (2011) point to a major ecological impact of fishing in the Clyde.

However, the picture portrayed by Heath and Speirs is not one of an ecological desert, but of an altered ecosystem. Their principal conclusions were,

- rather than commercial species being entirely removed from the Clyde, the biomass of the six main commercial species in the late 2000s was approximately double that prior to the onset of trawling in the 1960s.
- however, the size structures of these species were dramatically different, being markedly deficient in large commercially marketable individuals after the period of peak harvesting rates in the 1980s
- also the incidence of species with a maximum attainable length greater than 40 cm declined precipitously and did not recover during the period of low harvesting rates after the late 1990s possibly owing to internal predator–prey interactions.

This means that the Clyde Sea still functions as an ecosystem. Primary production still occurs, powered by the sun and supplied by water-borne nutrients, which sustains secondary zooplankton production, which in turn feeds an active food web. The Clyde is not an ecological desert.

However, the Clyde ecosystem has been changed. The biomass of fish in the Clyde is the same, or for some species more, than when intensive fishing started.

Additionally, a large and healthy population of shellfish (*Nephrops*) living on the sea bed of the Clyde is present.

However, the community of fish is now made up mostly of small fish, and mostly small whiting.

If we were to seek a terrestrial analogy it would not be that of a desert. Rather it might be that of used agricultural land in need of restoration. Comparing the Clyde to an ecosystem modified by human use yet capable of restoration portrays a much less news-worthy image than an ecological desert.

The Clyde ecosystem is one that has been used by humans for centuries, and hence it is changed. But humans can also now influence the direction the ecosystem takes by managing human activities in the future, precisely because the Clyde is not an ecological desert, but is an active ecosystem with great potential for future sustainable use.

In some respects this report marks the start of a process, rather than the conclusion of one. It poses more questions than it answers, and presents preliminary analysis of a new data set that requires further validation, checking and expansion.

However, it provides a start point from which government and stakeholders concerned with the future of the Clyde can build upon and progress. It puts into context some secondary issues which may cloud the primary focus of future work to recover the Clyde ecosystem; how we manage fisheries in the Clyde.

The report which follows has the following objectives,

- To present a brief review of previously published information and knowledge concerning the Firth of Clyde ecosystem.
- To present the findings of Heath and Speirs (2011) in a format accessible to stakeholders and managers.
- To propose a data tool which may help inform future management options in the Clyde.
- To make suggestions for further studies in the Clyde required in order to support sustainable use of this active Scottish marine ecosystem.

## **1.2 Literature Review - Environment**

The Clyde Sea presents the overall characteristics of a semi-enclosed fjordic basin, receiving freshwater inputs from the land and having partial exchange with the waters on the adjacent coastal shelf at its mouth.

The sea bed physical habitats in the Clyde are dominated by the local depth, the local sediment type and the local tidal currents and wave action. The predominant shape and bathymetry of the Clyde basin, and the distribution of the principal sea bed types, including the gravels, sands and muds, have been little changed since the end of the last glacial period (ice age).

The basis of the marine food web in the Clyde, i.e. the annual cycle of plant (phytoplankton) growth, fed by water-borne nutrients, and the subsequent feeding and growth of microscopic animals (zooplankton), appears healthy and productive in the Clyde.



From large scale observations, there are no obvious signs of negative effects on the food web of pollution, nutrient enrichment or any other man-made source of contamination. This does not preclude the possibility of small-scale local effects.

Although the waters of the Clyde Sea are warming, this is in line with other coastal areas west of Scotland. There is no evidence that the warming in itself has reduced the potential productivity of the Clyde.

### **1.3 Literature Review - Biodiversity**

The Clyde Sea area has a wide range of habitats which support a large diversity of plant and animal species.

There is some concern that human activities may have already had effects on those species and habitats, through overexploitation, habitat destruction and environmental change.

Historically the Clyde has supported large populations of herring and whitefish, which have in recent years undergone a dramatic decline, and commercial fishing is now largely dependent on shellfish species.

The fauna of the Clyde does show some anomalies when compared with that of the west coast, particularly the Clyde algal fauna, with some species only found in the Clyde.

The seas of the Clyde also support populations of megafauna such as seals, dolphins, whales and basking sharks. Many of these species and habitats of the Clyde are recognised as being of national or international importance and have been afforded some level of protection under legislation to protect marine biodiversity.

#### *Maerl*

One benthic habitat of particular interest and concern in the Clyde is that associated with maerl beds.

Maerl beds are living sediments characterised by accumulations of unattached calcareous red algae (Corallinales, Rhodophyta), also known as rhodolith beds. They occur in many environments including tropical, temperate and polar environments. In Europe they are patchily distributed occurring throughout the Mediterranean and along the Western Atlantic coast.

Maerl beds appear as patchy, poorly sorted and complex sediment that differ greatly from more uniform habitats such as mud. The interlocking of the branching thalli creates a highly complex habitat that provides numerous microhabitats for macrofaunal organisms. They have high ecological importance as they support a wide range of species, some of which may be unique to this habitat.

Maerl beds can also be of importance to fisheries, providing nursery grounds for commercial species of fish and shellfish.

In the Clyde Sea area, maerl beds coincide with many of the productive fishing grounds for scallops and infaunal bivalves and are under threat from dredging and bottom trawling in spite of their ecological and economic importance.

Maerl beds are known to be highly sensitive to physical disturbance and have a very low regenerative capacity and thus may require protection through appropriate conservation management strategies.

In terms of sea bed type, Maerl beds can be found in association with a range of different sediments, varying in size from fine mud to coarse gravel and pebbles.

A comprehensive study of the depth range within which maerl beds are found in the Clyde has not been performed, although Hall-Spencer (1995) suggested a range of 6-18m.

A further requirement for living maerl is in terms of currents near the sea bed. Maerl requires a moderate flow of water, but can not withstand intense current or wave action. Therefore it will not be found in either water that has limited movement, or extreme sea bed currents from either tide or waves.

A critical factor limiting the location of living maerl is related to smothering by fine sediment. Maerl will not be found where there are natural sources of depositing sediment, for example near river mouths or within the centre of persistent oceanographic gyres, or where there is frequent resuspension of fine sediments by tide or wave action. Sedimentation from human activity, including trawling, dredging, sediment extraction, sewage discharges or fish farming can kill maerl.

Within the Clyde studies have found both living and dead maerl beds, as well as living but heavily impacted maerl beds, affected by the effects of fishing, primarily scallop dredging.

Surveys for maerl could include those by diver, direct remote physical methods from vessels such as grabs or towed dredges, direct visual methods from vessels such as lowered cameras or towed video, and indirect remote sensing from vessels using acoustic methods including ground determination acoustics (e.g. RoxAnn).

### *Seabirds*

Ailsa Craig, the cliffs of the Ayrshire coast and Sanda Island located off the southeast coast of Kintyre, are the most notable seabird sites of the Firth of Clyde.

Ailsa Craig and Sanda Island are both designated Sites of Special Scientific Interest (SSSIs) set up for the protection of the breeding seabirds.

### *Sharks and Cetaceans*

The basking shark (*Cetorhinus maximus*) is the world's second largest fish and is regularly observed off the western British and Irish coast, mostly between April and October. It is entirely planktivorous and in Scotland basking sharks are regularly sighted around the outer Firth of Clyde where waters are plankton rich. In particular the coastline of the Isle of Arran is a 'hotspot' for basking shark sightings.

In the waters of the Clyde, fifteen species of cetaceans have been recorded since 1980. However, there is a lack of data available on the abundance of cetaceans in the Clyde which limits the ability to determine trends and current status. Any reliable scientific data is restricted to observations of distribution rather than determining numerical abundance.

### *Protected Sites*

The Clyde Sea area contains a wide range of protected sites of national and international importance for both biological and ornithological reasons. There are three types of protected

areas related to the marine environment in the Clyde; Sites of Special Scientific Interest (SSSI), Special Protection Areas (SPA) and Marine Consultation Areas (MCA).

Further work is progressing under the Scottish MPA project, and through SNH and JNCC, in order to consider additional protection measures in the Clyde.

#### **1.4 Literature Review – Non-Fishing Human Impacts**

The following is adapted from Scotland's Marine Atlas, Regional assessments, Solway, North Channel and Clyde

##### *Activities and Pressures*

The Clyde hosts a wide range of human activities and consequently is subject to a number of pressures. Aquaculture, particularly salmon and shellfish production, takes place in a number of sea lochs and there is widespread fishing, mainly for *Nephrops* and scallops.

There are significant ports, shipping and ferry activities with 20% of Scottish cargo volume passing through the Clyde ports. The Clyde is one of the busiest areas for ferry traffic with key links to various islands and peninsulas, as well as Northern Ireland, accounting for ~60% of overall Scottish passenger traffic.

Scotland's only Naval base is on the Clyde.

The Clyde is popular for recreational sailing, supporting ~40% of Scottish boat berths. There are also popular bathing beaches on the Ayrshire coast.

The Clyde Estuary and Ayrshire coast are relatively urbanised and industrialised compared with other parts of Scotland. This results in discharges from waste water treatment works and industrial effluents to estuary and coastal waters, as well as water abstraction, mainly for power generation.

Pressures resulting from these activities include the introduction of contaminants from industrial effluents and sewage works and dumping of dredge spoil from harbour maintenance. Fishing using trawls and dredges results in the abrasion of the seabed. There are also local effects of aquaculture on seabed ecology. Recreational boating and commercial shipping activities have probably led to the introduction of non-native species.

##### *Clean and Safe*

At the area level (i.e. all Clyde Sea) there are few concerns in relation to hazardous substances, radioactivity, oil and chemical spills and algal toxins.

Contaminant loadings to the Clyde Estuary are lower now compared to historical discharges but a legacy of localised contaminated sediments remains. These in turn have caused elevated concentrations of contaminants in mussels in the Clyde Estuary.

Water quality in the Clyde Estuary is compromised by discharges of industrial effluent and treated sewage although effluent treatment has improved resulting in returning populations of residential and migratory fish.

The quality of bathing and shellfish waters in the Firth of Clyde is affected by inputs of bacteria from diffuse sources, which increase during periods of high rainfall.

Local accumulations of litter are observed on some beaches possibly being transported by the prevailing currents. The source is not always possible to identify.

#### *Healthy and Biologically Diverse*

The status of habitats within the Clyde is mixed. Intertidal habitats (rock and sediments) are deteriorating. In relation to rocky intertidal habitats this is due to invasion of non-native species, in particular wireweed. Shallow subtidal sediments are relatively degraded while shallow, subtidal rocky habitats appear to be in a better state.

In general, mobile species such as cetaceans, seals and seabirds also show a mixed picture but overall are stable at the area level.

In contrast, the reduced populations of commercial fish are a major concern.

The introduction and establishment of a number of invasive non-native species, for example, intertidal wireweed (*Sargassum muticum*) and the subtidal carpet sea squirt (*Didemnum vexillum*), first found at Largs in 2009, is very concerning.

#### *Response / Forward Look*

Many of the concerns associated with the Clyde result from historical practices and management approaches. Enhanced scientific knowledge, improved regulation and greater environmental awareness have resulted in significant reductions in inputs of contaminants and improvements in water quality.

Pressure on coastal and inshore habitats is increasing from industry such as the proposed Hunterston power station (with a possible change in cooling water requirements), aquaculture and recreational activities.

The Clyde may have a potential resource to support the generation of marine renewable energy, mainly offshore wind and tidal. Growth of the industry and development of associated infrastructure, including seabed cables, is anticipated. Further work will be required to understand the effects on seascapes and landscapes, communities, tourism and recreation.

Increasing shipping activity, possible new container facilities at Hunterston, and recreational sailing will risk the further introduction of non-native species.

Underwater noise associated with industrial and recreational activities is expected to increase. There is also the possibility of increased ferry traffic to Northern Ireland with facilities in Loch Ryan due to expand.

### **1.5 Literature Review - Fishing (Pelagic and Shelfish)**

The fishing industry has had a major impact on the image and character of the Firth of Clyde and many of its coastal towns. It is a complex, traditional industry and holds great economic importance for many rural communities around Scotland's coast, including the Clyde, as well as political influence.

#### *Fishing legislation in the Clyde*

Fishery legislation changes have had a profound effect on the fisheries in the Clyde.

A ban on trawling in the Clyde was originally introduced in the late nineteenth century after fishery scientists at the time suggested that the Firth of Clyde fisheries were becoming depleted due to excessive trawling.

The Act was then amended in 1934 to include beam and otter trawling under the Illegal Trawling (Scotland) Act 1934.

The closure remained in place until 1962 when the Sea Fisheries (Scotland) Byelaw (No.65) came into effect which permitted summer (1 May to 30 September) otter trawling within the Firth of Clyde except within a 3 nautical mile limit.

Further legislation in 1968 (Sea Fisheries (Scotland) Byelaws no.'s 80 and 83) enabled fishing to take place throughout the year. The 3 nautical mile limit remained until 1984 (Inshore Fishing (Scotland) Act) when it was repealed under pressure from the industry during a time when demersal finfish landings were in decline.

### *The Herring Fishery*

The Firth of Clyde was once the centre of a major herring fishery which had been prosecuted in Scottish inshore waters since the 15th century, although it has been subject to major fluctuations.

With regards to legislation applicable to the herring fishery in the Clyde, it was prohibited to pelagic trawl for herring until 1962. In the same year a Byelaw was passed which prohibited fishing for herring by any method between midnight on Fridays and midnight on Sundays.

The spawning ground for herring located on the Ballantrae Bank had originally been closed in 1860 but this was repealed in 1867. The bank stayed open to fishing until 1972 when a seasonal closure was introduced from 15 February until the 30 April each year. There was an exemption for anchored drift nets but they became included in the seasonal closure in 1977.

The measures which remain in force in order to protect the spring-spawning herring are: a complete ban on herring fishing from 1 January to 30 April; a complete ban on all forms of active fishing from 1 February to 1 April on the Ballantrae Bank spawning grounds; a ban on herring fishing between 00,00 Saturday morning and 24,00 Sunday night.

In the past the fishery was almost entirely dependent on spring-spawning herring which spawn locally on Ballantrae Bank in the Firth of Clyde until about 1969 when a new component of autumn-spawning herring gradually increased in importance in landings and was predominant by 1972.

Although autumn-spawned herring formed a greater part of the Clyde population, there was no evidence of autumn spawning occurring within the Firth.

Although there had been no significant change in the abundance of the total herring population, the spring-spawners had decreased in the early 1970s which was accompanied by an increase in the absolute abundance of autumn-spawners.

In 1979 TAC regulations were imposed on the stock in addition to a closure of the fishery from October through till May in response to the clear evidence of a decrease in the abundance of spring-spawning herring.

The cause of this decline may be natural as it can be attributed with the reduced recruitment of the local spring-spawning stock, but the effects of intensive exploitation cannot be ruled out.

Landings of herring from the Firth of Clyde fluctuated about a long-term average of 14,200 tonnes in the period 1893-1960, from 1960-1978 the average landings were down to 8300t and only 2400 tonnes from 1978-1984 when landings became regulated.

Since 1991 catches in the Clyde have exceeded 1,000 tonnes only once. The reasons for the collapse of the Clyde herring are not clear cut. However, declining spawning stock biomass, high fishing mortality and lack of recruitment to the local spring-spawning stock may well have been causative.

Today herring in the Clyde are exploited by a small number of local trawlers and by pair trawlers from Northern Ireland. There is not much information on the current status of the stock as catch and sampling data availability has been minimal since the early 2000s. Thus, the precise status of the stock is uncertain; the stock is low but there is currently no evident downward trend. The Clyde herring stock is recognised as a separate stock but is not currently assessed analytically.

### *The Nephrops Fishery*

The Langoustine, Norway Lobster, Dublin Bay Prawn or *Nephrops norvegicus* (L) is the most commercial shellfish resource in UK waters and is extensively exploited throughout Europe.

Up until the early 1950's *Nephrops* attracted little commercial attention in Scotland and was rarely on sale in the region. However, in the last 50 years an important fishery for *Nephrops* has developed in Scotland and is now the largest in Europe.

These developments were delayed in the Clyde by the Herring Fishery (Scotland) Act 1889, which prohibited otter and beam trawling in the Clyde until 1962 when otter trawling for *Nephrops* in the Firth of Clyde was permitted in the summer. Shellfish such as *Nephrops*, scallops, lobster, edible and velvet crab are now the most important resource to the inshore fleet of the region. The majority of the inshore trawling fleet are dependent on *Nephrops* which are landed all year.

*Nephrops* are targeted by small demersal trawlers of no more than 30 m and are allowed to use a mesh size of 70mm, prior to 2009, and 80mm from 2009 onwards in the cod-end provided that *Nephrops* constitute a certain minimum proportion by weight of the total landings.

In more detail, the changes in technical measure regulations applying on the West of Scotland (ICES VIa) were designed to improve the selectivity and reduce unwanted catches of small fish. The minimum mesh size in the *Nephrops* fishery was increased from 70mm to 80mm as part of the 2009 EU emergency measures to deal with reduced gadoid populations. A second measure was the requirement for *Nephrops* vessels operating on the west coast to use a square mesh panel with a mesh size of 120mm as part of the Scottish Conservation Credits scheme (in place since 2008).

Owing to its burrowing behaviour, the distribution of *Nephrops* is restricted to areas of a particular sediment type; mud, sandy mud and muddy sand.

In the Clyde, burrow densities are higher in the south and the average size of *Nephrops* is smaller. This is particularly evident from the differences in discard composition between the north and the south of the Clyde. Catches from the south have a higher proportion of small

*Nephrops* resulting in large proportions of undersized *Nephrops* and *Nephrops* heads. Trawls in the south also generate larger quantities of roundfish discards (35%), including the important commercial species whiting, cod and haddock.

Survey assessments of the Clyde *Nephrops* stock are carried out annually by an underwater TV survey (UWTV) which determines *Nephrops* burrow density on the seabed. The information gathered provides an index of stock abundance which is independent of the fishery and together provides information on the status and predicted stock level.

The *Nephrops* fishery has also developed in recent years due to an increase in catches by static gear such as creeling.

The perception of the state of the stock in the Firth of Clyde is that it is stable and with the recent high catches by trawlers it is perceived to be a sustainable fishery. However, a reduction in abundance in 2007 coupled with the increase in landings has led ICES to advise a more precautionary approach in recent years.

### Scallops

The most important commercial molluscan species in the Clyde Sea are the scallop (*Pecten maximus*) and the related but smaller queen scallop (*Chlamys opercularis*).

Both species occur wherever the sea bed consists of sand, fine gravel or sandy gravel. The distribution of suitable sediments results in the species being found in a narrow strip of sea bed on each side of the Clyde and around Arran in depths no greater than 40m. Both the scallop and the queen are filter feeders, the scallop lies recessed in the sediment. The queen, however, do not recess into the sediment and will swim sporadically for a short time.

A dredge fishery for the scallop started in the Clyde Sea in the 1930's but remained small during the 1940s and 1950s with landings averaging 112 tonnes.

In the 1960s there was a radical change in the fishery; a large demand for scallops had developed in continental Europe resulting in a huge expansion of the fishery. The advent of processing factories in Scotland also allowed fishing for scallops to occur throughout the year.

Scallops are now exploited in the Clyde by a fleet of dredging boats which developed in the area in the late 1960's. The Ayr and Campbeltown Fishery District, includes the Clyde Sea Area and has been the major locus of the fishery in Scotland since the fishery began.

The traditional method of catching scallops is by dredge which basically consists of a rigid metal frame and toothed bar that digs into the sea bed at an angle of 60-70°; this is towed along the sea bed and the scallops are scraped into a netted bag. There is some commercial diving for scallops.

In September 2003 The Prohibition of Fishing for Scallops (Scotland) Order 2003 was implemented. This put in place new measures for scallop conservation that limited the number of dredges a scallop vessel can tow to a maximum of 8 per side for Scottish Inshore waters.

Currently there is no catch limit on UK scallop fisheries. They are mostly managed through minimum sizes, restriction on dredge numbers and seasonal closures in some areas.

Scallop stocks are highly susceptible to overfishing due to their limited mobility and confinement to a particular type of sea bed. However, scallop stocks have largely held up well on all grounds, even in the Clyde where fishing has gone on the longest.

#### *Other Shellfish*

There are small creel fisheries for crabs, lobsters and shrimp mostly on a part-time basis.

Gathering mussels was a flourishing industry in Scotland at the end of the nineteenth century and accounted for 29% of the total shellfish landings, but now only a few are taken, mainly in the lochs and mainly for human consumption.

Beds of cockles are found in several parts of the Clyde, including the Isle of Bute, the Ayrshire coast and at Stranraer.

The native oyster was once abundant and widespread in Scottish waters and now it is scarce with the only commercial fishery remaining in Scotland is in Loch Ryan.

Around the Arran coast electric fishing for razor fish is known to occur. Fishing for razors using electricity is reported to be a very effective method. However, there is limited knowledge of the effect of the electric field on other species (Breen *et al.*, 2011). The legality of using electricity as a fishing method is an issue of concern.

#### *Environmental Impacts of Fishing*

This report does not cover the subject of the environmental impact of fishing, other than on the health and diversity of fish stocks, in detail. Additional reports are being prepared on the subject, for example a report on the benthic impact of fishing gears funded by COAST and SIFT. This report does, however, present a brief review of the subject of sea bed impacts and discards.

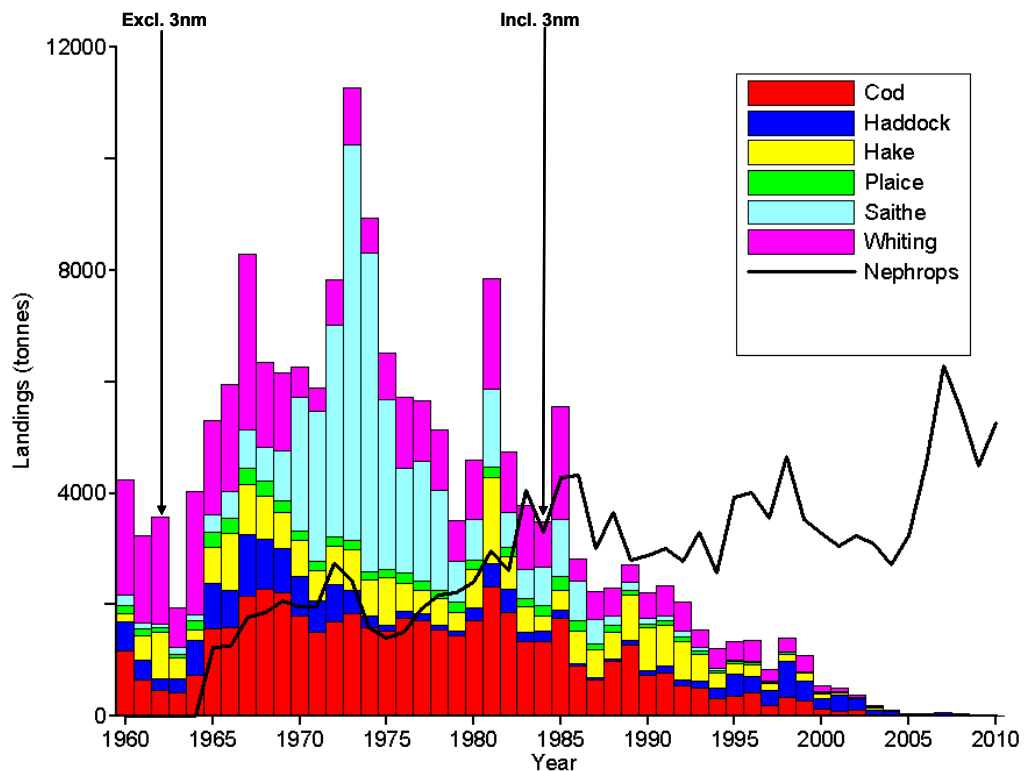
### **1.6 Heath and Speirs (2011)**

The report goes on to describe changes in the demersal fish populations of the Clyde in some detail, principally using the results of Heath and Speirs (2011).

#### *Landings*

The landings of the principal demersal fish, and of Nephrops, from the Clyde since 1960 are shown in the figure below.





Following the opening of the Clyde to trawlers in 1962, landings rose towards a maximum in the early 1970s, and then have subsequently crashed. The removal of the 3 nm limit in 1984 resulted in the landings rising slightly for one year, before the steep decline continued. *Nephrops* landings, in contrast, have steadily risen since the mid-1960s.

From landings data alone it would seem that demersal fish have disappeared from the Clyde, to be replaced by *Nephrops*. However, this is far from the actual true picture of the health of the Clyde Sea ecosystem.

Landings of a particular species can be affected by a diverse multitude of factors, including the amount discarded, market demand for that species, legislative controls including quotas and effort restrictions. For this reason, analyses that use just landings data (e.g. Thurston and Roberts, 2010) require significant caveats to be applied.

### Survey Data

For this reason Heath and Speirs (2011) used research vessel survey data.

Since early in the 20<sup>th</sup> century, the Scottish Government, through its Marine Laboratory in Aberdeen, have conducted trawl surveys of the Clyde fairly consistently on an annual basis. Since 1985 standardised survey methods have been used. *Heath and Speirs (2011)* took a statistical approach in order to reconstruct time-series describing the demersal fish community back until 1927.

### Biomass

Using the survey data, they found that:

- landings of demersal fish from the Clyde in the decade 1960-1969 appear to have been 46% of the total biomass. This percentage became 99% in the decade 1970-1979, 91% in 1980-1989, 18% in 1990-1999 and 2% in 2000-2009.

- the biomass of demersal fish in the Clyde in the decades 1990-1999 and 2000-2009 was over 8000 tonnes. This is approximately twice the biomass of fish in the decade 1930-1939 (~4000 tonnes) and approximately four times the biomass in the decade 1940-1949 (~2000 tonnes).

- in the decades 1930-1939 and 1940-1949, fish smaller than the minimum landings size made up on average 11% of the total biomass, whereas in the decades 1990-1999 and 2000-2009, fish smaller than the minimum landing size made up on average 85% of the biomass.

It is quite clear there was extremely heavy exploitation of the demersal fish stocks in the Clyde in the decades 1960-1969, 1970-1979 and 1980-1989.

What is also clear is that, despite the intense fishing pressure on demersal stocks that took place in those decades, the biomass of demersal fish bounced back and in fact became greater than in the decades when fishing pressure was much lower, prior to the 1960s.

Although the total biomass of demersal fish recovered, the size of individual fish was much changed in recent decades compared to previous decades. While there was a recovered biomass, it was predominantly small fish, with >80% being smaller than the minimum landing size.

In terms of species, >70% of the small fish was whiting.

In terms of age, the small whiting have been predominantly 1 year olds at least since the late 1990s.

These observations imply that the Clyde is indeed productive. Primary production in the form of phytoplankton growth, and secondary production in the form of zooplankton growth each year supports a large biomass of young, 1 year old whiting.

A valid question is where are the spawners? What fish are reproducing and producing each year an influx of new 1 year olds?

There are no comprehensive answers to these questions. Whiting can sexually mature at age 1, although no maturity data has yet been examined for Clyde whiting. The surveys may have missed the spawning older fish. They may be in the areas the survey did not cover, including the upper Firth, the sea lochs and the coastal zone. An alternative may be that the spawning population is not within the Clyde at all, and the population of small whiting in the Clyde is created by recruitment from a distant spawning population, although this is thought to be unlikely. In order to find the answer to these questions, a survey of small fish in the Clyde is needed, focussing on sexual maturity.

Another valid question is; what happens to the older fish? Again no conclusive answers are available. However, analysis of data from the MSS observer programme suggests that the *Nephrops* fishery in the Clyde may be partly responsible for the current absence of older, larger fish in the Clyde.

In summary, from the estimates of biomass in the Clyde Sea the conclusions are:

- the biomass of demersal fish in the Clyde is now greater than it was in the 1930's and 1940's. In fact more than twice as great.
- but 90% of this biomass is smaller than the minimum landing size, and 72% of it is whiting.
- the demersal fish biomass has recovered from the incredibly high exploitation rates in the 1970's and 1980's.
- hence the Clyde marine ecosystem is productive. It therefore has the potential to be restored.
- however, it is in a new regime with abundant small fish and few large fish.
- in order to recover the ecosystem towards a healthy state, we need to find measures which allow large fish to survive and increase.

Using the survey data, Heath and Speirs (2011) show how the mix of fish species in the Clyde has altered. Conclusions from the study of the mix of species in the Clyde can be summarised as follows:

- Fishing has significantly altered the mix of species in the Clyde.
- The fish community has changed from an even one, with many large predator species, to one dominated by whiting and other small fish.
- Along with other indicators and tagging data, the fact that species evenness changes in the Clyde very differently than that observed in nearby waters in the Sea of the Hebrides and the Irish Sea confirms that the Clyde fish populations respond locally to fishing pressure.
- This also suggests that the Clyde can be managed separately from the Scottish west coast, with a good chance of recovery using local restoration measures irrespective of what happens elsewhere.
- Indeed, conservation measures applied to the west coast as a whole may not be sufficient for the Clyde, as it responds differently and independently from the adjacent coastal waters.
- Heath and Speirs (2011) found that there was a lag of about 20 years between the maximum average relative removal of fish from the Clyde (the Harvest Ratio peaked in about 1980) and the maximum effect on the mix of species (which reached a minimum in 2000). Such a lag is found in other indicators Heath and Speirs (2011) use of the health of the demersal fish community in the Clyde. It is typical of the complex interactions which exist in an ecosystem, and shows that we can not expect restoration measures to have immediate effects. This is particularly true if we have forced the Clyde ecosystem from one stable state to another.

### *Summary*

There are already positive signs of change in the Clyde Sea demersal fish populations.

Since 2000 the species evenness index is increasing. In the period 1995-2004 just 4 fish species made up 95% of the biomass of Clyde demersal fish, whereas in 2005-2009 this had increased to 8. In the earlier period 87% of the biomass was whiting, while in the later period this had decreased to 72%. Possibly the most positive sign is in the size of the biomass itself, which has shown a significant increase since 1990. All of these indicators of improving

conditions in the Clyde should be strong arguments supporting the prospect of a restored Clyde.

The changes in technical measures in the Clyde *Nephrops* fishery (change from 70mm to 80mm mesh size, introduction of square mesh panels) potentially assisted in reducing catches of small fish and may have contributed to some of the early signs of improvement recorded in this study. For this improvement to continue, further developments are required in order to allow higher proportions of medium and large size fish to escape and grow.

If we are to design optimum restoration plans for the Clyde Sea, they must be built on sound science. However, we can not wait indefinitely for the results of further scientific studies. An integrated science / policy approach is needed so that progress can be made on both fronts at the same time. To be successful, this should intimately involve all sectors of society with an interest in the future of the Clyde Sea.

It could be argued that the Clyde gives Scotland an opportunity to demonstrate leadership in terms of ecosystem restoration. It is our own inland sea, over which we have significant management control. We will be required to bring the Clyde to Good Environmental Status by 2020 by the Marine Strategy Framework Directive. Currently the Clyde would certainly fail tests such as the Large Fish Indicator, and measures of biodiversity health. A restored Clyde ecosystem could bring market advantages to the fishing industry, through ecolabelling and headline conservation achievements. However, fishing sectors will have to work together in an open and transparent way. The allocation of blame is an entirely wasteful activity. Conservationists must also accept that the Clyde is not a pristine ecosystem and never will be. It is heavily used by society for many legitimate purposes, of which food extraction is one. Focus must always be on the best way forward for all. Compromises will be possible if all stakeholders approach the challenges in a constructive way.

## 1.7 A Management Data Tool

Gridded data sets, with a 500m by 500m resolution, of depth, sediment type and fishing activity have been created for the Clyde.

These data sets provide the following information:

### *Depths and Volumes*

<b>Spatial Domain</b>	<b>Surface Area (km<sup>2</sup>)</b>	<b>Surface Area (%)</b>	<b>Volume (km<sup>3</sup>)</b>	<b>Mean Depth (m)</b>	<b>Max. Depth (m)</b>	<b>Min. Depth (m)</b>	<b>No. of Valid Grid Points</b>
Clyde Sea	3671	100%	179	48.66	170	3	15,129
Coast to 1 nm	1206	33%	36	30.22	165	3	4,971
Coast to 2 nm	1858	51%	72	38.97	170	3	7,659
Coast to 3 nm	2354	64%	102	43.40	170	3	9,702

Hence from these figures we can see that, of the 3671 km<sup>2</sup> of the Clyde Sea, 33%, 51% and 64% lies within 1 nm, 2nm and 3nm from the coast respectively, by area.

### *Habitat Types*

Spatial Domain	Gravel		Sand		Mud	
	Surface Area (km <sup>2</sup> )	% of Clyde Total	Surface Area (km <sup>2</sup> )	% of Clyde Total	Surface Area (km <sup>2</sup> )	% of Clyde Total
Clyde Sea	327	100	2408	100	929	100
Coast to 1 nm	229	70	850	35	127	14
Coast to 2 nm	288	88	1289	54	281	30
Coast to 3 nm	299	92	1584	66	471	51

From these figures we can see that 70%, 35% and 14% of all Clyde gravelly, sandy and muddy sediments, respectively, lie within 1nm from the coast. Similar figures are presented for the 2nm and 3nm zones.

In total, using 2010 VMS and FIN data, 66 vessels were found which landed *Nephrops* in the Clyde, and 24 landed scallops.

### Fishing Activity

In relation to possible spatial management measures in the Clyde, a summary of fishing activity of the following type may be of relevance,

	Hours				Percentage			
	All Clyde Sea (Hours)	Coast to 1 nm (Hours)	Coast to 2 nm (Hours)	Coast to 3 nm (Hours)	All Clyde Sea (%)	Coast to 1 nm (%)	Coast to 2 nm (%)	Coast to 3 nm (%)
<b>ALL</b>	56,802	13,652	20,881	25,801	100	24	37	45
<b>NEP</b>	53,520	13,298	19,902	24,536	100	25	37	46
<b>SCL</b>	3,223	336	956	1,239	100	10	30	38
<b>HAD</b>	814	156	210	231	100	19	26	28
<b>COD</b>	60	17	19	19	100	28	32	32

From these figures we can see that of the total 56,802 fishing hours that took place in the Clyde Sea in 2010, 53,520 hours (94%) resulted in a landing of *Nephrops*, 3,223 (6%) hours landed scallops and just 814 hours and 60 hours landed haddock or cod respectively, most probably as by-catch in the *Nephrops* fishery. Hence the 66 boats which landed *Nephrops* from the Clyde in 2010 spent on average 810 hours fishing through the year, and the 24 scallop vessels spent, on average, 134 hours.

In terms of where fishing takes place, of the total 56,801 fishing hours of 2010, 24% occurred within 1 nm from a coastline, 37% within 2 nm and 45% within 3 nm. Therefore 55% of the total fishing activity occurred outwith 3 nm from a coast. This distribution of fishing activity is virtually identical for fishing which landed *Nephrops*, while it is different for fishing which landed scallops. Here, 10%, 30% and 38% of fishing activity occurred 1 nm, 2 nm and 3 nm from a coast within the Clyde Sea.

It is clear from the fishing activity maps that it is governed by the habitat types which favour the different species. Boats landing *Nephrops* principally target the areas where muddy sediments predominate, principally the deep basins of the Clyde, whereas vessels landing scallops target the harder sediments found around the shallower periphery of the Clyde as well as on the Great Plateau. The table below compares the percentage of each sediment type to the percentage of fishing activity in each of the spatial zones.

Spatial Domain	Gravel	Sand	Scallops	Mud	<i>Nephrops</i>
	% of Clyde Total	% of Clyde Total	% of Fishing Activity	% of Clyde Total	% of Fishing Activity
Coast to 1 nm	70	35	10	14	25
Coast to 2 nm	88	54	30	30	37
Coast to 3 nm	92	66	38	51	46

For *Nephrops* the percentages of muddy sediment and fishing activity within the three spatial zones of 1nm, 2nm and 3nm are comparable. However, for scallops the percentage of fishing activity outwith the 3nm zone seems excessively large. This must take place predominantly on the Plateau. Further investigations of this anomaly are underway.

### Summary

The analysis of VMS data, in conjunction with the other data layers in the CMEM databases, shows how useful this data can be to describe the current fishing practices in the Clyde and to evaluate different management options. However, more can be done.

It is possible to link actual landings to VMS pings if it is assumed each catch is evenly distributed along the vessels fishing path. This would allow summaries as above for spatial measures in terms of weight, and hence value, of landings per species per management area.

Here we have analysed the year 2010 as the most recent full year of data available to this study. However, earlier years and the more recent data can be added to look at changes over time. Similarly seasonal patterns of fishing could be examined.

Simple spatial measures involving set distances from the shore have been examined here. However, CMEM could be used to develop more complex spatial management measures based on, for example, habitat type. Temporal closures could also be examined in addition to spatial ones.

A warning should, however, be sounded. The effects of the displacement of fishing have not been touched upon here. Fishers behaviour faced with closures needs to be considered, and the impact of displaced fishing effort on other areas and habitats evaluated.

The analysis presented here only uses data from those vessels with VMS systems installed, i.e. >15m in length. Data from smaller vessels needs to be collected and analysed using CMEM.

## 1.8 Suggestions for Future Work

### 1.8.1 Clyde Hydrodynamic Model

The physical environment of the Clyde is determined by water movements driven by tide, wind and density-related forces arising from the input of freshwater within the Clyde. Additional water movement is driven by the effect of surface waves. Numerous hydrodynamic models of the Clyde have been constructed. However, as the physical environment is critical in determining the location and possible health of key sea bed habitats such as maerl beds, there is a need now for a state-of-the-art fine resolution (e.g. 100m)

three-dimensional hydrodynamic model using modern modelling technology such as the F-VCOM approach.

#### *1.8.2 Clyde Ecosystem Model*

The picture presented here of a productive base of the food web in the Clyde is qualitative only. Although there have been numerous individual studies of aspects of the food web in the Clyde, no one quantitative overall assessment of the post-industrial (particularly after the cessation of the use of the Clyde for sewage disposal and the inclusion of the current effects of climate change) ecosystem productivity is available. The best way to integrate the physics, chemistry and biology driving the Clyde marine ecosystem in a quantifiable way is by establishing an ecosystem model of the Clyde. Some already exist, although existing models each have particular limitations and focussed uses. When assembling such a model, critical parameters will be unavailable for the Clyde and this will direct observations and experiments.

An overall ecosystem model of the Clyde Sea is needed, whether spatially-resolved or simply a sub-basin scale box-type model (e.g. based on an ecopath-type approach), through which scientific consensus can be achieved concerning the health and productivity of the Clyde marine ecosystem.

#### *1.8.3 Clyde Inshore Benthic Survey*

There is much concern over inshore benthic habitats, especially those associated with maerl beds. It is estimated here that 10% of the sea bed of the Clyde might be able to support living maerl, although the figure may be smaller owing to constraints such as water flow and exposure. Most of these potential sites are within the 1 nm zone from the coast. In this zone the existing data sets of sea bed type, and also water depth, may be most in error. A comprehensive ground-determining acoustic survey, with associated validation using direct and indirect sampling methods, is needed of the Clyde 1 nm zone and waters out to the 20m depth contour.

#### *1.8.4 Clyde – an MSFD Development Area?*

As Europe, the UK and Scotland prepares to implement the Marine Strategy Framework Directive, the Clyde Sea offers a potentially exciting test area, where indicators and targets describing Good Environmental Status (GES) could be developed, an integrated ecosystem monitoring scheme devised involving cross-organisational working (i.e. Marine Scotland, SEPA, SNH) and a series of management measures implemented to take the Clyde towards GES by the target date of 2020. The Clyde offers: a pragmatic scale; a solely national management regime; a varied mix of status and pressures; diverse habitats; a representative range of stakeholders.

#### *1.8.5 Clyde Pelagic Fish Stock Acoustic Survey*

In order to estimate the current abundance and distribution of herring and sprat in the Clyde Sea, a fisheries acoustic survey should be conducted, using a multi-frequency scientific echosounder and a pelagic trawl for validation. The survey should include all areas of the Clyde Sea, as close inshore as is possible to navigate the survey vessel, and include the major loch areas (Kyles of Bute, Loch Fyne, Loch Striven, Loch Ryan) and the Clyde Estuary (to Port Glasgow). This survey should result in estimates of abundance at age for herring and sprat, and maps of their distribution.

#### *1.8.6 Clyde Demersal Fish Survey*

A comprehensive survey of demersal fish in the Clyde is required, including small fish. The survey should include a focus on the sexual maturity and stock identification of whiting. The survey could be accompanied by increased observations of the discards of demersal fish in the *Nephrops* fishery.

#### *1.8.7 Improving the Clyde Management Evaluation Model*

CMEM needs to be further developed. Data sets of habitat type can be improved using finer scale surveys, and additional environmental parameters such as sea bed temperature and sea bed water flow could be added. More years of VMS data need to be included. Seasonal patterns of fishing can be examined. Landings, by species and gear type, from each grid square, as well as value of landings, can be estimated using various methods developed at MSS. A glaring lack currently is information on fishing activity by creel boats, as well as fishing activity by all vessels smaller than 15m. This could be provided by an interview-based data gathering exercise (e.g. ScotMap, A.McLay *pers. comm.*).



## 2. INTRODUCTION

### 2.1.1 *An Ecological Desert - Thurston and Roberts (2010)*

In July 2010 a scientific paper authored by researchers from York University was published, entitled,

Ecological Meltdown in the Firth of Clyde, Scotland, Two Centuries of Change in a Coastal Marine Ecosystem

(Thurston and Roberts, 2010).

This stimulated immediate media interest (Glasgow Herald and Sunday Times articles, Radio 5 live) and a BBC Panorama programme in August. Newspaper headlines at the time included;

Clyde cleaned out to become marine desert (The Sunday Times, 11 July 2010)

Clyde ecosystem in meltdown (The Herald, 12 July 2010)

Report warns Clyde is fished out (Glasgow Evening Times, 12 July 2010)

Subsequently the Scottish Government held various meetings with local stakeholders around the Clyde to discuss the implications of the published study. Following these initial meetings, on the 1 October 2010, at the Ardoe House Hotel near Aberdeen, Mr Richard Lochhead (Cabinet Secretary for Rural Affairs and the Environment) met with scientists from Marine Scotland Science (MSS) in order to discuss possible avenues of research into the conditions of the Clyde Sea ecosystem. At that time it was considered too early to commission externally contracted work. Instead MSS were asked to carry out an initial internal review and propose a way forward.

Following the meeting MSS scientists commenced an assessment of the work needed and a collation of available data sets. A principal relevant data set identified was that derived from the catches recorded during research vessel surveys which Marine Scotland Science, and its predecessors at the Marine Laboratory Aberdeen, have carried out since the 1920s. However, at that time no staff resource was immediately available to complete the work needed and a recruitment process commenced which resulted in the appointment of a temporary researcher, Ms Fiona McIntyre, on an 11 month contract. Ms McIntyre commenced work on 10 January 2011 supervised by Dr Paul Fernandes.

### 2.1.2 *A Changed Ecosystem - Heath and Speirs (2011)*

Independently from the process underway within Marine Scotland, the University of Strathclyde also commenced work on the issue of the ecological status of the Clyde. While Thurston and Roberts (2010) relied entirely on landings data, Professor Mike Heath of the University of Strathclyde contacted Marine Scotland Science to request the research vessel survey data noted above. This was provided, and as a result of a detailed and well-founded analysis, in July 2011 Professor Heath published a definitive analysis of the present state of the Clyde Sea demersal fish community in his paper, with Dr Doug Speirs, entitled,

## Changes in species diversity and size composition in the Firth of Clyde demersal fish community (1927-2009)

(Heath and Speirs, 2011)

Although a comprehensive statement on the status of the Clyde ecosystem, this paper did not attract the media attention received by Thurston and Roberts (2010). This, unfortunately, reflects the nature of how science is covered in today's media, which in many instances appears agenda-driven rather than representing objective reporting of scientific progress.

The conclusions of Heath and Speirs (2011), although expressed in less emotive terms than Thurston and Roberts (2010), nevertheless point to a major ecological impact of fishing in the Clyde. The picture portrayed by Heath and Speirs is not one of an ecological desert, but of an altered ecosystem. Their principal conclusions were,

- rather than commercial species being entirely removed from the Clyde, the biomass of the six main commercial species in the late 2000s was approximately double that prior to the onset of trawling in the 1960s.
- however, the size structures of these species were dramatically different, being markedly deficient in large commercially marketable individuals after the period of peak harvesting rates in the 1980s
- also the incidence of species with a maximum attainable length greater than 40 cm declined precipitously and did not recover during the period of low harvesting rates after the late 1990s possibly owing to internal predator-prey interactions.

This means that the Clyde Sea still functions as an ecosystem. Primary production still occurs, powered by the sun and supplied by water-borne nutrients, which sustains secondary zooplankton production, which in turn feeds an active food web. The Clyde is not an ecological desert.

However, the Clyde ecosystem has been changed. The biomass of fish in the Clyde is the same, or for some species more, than when intensive fishing started. Additionally, a large and healthy population of shellfish (*Nephrops*) living on the sea bed of the Clyde is present. However, the community of fish is now made up mostly of small fish, and mostly small whiting. If we were to seek a terrestrial analogy it would not be that of a desert. Rather it might be that of used agricultural land in need of restoration. Comparing the Clyde to an ecosystem modified by human use yet capable of restoration portrays a much less newsworthy image than an ecological desert.

The Clyde ecosystem is one that has been used by humans for centuries, and hence it is changed. But humans can also now influence the direction the ecosystem takes by managing human activities in the future, precisely because the Clyde is not an ecological desert, but is an active ecosystem with great potential for future sustainable use.

### 2.1.3 This Report

With the publication of Heath and Speirs (2011), the role of this report changed. Significant staff changes during the life of the project have resulted in additional changes to the direction and timing of this work, as both Dr Paul Fernandes and Ms Fiona McIntyre left to pursue academic careers.

Hence this report now has the following objectives,

1. To present a brief review of previously published information and knowledge concerning the Firth of Clyde ecosystem.
2. To present the findings of Heath and Speirs (2011) in a format accessible to stakeholders and managers.
3. To propose a data tool which may help inform future management options in the Clyde.
4. To make suggestions for further studies in the Clyde required in order to support sustainable use of this active Scottish marine ecosystem

In some respects this report marks the start of a process, rather than the conclusion of one. It poses more questions than it answers, and presents preliminary analysis of a new data set that requires further validation, checking and expansion.

However, it provides a start point from which government and stakeholders concerned with the future of the Clyde can build upon and progress. It puts into context some secondary issues which may cloud the primary focus of future work to recover the Clyde ecosystem; how we manage fisheries in the Clyde.

### 3. THE ENVIRONMENT OF THE CLYDE SEA

#### 3.1 Definition of the Clyde Sea

The Clyde Sea is defined as the marine tidal extent which encompasses the Firth of Clyde, the Clyde Estuary and the sea lochs to the north of the Firth and Loch Ryan in the south of the area. The islands of Bute, Arran, Ailsa Craig and the Cumbraes lie within the main body of the Firth. The outer boundary where the Firth of Clyde meets the Irish Sea extends from the southern tip of the Mull of Kintyre to Corsewall Point (Halliday, 1969). In total the Clyde Sea encompasses an area of 3600 km<sup>2</sup> and has a volume of approximately 180 km<sup>3</sup>. (Figure 3.1)



**Figure 3.1** The Clyde Sea - defined by the boundary from the Mull of Kintyre to Corsewall Point.

#### 3.2 Geological History of the Clyde

The formation of the Clyde Sea as we know it today, along with the rest of the Highlands, began 500 million years ago (all the description that follows comes from Jardine, 1986). It lay between a major land mass to the northwest, and an ocean (the Iapetus Ocean) to the southeast. It then lay far south of the equator. Over the next 150 million years it drifted northwards to the equator with the movement of the continental plates, undergoing changes

in the geology and structures associated with the Highland Boundary Fault. About this time volcanic lavas produced the structure that would become the Great Plateau at the mouth of the Clyde. Further changes occurred caused by the immense geological processes underway, but the underlying rock structure of the Clyde basin as it is today was complete about 70 million years ago, by which time the Clyde lay roughly at its current latitude.

During the Tertiary period, from about 70 million years ago to 2 million years ago, the Clyde underwent numerous erosional and depositional events, including local volcanism. Then during the Quaternary period, from 2 million years ago to about 10,000 years ago, Scotland was covered by ice sheets more than 17 times. During each coverage of ice, and in the warmer periods between the ice sheets, areas were eroded, sediments laid down, and the land moved vertically up and down owing to the removal and imposition of the weight of the ice. At the same time sea level changed repeatedly. Thus there is a complex patchwork of eroded gullies and basins, deposited marine and riverine sediments and rock structures throughout the current Clyde basin, both below and above present sea level.

Finally, the last glacial period occurred, reaching its coldest about 18,000 years ago and ending about 10,000 years ago. An aerial view of the Clyde during this time would have shown huge ice sheets flowing as glaciers across the area from the highlands westwards out to the continental shelf edge. The deep rock basins of Kilbrannan Sound and southeast Arran were carved out down to 160m, much deeper (i.e. "over-deepened") than the hard volcanic rock "sill" of the Great Plateau. Between Arran and Bute a basin 320m deep was carved. It is estimated that the amount of hard rock the ice sheet carved away was probably much greater than the total volume of the Clyde Sea today.

As the ice sheet began to retreat, it deposited "till", mainly sand, in the deep basins it had carved out, reducing their depth by up to 80m. As the ice melted, the sea began to flood the Clyde, probably starting 14,000 years ago and the Clyde Sea as we would begin to recognise it today forming over the next 500 years, although ice persisted latest in Loch Long and Gareloch. The Clyde Sea then became bigger than today, as land was lower compared to sea level owing to the effect of the weight of the ice sheet.

Once the sea flooded into the Clyde, so the deposition of the muds and clays began which again reduced the depths of the ice-carved basins behind the Great Plateau. These were partly eroded sediments, and partly the skeletons of dead marine plankton. The location of the shoreline now varied greatly as the level of both the sea and the land altered following the removal of the ice sheets, resulting in shoreline features seen today above current sea level.

Today, the land around the Clyde continues to rise slowly, and deposition of silts and clays in the deep basins continues.

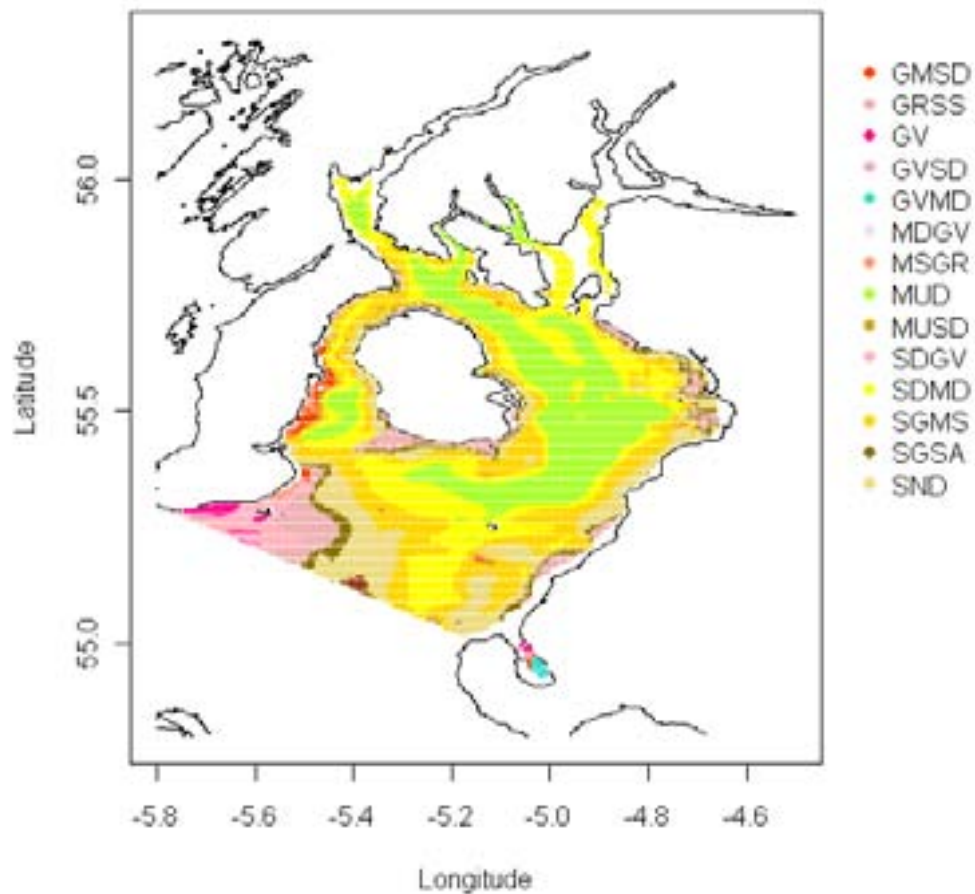
### **3.3 Bathymetry and Sedimentology**

As a result of the erosional and depositional processes described above, the Firth of Clyde is a region of complex bathymetry and sea bed sediment (Tivy, 1986). The glacial action has created a large fjordic system separated from the Irish Sea by a broad underwater sill and from the Atlantic by the Mull of Kintyre (SSMEI). The broad sill, termed the Great Plateau, has an average depth of 40-50m, which divides the North Channel from the Arran Basin where water depths can reach 150m. The Arran basin itself exhibits complex bathymetry consisting of both deep channels to the north and relatively shallow shelving areas to the east (Figure 3.2).



**Figure 3.2** Bathymetry of the Clyde Sea. Lightest blue – depths of 22m, darkest blue – depths of 114m.

The sub-tidal environment of the Clyde Sea is predominantly sedimentary in nature. Moore (1931) described it as consisting of predominantly fine grained layered muds. The large expanses of muds in the deeper water extend around Arran into the deep basins of the upper lochs. Although the substrate is muddy throughout much of the area, the area does contain a wide range of habitats; there are long sandy stretches along the Ayrshire coast and there is hard ground along the edge of the deep channels in the North Channel and Loch Fyne. There are also narrow sea lochs with rocky shores and sandy bays (Figure 3.3).



**Figure 3.3** Sea bed sediments of the Clyde using the Folk triangle classification based on the gravel percentage and the sand to mud ratio. See Section 9.3.4 for a full explanation of sediment type codes.

### 3.4 Hydrography

The hydrography of the area is also complex and is largely driven by its bathymetry. Salinity and temperature distributions described by Craig (1959) and Dooley (1979) point to a front on the Great Plateau which separates the tidally mixed waters of the North Channel from the stratified waters and weak tidal currents of the Firth. The maximum velocity of the tidal currents in the Clyde is generally less than  $0.5 \text{ ms}^{-1}$  and within the sea lochs they are even weaker attaining about  $0.2 \text{ ms}^{-1}$ . The bathymetry controls the balance of processes at any particular depth. At the surface there is free connection throughout and movement is dominated by pressure gradients set up by tide, wind and freshwater outflows. In the deeper waters below the sills, dense water settles, flows are blocked and are dominated by oscillatory internal movements; bottom water stagnation, some oxygen depletion and nutrient build-up can occur within the lower levels of the sea lochs. However the importance of the deep water is sometimes overemphasised, by area only 20% lies below 70 m and 6% below 100 m (See section 9).

The basin also receives large inputs ( $60\text{-}700\text{ m}^3\text{s}^{-1}$ ) of freshwater from the River Clyde and other river sources which enter mainly through the north of the region (Poodle, 1986). The freshwater inflow produces a typical fjordic regime with the salinity of the outflow surface water reduced by up to 1.5 relative to the inflow over the sill. The effect of this surface water tends to maintain a stable stratification which is not seriously eroded by tidal stirring on account of the generally weak tidal flows (Simpson and Rippeth, 1993).

The temperature of the Clyde Sea, compared to the North Channel, is warmer in the summer and colder in the winter. The shallow waters of the lochs and estuaries experience much greater temperature fluctuations, surface ice forms at the heads of some lochs in the winter and a thermocline is established during the summer (Connor, 1991). Mean surface temperature and salinity vary quite considerably (depending on the season) from  $6\text{-}14^\circ\text{C}$  and from  $<30\text{-}34.75$  respectively.

### 3.4.1 *An Annual Cycle in the Clyde*

Slesser and Turrell (2005) provide annual cycles of physical, chemical and some biological parameters in the waters around Scotland. These have been derived from the extensive water sampling performed by Marine Scotland Science since 1960. In this section we present average annual cycles of these parameters in the Clyde Sea, averaged throughout the Sea over a surface (0-10m) layer, and bottom layer (40m – sea bed). Note that as the values presented in this section are averages over both space and time, actual values at individual locations, at specific times, can be very different, particularly for the biological parameter chlorophyll-a.

For comparison, data from an area defined by Slesser and Turrell (2005) as the Inner Malin Shelf have been used. Results from this area reflect typical conditions in the coastal waters west of Scotland, outside the Clyde. Slesser and Turrell (2005) provide all details concerning sampling, data processing, accuracies etc. Data from approximately 1600 hydrographic stations are included in the Clyde averages while only 350 are available for the Inner Malin Shelf.

Slesser and Turrell (2005) present figures for monthly averages of temperature, salinity, density, oxidised nitrogen ( $\text{NO}_3$ ), orthophosphate ( $\text{PO}_4$ ), silicate (Si), ammonia ( $\text{NH}_3$ ), particulate organic carbon, particulate organic nitrogen, chlorophyll-a, phaeophytin, oxygen and water column stability. Here we will focus on the physical parameters temperature ( $^\circ\text{C}$ ), salinity and density (in terms of  $\sigma_T$ , units  $\text{kg m}^{-3}$ ) to describe a typical year in terms of changes to the physical environment of the Clyde Sea (Figure 3.5a). Chemical and biological parameters presented are oxidised nitrogen (referred to as nitrate for this text, units –  $\mu\text{g-at/l}$ ), chlorophyll-a ( $\mu\text{g/l}$ ) and oxygen content (percent saturation) to demonstrate the annual biological production cycle and its effects (Figure 3.5b).

#### *Annual changes in the physical characteristics of the Clyde Sea*

In the Clyde, coldest winter temperatures are experienced in March / April when temperatures in the surface and lower water column are the same ( $\sim 6^\circ\text{C}$ ). Temperatures then start to warm, reaching a maximum in the surface waters in August ( $\sim 13^\circ\text{C}$ ). At this time bottom layer temperatures are still warming towards their maximum, implying a degree of isolation from the surface waters. This is confirmed by the salinity and density differences between surface and bottom waters which is maintained throughout the year. As temperature cools towards winter, bottom layer and surface layer temperatures equalise after October. Density differences between the two layers are minimum in February and November when mixing between the layers may be most frequent.



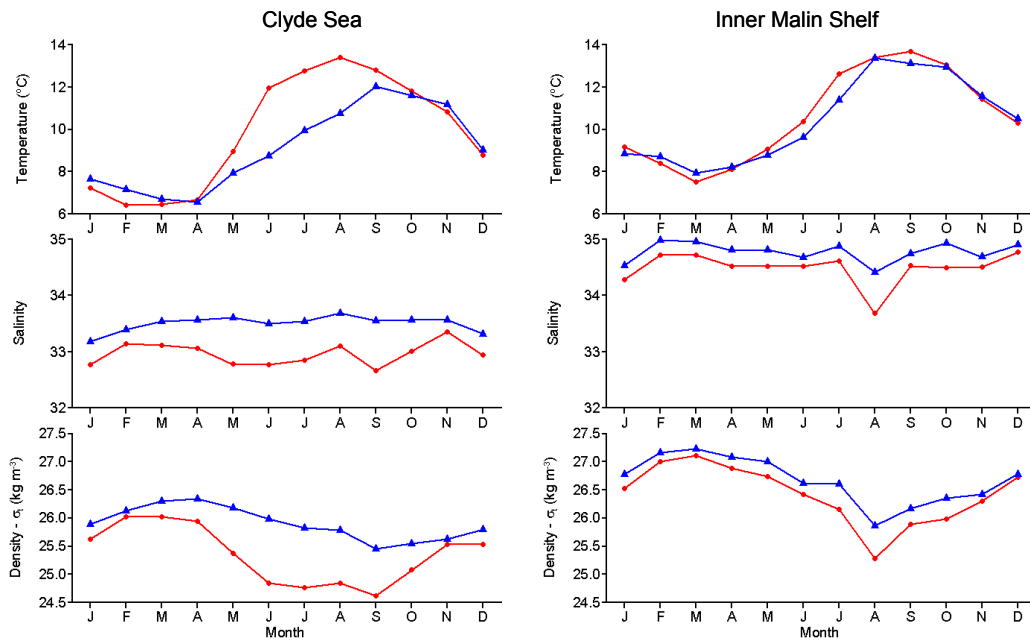
When comparing the average annual cycle of physical characteristics within the Clyde to those of the Inner Malin Shelf, the following comparison can be made: Clyde summer surface layer temperatures are similar to those in Scottish west coast coastal waters; maximum surface summer temperatures occur a month earlier in the Clyde; winter minimum temperatures are about 1°C cooler; salinities are fresher owing to the local freshwater inputs; density stratification persists all year in the Clyde, although weakest in the winter, whereas coastal waters are predominantly well mixed.

#### *Annual changes in the chemical and biological characteristics of the Clyde Sea*

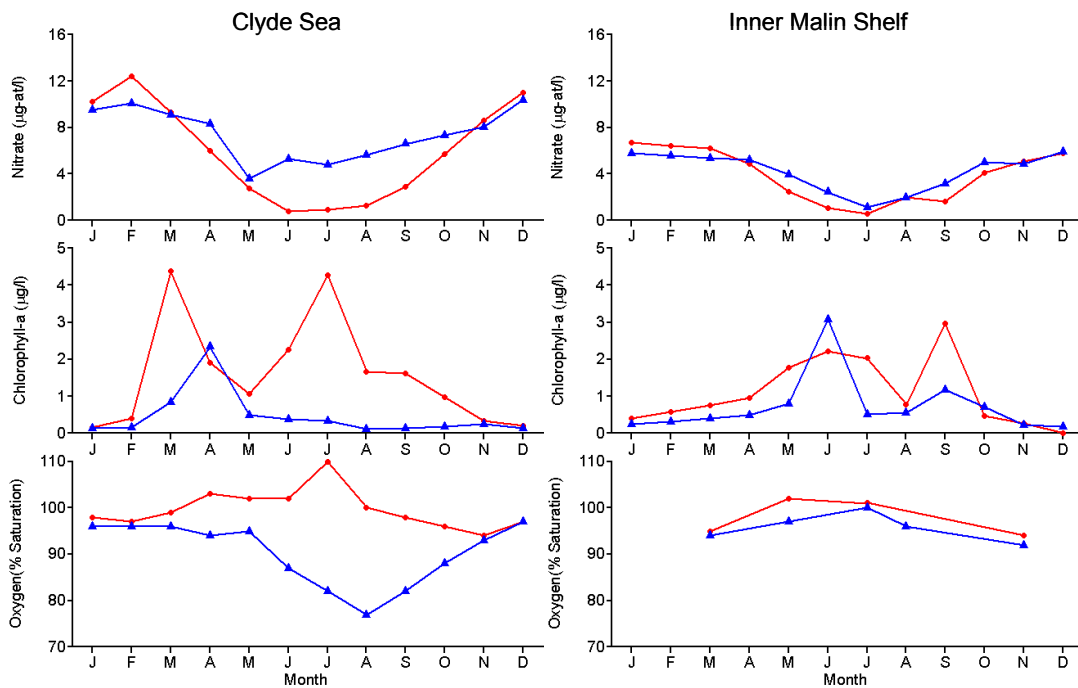
Nutrient content of the Clyde, using nitrate as an indicator, is generally higher in the Clyde than adjacent coastal waters, presumably owing to local nutrient supply from freshwater inputs. Winter values reach a maximum of 10-12 µg-at/l, whereas coastal maximum values are typically 6-8 µg-at/l. In the surface layer within the Clyde nutrient is depleted by June / July as a result of biological production, although bottom layer nutrient does not fall below 4 µg-at/l.

There are no available measurements of primary production found by this study from the Clyde. However, there are values of the instantaneous concentration of chlorophyll-a which can act as an indicator of the timing and magnitude of primary production. Two peaks are evident in the average annual values obtained from the surface layer within the Clyde, one in March and one in July. Both appear equal in magnitude. This contrasts to coastal waters, where a first peak in production may occur in June and a second, smaller peak in September. Maximum Clyde chlorophyll-a values are between 4-5 µg/l, whereas in coastal waters they are lower, typically 2-3 µg/l. These observations may suggest that, the Clyde is in general more productive than outside coastal waters, the biological cycle starts earlier in the Clyde and there are two distinct periods of productivity, one in the early spring and one in the summer. (Note that the values presented here are monthly averages over the entire Clyde Sea area. Maximum values at specific locations and times have been observed much higher than the maximum values stated here.)

A final parameter available from the annual cycles study of Slessor and Turrell (2005) is the oxygen content of the waters of the Clyde. Here, the percentage saturation is presented, although in biological terms the absolute oxygen concentrations may be more relevant. It is clear from Figure 3.5b that the surface layers of the Clyde are generally fully saturated, with values close to 100%. However, the oxygen saturation in the deeper waters decline in the summer months as stratification of the water column leads to partial isolation of the denser bottom waters. Natural utilisation of oxygen through the decay of organic material uses up oxygen until the waters are flushed by oxygen rich water in the autumn, when increasing winds and decreasing stratification mixes up the deeper waters and replaces them with oxygen rich surface waters. The seasonal depletion of oxygen is not seen in adjacent coastal waters as they remain vertically mixed throughout the summer. The lowest oxygen levels in the Clyde are seen in August, and are approximately 80%. It is not thought that these levels will cause mortality to fish or shellfish populations. The lowest values will occur in the deep basins, where the sediment is primarily mud and the predominant benthic fauna will be *Nephrops*. Owing to their burrowing activities, *Nephrops* are adapted to lower oxygen levels.



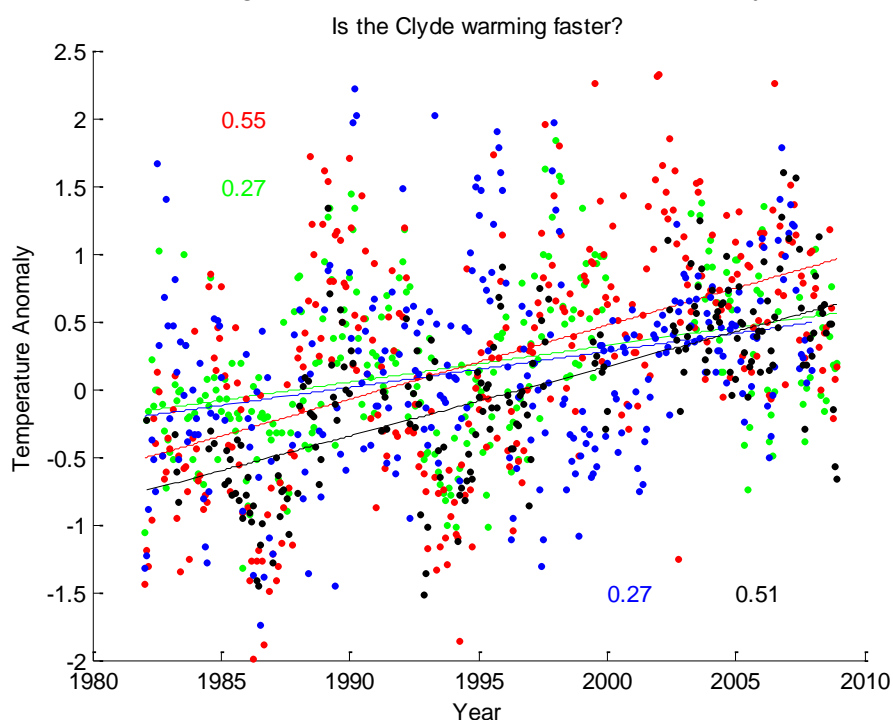
**Figure 3.5a** Average annual cycles in the Clyde Sea (left) and Inner Malin Shelf (right) of temperature ( $^{\circ}\text{C}$ ), salinity and density ( $\sigma_T \text{ kg m}^{-3}$ ). See Figure 3.5b legend below for details.



**Figure 3.5b** Average annual cycles in the Clyde Sea (left) and Inner Malin Shelf (right) of nitrate ( $\mu\text{g-at/l}$ ), chlorophyll-a ( $\mu\text{g/l}$ ) and oxygen (percent saturation) from Slesser and Turrell (2005). Data is presented for a surface layer (0-10m and 0-20m for Clyde and Inner Malin Shelf respectively - red symbols and lines) and for a bottom layer (40m to sea bed and 30m to sea bed for Clyde and Inner Malin Shelf respectively – blue symbols and lines). See Slesser and Turrell (2005) for a full description of the data and it's accuracy.

### 3.4.2 Warming Sea Temperatures

There is increasing evidence and agreement within the scientific community that the release of greenhouse gases into the atmosphere is the major cause of the observed average increase in global temperatures over the last century. Around the coast of Scotland an increase in sea temperatures has been observed which has the potential to alter the abundance and distribution of marine species. Marine Scotland currently maintains a network of coastal temperature monitoring stations around the coast of Scotland and at three of the sites (Millport, Fair Isle and Peterhead) data has been collected for more than 25 years. Recent analysis of temperature data from the sites currently monitored in the inshore areas show that the Clyde Sea may be warming faster than coastal waters within the North Sea (Figure 3.4). The warming rate at Tiree is similar to that of the Clyde.



**Figure 3.4** Long-term temperature anomalies plotted against year over common time period (1982-2008). Warming rates ( $^{\circ}\text{C decade}^{-1}$ ) from the linear fit to the data, Red, Millport, Green, Fair Isle, Blue, Peterhead, Black, Tiree.

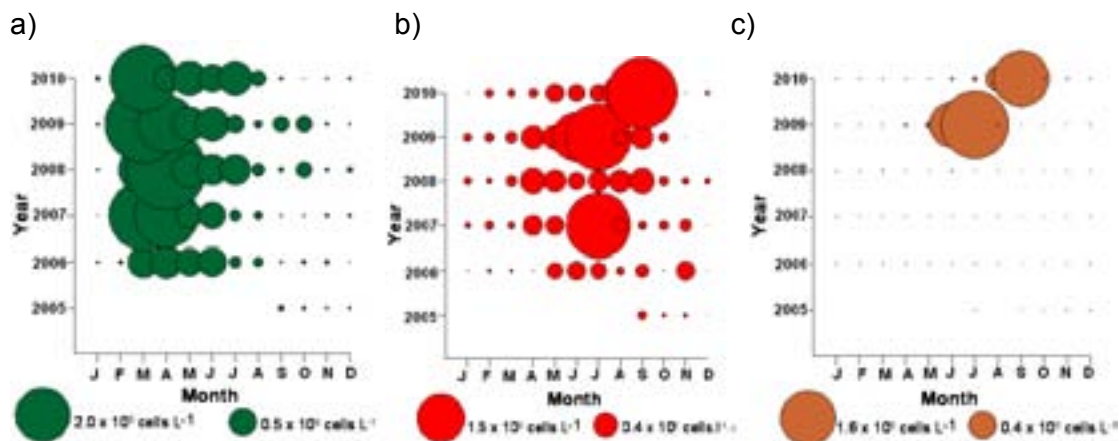
### 3.5 Plankton

Plankton are at the base of the marine food web providing food for many species of fish and shellfish, and hence for the fish, birds and marine mammals which feed on them. They include bacteria, plants (phytoplankton) and animals (zooplankton). They play a fundamental role in the functioning of marine ecosystems by providing half of the global primary production (Waniek and Holliday, 2006). For an ecosystem, the availability of nutrients, larval survival, maintaining populations and the timing of egg production are highly dependent on the amount of plankton available (Barne *et al.*, 1997).

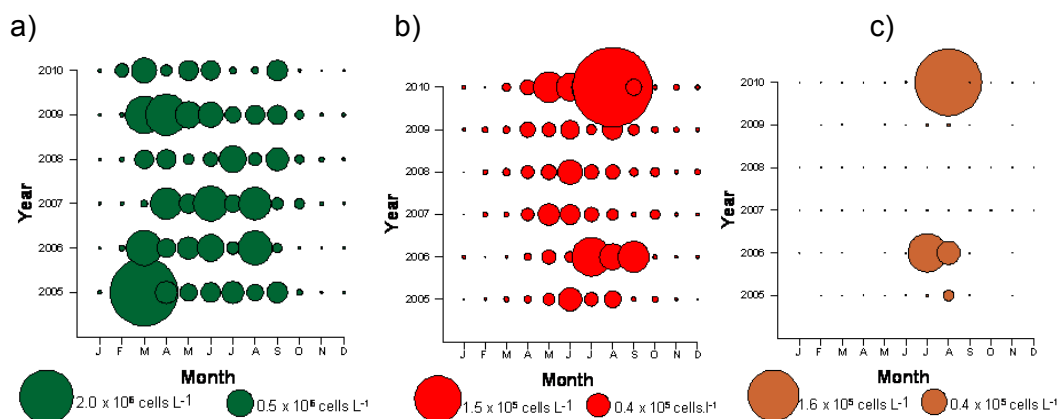
The abundance of plankton is strongly influenced by factors such as light and nutrient availability, water temperature, depth within the water column, tidal mixing and the vertical stability of the water column. Plankton communities are surprisingly diverse and seasonal successions of communities are usually observed due to environmental conditions and the different adaptive strategies of plankton populations (Reynolds *et al.*, 2001). The Firth of Clyde supports a rich flora and fauna (Haig, 1986) and early studies from the area showed that the main food pathway in this region was diatoms (one of the most common types of phytoplankton) to copepod to herring (Marshall, 1924; Marshall, 1973).

### 3.5.1 *Phytoplankton*

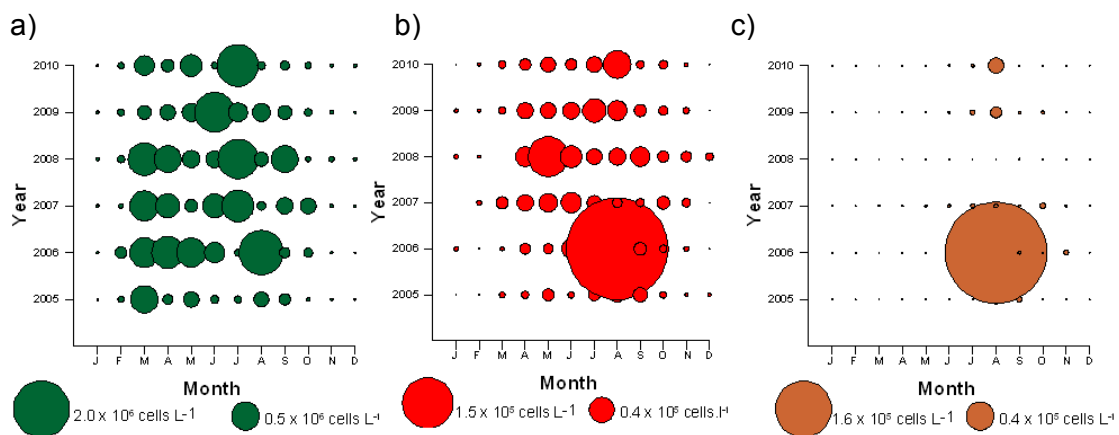
The spring increase in phytoplankton begins in March, with diatoms reaching a peak in May, dinoflagellates show a steady increase through the summer until September when abundance declines to winter levels. Dinoflagellates are of particular importance around Scotland because of the number of harmful genera that are routinely observed. Fish farms in the Firth of Clyde, particularly in Lochs Fyne and Striven, have lost stock due to such harmful phytoplankton blooms (Tett *et al.*, 1986) and algal toxins have been recorded in shellfish from the region (Stobo *et al.* 2008). Not all harmful species seen in Scotland pose a severe problem. At the Millport monitoring site, *Alexandrium* spp. is observed infrequently and *Pseudo-nitzschia* spp. cell densities are low compared with other Scottish sites. Lipophilic shellfish toxins associated with *Dinophysis* are recorded in this region (Stobo *et al.* 2008) High cell densities of *Karenia mikimotoi* have been observed during the last two years at the Millport monitoring site (Figure 3.6). *Karenia* blooms along the west coast of Scotland are sporadic in occurrence and there is some suggestion that they may have an offshore influence (Davidson *et al.*, 2009). The 2006 bloom which had devastating impacts along the West Coast did not impact the Clyde. Although the cell densities at Millport were not associated with catastrophic mortalities of the benthos or wild or farmed fish, the impact on the biota of exposure to sub-lethal densities is relatively unknown. Figure 3.6 shows the diatom and dinoflagellates cell counts at Millport since 2005 which indicates a large amount of phytoplankton and thus high productivity during the phytoplankton blooms. Comparison with two other sites (Loch Ewe, Wester Ross and Scapa Bay, Orkney) from the MSS monitoring programme show a greater abundance of diatoms and dinoflagellates recorded at the Millport site (Figures 3.7 and 3.8).



**Figure 3.6** Monthly averaged cell densities from 2005-2010 at Millport of a) diatoms; b) dinoflagellates and c) *Karenia mikimotoi*. Note data has been root-square transformed.



**Figure 3.7** Monthly averaged cell densities from 2005-2010 at Loch Ewe of a) diatoms; b) dinoflagellates and c) *Karenia mikimotoi*. Note data has been root-square transformed.



**Figure 3.8** Monthly averaged cell densities from 2005-2010 at Scapa Flow of a) diatoms; b) dinoflagellates and c) *Karenia mikimotoi*. Note data has been root-square transformed.

### 3.5.2 Zooplankton

The zooplankton of the Firth of Clyde has been particularly well documented (Adams, 1986); it is dominated by copepods, euphausiids, arrow worms and jellyfish (Tett, 1992). Although the euphausiids species *Meganyctiphanes norvegica* and *Thysanoessa raschii* are important in the deep water around Arran and Loch Fyne, in general, the copepod *Calanus* sp are the most important pelagic crustaceans (Adams, 1986). The abundance of copepods in this region is quite high compared with other sites around Scotland's coast and the duration of seasonal abundance is quite prolonged compared with the northern North Sea (Barne *et al.*, 1997). *Calanus* occurs in enormous numbers in surface waters throughout May and June after which this species is found mainly in deeper waters such as those of Loch Fyne (Tett, 1992).

### 3.6 Concluding Remarks

The Clyde Sea presents the overall characteristics of a semi-enclosed fjordic basin, receiving freshwater inputs from the land and having partial exchange with the waters on the adjacent coastal shelf at its mouth.

The sea bed physical habitats in the Clyde are dominated by the local depth, the local sediment type and the local tidal currents and wave action. The predominant shape and bathymetry of the Clyde basin, and the distribution of the principal sea bed types, including the gravels, sands and muds, have been little changed since the end of the last glacial period (ice age).

The basis of the marine food web in the Clyde, i.e. the annual cycle of plant (phytoplankton) growth, fed by water-borne nutrients, and the subsequent feeding and growth of microscopic animals (zooplankton), appears healthy and productive in the Clyde.

From large scale observations, there are no obvious signs of negative effects on the food web of pollution, nutrient enrichment or any other man-made source of contamination. This does not preclude the possibility of small-scale local effects.

Although the waters of the Clyde Sea are warming, this is in line with other coastal areas west of Scotland. There is no evidence that the warming in itself has reduced the potential productivity of the Clyde.

### 3.7 Suggestions for Further Work

The physical environment of the Clyde is determined by water movements driven by tide, wind and density-related forces arising from the input of freshwater within the Clyde. Additional water movement is driven by the effect of surface waves. Numerous hydrodynamic models of the Clyde have been constructed. However, as the physical environment is critical in determining the location and possible health of key sea bed habitats such as maerl beds, there is a need now for a state-of-the-art fine resolution (e.g. 100m) three-dimensional hydrodynamic model using modern modelling technology such as the F-VCOM approach.

The picture presented here of a productive base of the food web in the Clyde is qualitative only. Although there have been numerous individual studies of aspects of the food web in the Clyde, no one quantitative overall assessment of the post-industrial (particularly after the cessation of the use of the Clyde for sewage disposal and the inclusion of the current effects of climate change) ecosystem productivity is available.

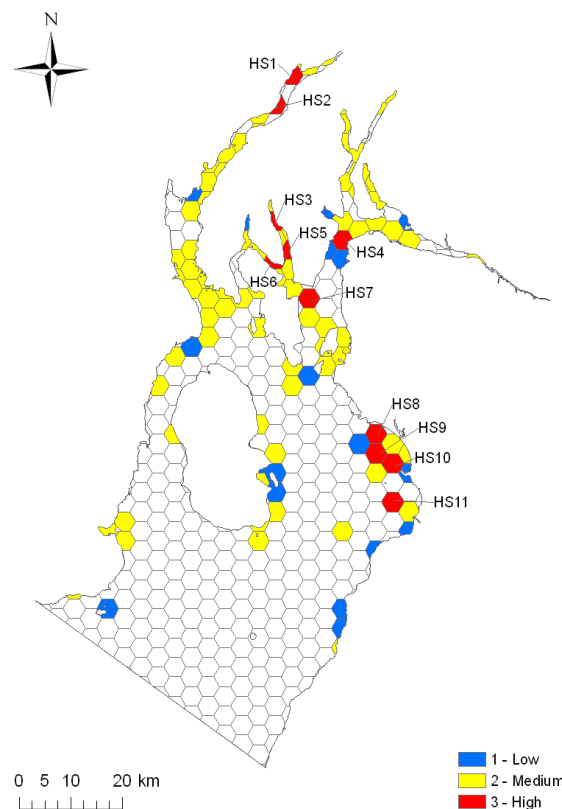
The best way to integrate the physics, chemistry and biology driving the Clyde marine ecosystem in a quantifiable way is by establishing an ecosystem model of the Clyde. Some already exist, although existing models each have particular limitations and focussed uses. When assembling such a model, critical parameters will be unavailable for the Clyde and this will direct observations and experiments.

An overall ecosystem model of the Clyde Sea is needed, whether spatially-resolved or simply a sub-basin scale box-type model (e.g. based on an ecopath-type approach), through which scientific consensus can be achieved concerning the health and productivity of the Clyde marine ecosystem.

## 4. BIODIVERSITY

### 4.1 Background

The Clyde Sea area has a wide range of habitats which support a large diversity of plant and animal species. There is some concern that human activities may have already had effects on those species and habitats, through overexploitation, habitat destruction and environmental change. Historically the Clyde has supported large populations of herring and whitefish, which have in recent years undergone a dramatic decline, and commercial fishing is now largely dependent on shellfish species. The fauna of the Clyde does show some anomalies when compared with that of the west coast, particularly the Clyde algal fauna, with some species only found in the Clyde (Maggs, 1986). An extensive amount of marine faunal lists have been published for the Clyde Sea over the past century from general accounts by Chumley (1918) to more specific accounts of specific groups, Polychaeta (Clark, 1960), Mollusca (Allen, 1962), fish (Bagenal, 1965), Amphipoda (Moore, 1984) and Echinodermata (Wilkie, 1989). The seas of the Clyde also support populations of megafauna such as seals, dolphins, whales and basking sharks. Many of these species and habitats of the Clyde are recognised as being of national or international importance and have been afforded some level of protection under legislation to protect marine biodiversity.



**Figure 4.1** Location of species hotspots (shown in red) in the Clyde Sea Area identified by Langmead *et al.* (2008). The five areas were Northern Loch Fyne (HS2) and Loch Shira (HS1); Irvine Bay (HS8-11); East of Dunoon in the upper Firth of Clyde (HS4); East of Rothesay, Bute (HS7); and The Kyles of Bute (HS6) and Loch Striven (HS3 and 5).



A recent review of the biodiversity of the Firth of Clyde (Langmead *et al.*, 2008) identified and collated c.133,000 species and habitat data records for the area. The review also analysed patterns of biodiversity and determined the location of 'hotspots' defined as areas of high species and habitat richness that include representative, rare and threatened features (Ross *et al.*, 2009). The locations of the species hotspots identified by this study are shown in Figure 4.1. It is the purpose of the following section to briefly describe the rich biodiversity of the area, discuss current threats and to describe some of the conservation and management measures that are already in place to protect biodiversity in the Clyde.

## 4.2 Benthic Fauna

In general, the Firth of Clyde benthic populations have been given selective attention according to the habitat type, location and research interests in relation to specific environmental problems. As a result much of the work on the benthic fauna of the Clyde has focussed on the shallower coastal sediments of the rocky shores and sandy bays. A widespread littoral survey was undertaken in 1979 by Paisley College of Technology who examined 82 sites of both rocky and sedimentary types of the lochs and open coasts of the Firth (Connor, 1991). The survey suggested that the richest sediment shores were concentrated in the more sheltered parts of the Clyde such as Loch Fyne, Striven and Gareloch. The shores on the more exposed coasts of Ayrshire, the Kintyre peninsula and the coast of Arran tend to have fewer individuals and less species diversity. The intertidal infauna is dominated by the bivalves *Angulus tenuis* and *Cerastoderma edule*, the amphipod bathyporeia sp. and polychaetes *Scoloplos armiger*, *Pygospio elegans*, *Arenicola marina* and *N. cirrosa*. The intertidal fauna of sandy beaches in the Clyde have also been studied by Eleftheriou and McIntyre (1976) examining shores which are moderately exposed or sheltered. The exposed shores were dominated by crustaceans and polychaetes and the bivalve *Angulus tenuis*. On the sheltered beaches crustaceans were generally less common and bivalves represented the greatest biomass. Areas of particularly high benthic infaunal biomass are concentrated in Upper Loch Long, Loch Striven, the Kyles of Bute, the central Kilbrannan Sound and the Irvine and Ayr Bays.

The benthos of the deeper sediments has also been investigated centred on the influence of the Garroch Head dumping site. Life in the deep muds of the Clyde is mainly buried in the soft, fine sediment. The most conspicuous species of the Clyde deep muds are the heart urchin *Brissopsis lyrifera*, the brittle star *Amphiura chiajei*, the bivalves' *Nucula tenuis* and *N. sulcata*, the polychaetes *Glycera alba*, *G. rouxii* and *Lumbrinereis hibernica*. In the shallower sandier muds *A. filiformis* tends to replace *A. chiajei*, *Echinocardium cordatum* becomes the dominant heart urchin and the most numerous bivalves in addition to *N. tenuis* are *Thyasira* spp., *Alba* spp. and *Mysella bidentata*. Sediments with significant admixtures of gravel in the Clyde tend to have the brittle stars *Ophiothrix fragilis*, *Ophiopholis aculeata* and *Amphipholis squamata*. The surfaces of the mud in the lochs of the Clyde Sea are also the habitat of the spectacular burrowing anemone, the fireworks anemone (*Pachycerianthus multiplicatus*).

Wireweed (*Sargassum muticum*) was first found in Loch Ryan in 2004 and since then has been recorded in a number of locations throughout the Firth of Clyde. It is a fast growing large olive-brown seaweed that competes with native seaweeds through overgrowing, shading and abrasion and can alter the ecology of the habitat. In harbours and shallow water it is considered a nuisance where large floating masses can become a hazard to vessels through the entanglement of propellers and blocking of engine cooling systems (Ashton *et al.*, 2006).

The gaping file shell (*Limaria hians*) is a small bivalve, distinguished by long orange filamentous tentacles, which has been recorded along the west coast of Scotland around Kintyre and in the Clyde Sea (Hughes *et al.*, 2009). In a study by Hall-Spencer and Moore

(2000) it was concluded that the gaping file shell has disappeared from regions where it was once common including Ayrshire, the Isle of Bute and Stravanan Bay. The decline of file shell reefs in this area was attributed, by Hall-Spencer (2006), to the destructive effects of scallop dredging. The file shell has a thin delicate shell and damaged individuals dislodged from their nests are rapidly consumed by scavengers. The file shell reefs also have ecological importance as they support a rich fauna of small invertebrates and provide attachment surfaces for algae and larger sessile organisms.

Sea pens are colonial cnidarians found on sandy and muddy sediments around the British Isle and in many Scottish sea lochs. They are typically found in areas of high salinity, highly sheltered areas where tidal streams are negligible. Some areas of the Clyde Sea may provide ideal habitats for sea pens. There are three sea pen species which occur in Scottish waters tall sea pens *Funiculina quadrangularis*, *Virgularia mirabilis* and *Pennatula phosphorea*. The two human activities which are most likely to affect this biotope are *Nephrops* trawling and organic pollution. Of the three sea pen species *Funiculina quadrangularis* is likely to be the most vulnerable to trawl damage due to its brittle stalk and inability to retract into the sediment. Heavy organic pollution can exclude sea pens from an area, with severe oxygen depletion probably having damaging consequence to sea pens.

### 4.3 Maerl beds

Maerl beds are living sediments characterised by accumulations of unattached calcareous red algae (Corallinales, Rhodophyta), also known as rhodolith beds (Barbera *et al.*, 2003; Steller and Foster, 1995). They occur in many environments including tropical, temperate and polar environments. In Europe they are patchily distributed occurring throughout the Mediterranean and along the Western Atlantic coast.

Maerl beds appear as patchy, poorly sorted and complex sediment that differ greatly from more uniform habitats such as mud. The interlocking of the branching thalli creates a highly complex habitat that provides numerous microhabitats for macrofaunal organisms (Steller *et al.*, 2003). They have high ecological importance as they support a wide range of species, some of which may be unique to this habitat (Keegan, 1974). Many studies have reported rare and unusual species living in association with maerl beds, they create areas of high biodiversity and hence the beds are of international conservation significance (BIOMAERL, 2003). In addition, maerl are slow growing and an ecologically fragile habitat considered to be a non-renewable resource. A study by Grall *et al.* (2006) demonstrated the high productivity of the maerl bed environment as shown by the co-dominance of endobenthic polychaetes (*Eupolymnia nebulosa*, *N. latericeus*), bivalves (*V. verrucosa*, *Venerupis aureus*) and Sipunculids with epibenthic crustaceans (*Melitid amphipods*, *P. longicornis*, etc.), Molluscs (chitons or gastropods) and sponges.

Maerl beds can also be of importance to fisheries, providing nursery grounds for commercial species of fish and shellfish (Hall-Spencer *et al.*, 2003). In the Clyde Sea area, the maerl beds coincide with many of the productive fishing grounds for scallops and infaunal bivalves and are under threat from dredging and bottom trawling in spite of their ecological and economic importance (Barbera *et al.*, 2003). Maerl beds are known to be highly sensitive to physical disturbance and have a very low regenerative capacity and thus may require protection through appropriate conservation management strategies.

It is thought that the UK, and particularly Scotland, is home to many of the most extensive maerl beds in Europe. It occurs on exposed west coasts, such as those in Scotland, Ireland and Brittany, but it is absent from large areas of European waters, such as most of the North Sea, the Baltic, the Irish Sea and the eastern English Channel (Birkett *et al.*, 1998).

However, studies which quantify the areas covered by maerl beds in anything other than very local studies, are rare.

#### *Maerl bed habitats in the Clyde*

There have been several observations of maerl beds, both dead and living, in the Clyde. However, a first question is what habitats in the Clyde could potentially be suitable for maerl?

The physical environment needed by living maerl has been difficult to determine, as it's slow growth (~1mm per year) makes experimentation difficult.

In terms of sea bed type, Birkett *et al.* (1998) suggest that Maerl beds can be found in association with a range of different sediments, varying in size from fine mud to coarse gravel and pebbles.

Maerl can not withstand exposure, thus only forms below the low-water level (Birkett *et al.*, 1998). As maerl is an algae, it requires light to grow. Thus light availability, and hence water turbidity, are parameters which will limit where maerl can live. These, in turn, will limit the depth-distribution of maerl as in clearer waters, maerl will be able to live at deeper depths compared to more turbid waters. A comprehensive study of the depth range within which maerl beds are found in the Clyde has not been performed, although Hall-Spencer (1995) suggested a range of 6-18m (Birkett *et al.*, 1998). Maerl has not been found extensively below 30m in UK waters and is generally found shallower than 10m (Birkett *et al.*, 1998).

A further requirement is in terms of currents near the sea bed. Maerl requires a moderate flow of water, but can not withstand intense current or wave action (Birkett *et al.*, 1998). Therefore it will not be found in either water that has limited movement, or extreme sea bed currents from either tide or waves. This implies there are minimum and maximum sea bed current tolerances of living maerl, although these have not been quantitatively determined.

Wilson *et al.* (2004) suggest that maerl is not as susceptible to changes in temperature, salinity or heavy metal pollution as was previously thought. However, a critical factor was smothering by fine sediment. Thus maerl will not be found where there are natural sources of such sediment, for example near river mouths, where there is natural deposition of fine sediment, for example within persistent gyres, or where there is frequent resuspension of fine sediments by tide or wave action. Sedimentation from human activity, including trawling, dredging, sediment extraction, sewage discharges or fish farming will kill maerl (Wilson *et al.* 2004).

Within the Clyde studies have found living (Kamenos *et al.*, 2004) and dead (Hall-Spencer, 1995) maerl beds, as well as living maerl beds, but heavily impacted by the effects of fishing, primarily scallop dredging (Hall-Spencer and Moore, 2000).

Surveys for maerl could include those by diver, direct remote physical methods from vessels such as grabs or towed dredges, direct visual methods from vessels such as lowered cameras or towed video, and indirect remote sensing from vessels using acoustic methods including ground determination acoustics (e.g. RoxAnn).

Studies such as the BIOMAERL programme are advancing our overall understanding of maerl and will hopefully allow management of maerl to have a firmed scientific basis.

#### **4.4 Seabirds**

Seabirds are species of birds which have adapted to exploit the potential food available from the marine environment. They fall into two broad categories; those which specialise in feeding from the air picking up food from the vicinity of the sea surface, such as terns and those which dive for food such as gannets which may swim underwater in pursuit of their prey (Monaghan and Zonfrillo, 1986). However, all seabirds are dependent upon the land to breed and their distributions are governed by the constraints of this environment, where there is a safe place to nest with sufficient food resources available in the surrounding waters. Although the Firth is home to three quarters of the UK's breeding seabirds, the Clyde coast does not support a major proportion of most species of the Scottish breeding population. This is largely due to the low-lying topography of the coast providing accessibility of the Clyde coast to the large human population which reside in central Scotland (Monaghan and Zonfrillo, 1986).

The primary foods of seabirds are densely schooling lipid-rich pelagic fishes, crustaceans and cephalopods in the upper-mid water column (Hunt *et al.*, 1996). Thus changes in the availability of pelagic fish may affect the breeding biology of these birds. Herring are especially important to the kittiwake and the decline in herring stocks may in part be responsible for the decline in kittiwakes in some areas.

Ailsa Craig, the cliffs of the Ayrshire coast and Sanda Island located off the southeast coast of Kintyre, are the most notable seabird sites of the Firth of Clyde. Ailsa Craig and Sanda Island are both designated Sites of Special Scientific Interest (SSSIs) set up for the protection of the breeding seabirds. Fishing activity in the Clyde is known to benefit seabirds by providing an easily exploitable food source in the form of discards. Regular scavengers include the fulmar (*Fulmarus glacialis*), the great black-backed gull (*Larus marinus*) and the kittiwake (*Rissa tridactyla*) which obtain a large proportion of their food from discards, the herring gull (*Larus argentatus*), great skua (*Stercorarius skua*) and gannet (*Morus bassanus*) also commonly scavenge behind fishing vessels.

#### **4.5 Megafauna**

The basking shark (*Cetorhinus maximus*) is the world's second largest fish and is regularly observed off the western British and Irish coast, mostly between April and October. It is entirely planktivorous and in Scotland basking sharks are regularly sighted around the outer Firth of Clyde where waters are plankton rich (Speedie *et al.*, 2009). In particular the coastline of the Isle of Arran is a 'hotspot' for basking shark sightings. The spatio-temporal distribution of basking sharks can be directly attributed to changes in zooplankton abundances and this can have important implications for the management and conservation of the species (Thom *et al.*, 1999).

Historically the basking shark was exploited for the high oil content of its liver, which was used in the steel, medical, and cosmetic industries, as well as as a fuel for lighting. A fishery remained in the Clyde until the 1980s, when declining numbers and reduced public support meant the fishery was no longer viable. The basking shark is now protected within the 12 nautical miles limit off Scotland under the Wildlife and Countryside Act 1981. Potential threats to basking shark populations include by-catch in fishing nets and disturbance or impact with vessels. The basking sharks slow growth rate and late sexual maturity coupled with overfishing has resulted in the shark becoming rare in areas where it was once common. As a result of the decline in numbers the species qualifies as vulnerable on a global level and the British population is classified as 'endangered' on the IUCN Red List.

In the waters of the Clyde, fifteen species of cetaceans have been recorded since 1980. However, there is a lack of data available on the abundance of cetaceans in the Clyde which

limits the ability to determine trends and current status. Any reliable scientific data is restricted to observations of distribution rather than determining numerical abundance.

## **4.6 Threats to Biodiversity**

Some of the most significant non-fishing threats to biodiversity are outlined in the following section. The effects of fishing are discussed in Sections 6 and 7.

### *4.6.1 Invasive species*

Non-native invasive species are considered by the UN to pose a great threat to biodiversity. Recently there has been an increase in the incidence of non-native marine species in coastal areas around the UK with potentially damaging impacts on native flora and fauna including commercial species. These effects can include competition with native species for food and space, alteration of habitats, changes in water quality and transmission of disease (Donnelly *et al.* 2010). Recent introductions into the marine environment of the Clyde include the cord-grass *Spartina anglica* which colonises shallow mudflats and competes with the seagrass *Zostera noltii*. Two of the most important vectors of invasive species are shipping and the aquaculture industry.

### *4.6.2 Climate change*

In the last 60 years climate change has altered the distribution and abundance of many marine species (MarClim, 2006) and there is now increasing concern of the impacts of climate change on the conservation and management of marine biodiversity. As temperatures increase a general shift in species distributions is expected as species respond to the changes of suitable 'climate space' available to them (Fields *et al.*, 1993; MarClim, 2006). Individual species are likely to respond to temperature increases at different rates due to differences in their metabolism and physiological processes (Sims *et al.*, 2004). In addition, climate change could cause local extinction of species that are unable to adapt to fluctuations in their physical environment.

## **4.7 Protection of Biodiversity**

In order to effectively manage habitats and/or species of conservation importance, monitoring and regulation of those human activities likely to damage the areas of interest is essential.

Criteria for assessing the conservation importance of a habitat or species are a matter of continued debate. Such criteria are especially difficult to establish in the marine environment where basic knowledge of ecosystem function is still at a relatively low level (Hughes, 1998). The UK already has obligations to protect internationally important species and habitats that are listed in a variety of directives and conventions. Scotland has been active in establishing closed areas to protect biodiversity, for example, through the establishment of a No Take Zone (NTZ) at Lamlash Bay, Arran. The Clyde Sea area also contains a wide range of protected sites of national and international importance for both biological and ornithological reasons. There are three types of protected areas related to the marine environment in the Clyde; Sites of Special Scientific Interest (SSSI), Special Protection Areas (SPA) and Marine Consultation Areas (MCA).

SSSI's are areas of land or water that Scottish Natural Heritage (SNH) considers to best represent our natural heritage – its diversity of plants, animals and habitats especially those of greatest value to wildlife conservation. They are designated under the Nature Conservation (Scotland) Act 1981 and are intended to form the essential building blocks of Scotland's protected areas for nature conservation (SNH website, 2011). There are currently 1,450 SSSIs in Scotland of which there are 14 that protect some aspect of the marine environment (e.g. Seabirds, saltmarsh) of the Clyde Sea Area (see Table 4.1).

SPA's are designated areas of the terrestrial and marine environment in response to the Wild Birds Directive which aims to protect the habitats of migratory and threatened bird species. In the UK, SPAs must first be designated as an SSSI before gaining the protection as an SPA. The Clyde has one designated SPA in the area – the island of Ailsa Craig (see Table 4.1).

The Nature Conservancy Council has identified MCAs which deserve particular distinction in relation to the quality and sensitivity of their marine environment. The sites have no statutory status but are known to bodies such as SNH for marine conservation issues. The MCAs located in the Clyde include Loch Fyne and Loch Ryan due to the presence of important species such as the fireworks anemone and gaping file shell reefs.

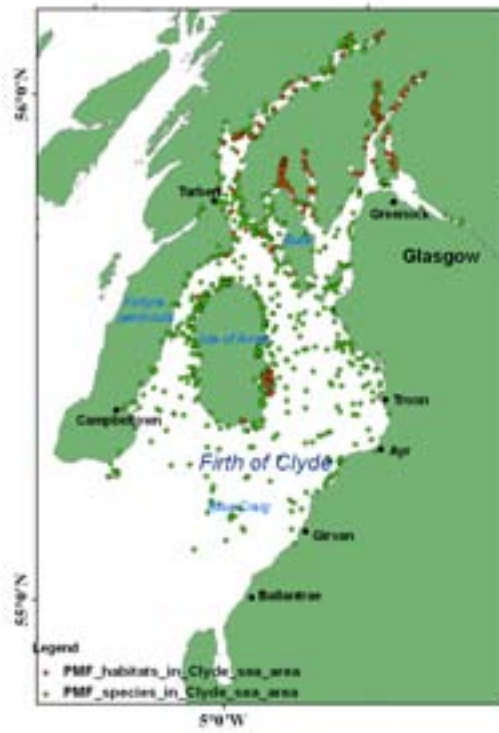
Implementing marine protected areas (MPAs) is a priority for Scotland as it has international commitments to establish an ecologically coherent network of MPAs under the OSPAR agreement and so alongside other management practices, establishing MPAs will underpin the future use of the seas around Scotland. Currently SNH, the Joint Nature Conservation Committee (JNCC) and Historic Scotland are working closely with Marine Scotland and stakeholders to provide advice to the Scottish Government on where MPAs should be designated. To help target biodiversity conservation action SNH and JNCC have put together a focused list of habitats and species of importance in Scottish waters – Priority Marine Features (PMFs) which will underpin the selection of MPAs (Figure 4.2). The Clyde sealochs have been identified as areas which represent major priorities for the establishment of MPAs due to the presence of many PMFs such as sea pens, native oysters and flame shell beds (Moore and James, 2011).

#### **4.8 Suggestion for Further Work**

There is much concern over inshore benthic habitats, especially those associated with maerl beds. It is estimated here that 10% of the sea bed of the Clyde might be able to support living maerl, although the figure may be smaller owing to constraints such as water flow and exposure (see Section 9). Most of these potential sites are within the 1 nm zone from the coast. In this zone the existing data sets of sea bed type, and also water depth, may be most in error. A comprehensive ground-determining acoustic survey, with associated validation using direct and indirect sampling methods, is needed of the Clyde 1 nm zone and waters out to the 20m depth contour.

Site of Special Scientific Interest (SSSI)			
	SSSI	Protection	Area (ha) National Grid Reference
1	Sanda Islands	Birds Maritime Cliffs	81.45 NR 725037
2	Ballantrae Shingle Beach	Shingle	32.74 NX 080818
3	Turnberry Dunes	Beetle Assemblage	55.71 NS 199060
4	Maidens to Doonfoot	Shingle Maritime Cliffs	224.5 NS 316194 - NS 265177
5	Troon Golf Links and Foreshore	Sand dune	150.11 NS 335287
6	Western Gailes	Sand dune Invertebrate assemblage	92.58 NS 320358
7	Portencross Coast	Mudflats Birds (non-breeding)	477.9 NS 190521
8	Kames Bay	Sandflats	4.6 NS 171550
9	Ballochmartin Bay	Sandflats	18.9 NS 182570
10	Inner Clyde	Saltmarsh Birds	1824.92 NS 312811-NS494698
11	Ruel Estuary	Saltmarsh	332.78 NS 010800
12	Ailsa Craig	Birds Seabird colony	99.94 NX 020998
13	South Coast of Arran	Shingle Maritime Cliff	218.3 NR 042213
14	Clauchlands Point - Corrygills	Saltmarsh Maritime Cliff	46.18 NS 048338

**Table 4.1** Sites of Special Scientific Interest located in the Firth of Clyde.



**Figure 4.2** The location of Priority Marine Features determined by SNH survey of the Firth of Clyde 2010.



## 5. HUMAN IMPACTS (OTHER THAN FISHING)

### 5.1 Background

In UK waters most problems associated with human impacts other than fishing are local in nature particularly in industrialised estuaries and coasts such as the Firth of Clyde. The major component affecting the Clyde is associated with the substantial historical and current inputs of hazardous substances from industrial and domestic waste. The region is the most industrialised and urbanised area of Scotland and is arguably Scotland's most heavily contaminated water body (Webster, *et al.* 2005). The marine environment is described as the ultimate sink for many hazardous substances that result from the waste produced by industry. Substances identified as a particular cause for concern in the Clyde include cadmium, lead, mercury, pesticides and persistent organic pollutants (POP's). Although the use of some of these substances has been banned they still continue to be present in the marine environment as a result of historical use (Baxter *et al.*, 2011). Information on sewage and industrial discharges into the Clyde and their effects on the environment have been well-documented as part of the Annual Reports produced by the former Clyde River Purification Board which is now incorporated into the Scottish Environment Protection Agency (SEPA).

The most concentrated source of contaminants into the Clyde is at Garroch Head, south of the Isle of Bute and at Cloch Point (Figure 5.1). Sewage sludge has been disposed of at Garroch Head since 1904 until the site was closed under the EC Urban Waste Water Treatment Directive 91/271/EEC 1998. By the 1990's more than 1,500,000 tonnes of sewage sludge was being disposed of annually at Garroch Head. The site had been moved 4 km south in 1974 after the introduction of the Dumping at Sea Act where dumping was confined to a circular area one nautical mile in diameter. Levels at the old site were particularly persistent as the effects of the new site, which experienced higher rates of input and more precise dumping, had amplified the effects of sludge disposal at the former site (Rodger *et al.*, 1992). The problem was further exacerbated due to the hydrology of the area, where currents are relatively slow ( $<10 \text{ cm s}^{-1}$ ) and does not allow enough dispersion of pollutants; this causes localised problems to occur (Mojtahid *et al.*, 2008). Monitoring has been undertaken at Garroch Head following the cessation of dumping in 1998, to assess recovery. However, the disposal of dredged material at sea continues in the Clyde at Cloch Point and is authorised under part II of the Food and Environment Protection Act 1985 (FEPA). Other sources of contaminants into the Clyde include run-off from urban areas, oil spills and atmospheric deposition which diffuses into the marine environment.

The pollution into the Clyde constitutes a major source of persistent organic pollutants (POPs) such as polychlorinated biphenyls (PCBs) and polycyclic aromatic hydrocarbons (PAHs). In more recent times increased regulation has reduced contaminant inputs. However, due to the persistent nature of many hazardous substances, high concentrations can still be found in marine sediments as a result of historical inputs. The extent to which these hydrophobic compounds are accumulated is dependent on sediment type. Sediments with high organic carbon content and a small particle size, such as those of the inner Clyde, have a greater potential to accumulate hydrophobic contaminants than coarser sediments (Webster *et al.*, in press). The immediate effect of the accumulation of such contaminants has been to cause organic enrichment of the sediment which in turn causes changes in the benthic infauna and a decrease in biodiversity (Rodger, 1992, Kelly and Campbell, 1995).



**Figure 5.1** Map showing the dump sites at Garroch Head, pre- and post- 1974.

PCBs are synthetic substances which have been produced in Europe since 1929 until the mid 1980s and used in hydraulic fluids, insulators, sealants and grouting (OSPAR, 2010). PCBs are toxic, persistent and lipophilic and are bioaccumulated by fish especially in the liver due to its high lipid content. They can adversely affect reproduction, and may affect immune systems which can result in disease epidemics. Organisms at the higher levels of the food web, especially seabirds and marine mammals, can be particularly affected (OSPAR, 2010).

PAHs are widespread chemical pollutants that are introduced into the marine environment from many different sources. They are natural components of coal and oil and are mainly produced by the incomplete combustion of carbon-containing fuels; as a result they are one of the most widespread organic pollutants (OSPAR, 2010). PAHs are toxic, persistent and are known to be both mutagenic and carcinogenic. Due to their low aqueous solubility and hydrophobic nature, PAHs tend to associate with particulate matter and can be bio-accumulated especially by shellfish.

Inputs of trace metals such as cadmium and mercury result from discharges of sewage and from the fish farm industry. Most trace organic compounds are insoluble in water and are below detection concentration levels. However, Lindane ( $\gamma$ -hexachlorocyclohexane (HCH)) which is used in insecticides is relatively soluble in water and present in measurable concentrations. The Clyde Sea currently has the highest inputs of Lindane ( $\gamma$ -HCH) compared to the rest of Scotland (Baxter *et al.*, 2011).

## 5.2 Assessment of Pollution

The Water Framework Directive (WFD) establishes a legal framework for the protection, improvement and sustainable use of surface waters, transitional waters, coastal waters and

groundwater across Europe. In Scotland, this work is undertaken primarily by SEPA in conjunction with the Scottish Government. For aspects of coastal waters not covered by the Water Framework Directive, the Marine Strategy Framework Directive (MSFD) sets out environment protection and improvement measures for marine waters.

Monitoring of hazardous substances in the Scottish marine environment is required in order for Scotland to meet international obligations to OSPAR and under EU legislation. Hazardous substances highlighted to be of concern such as those already mentioned are monitored routinely in Scotland by either Marine Scotland or SEPA. The monitoring programmes cover the different marine components measuring contaminants in waters, sediments and biota to determine the long term fate of these materials. Those that are soluble remain in solution where insoluble contaminants are more likely to be incorporated in the sediments or bio-accumulated in animal tissue.

To assess contaminant concentrations in the Firth of Clyde in relation to the Garroch head dump site, fish have been sampled annually since 1992 and sediment samples taken since 1999 (Webster *et al.*, 2005). Assessment criteria have been developed for metals and organic contaminants (PAHs and PCBs) in both sediment and biota on an international basis through the auspices of OSPAR, ICES and the EU. The main programme for monitoring the status of contaminants in UK waters is the 'Clean Seas Environmental Monitoring Programme' (CSEMP). CSEMP measures the concentrations of specific chemicals which are persistent, toxic and have the ability to accumulate in food chains, at almost 500 sites around the UK (UKMASS, 2010). Assessment criteria for these sites have been developed based on concentration thresholds (in sediments and biota) above which these contaminants could be toxic to both marine organisms and to human consumers of seafood.

**Blue**, Status is acceptable. Concentrations are near background for naturally occurring substances (e.g. PAHs) or close to zero for man-made substances (e.g. PCBs).

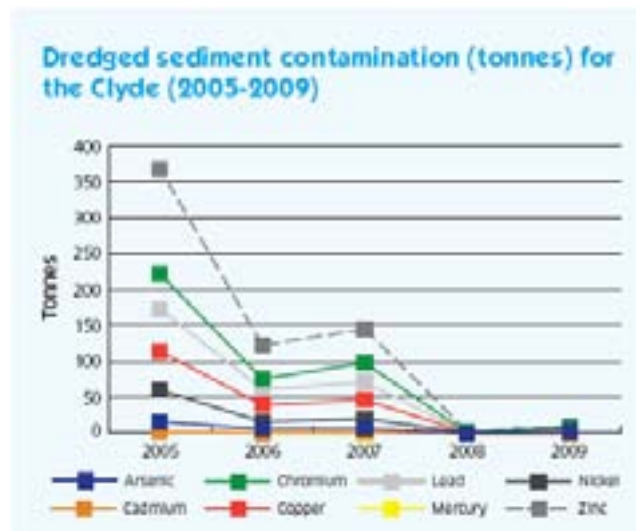
**Green**, Status is acceptable. Concentrations of contaminants are at levels where it can be assumed that little or no risks are posed to the environment and its living resources at the population or community level.

**Red**, Status is unacceptable. Concentrations of contaminants are at levels where there is an unacceptable risk of chronic effects occurring in marine species, including the most sensitive species.

OSPAR international standards for concentrations of contaminants are as follows; contaminant concentrations are considered to be low if they are below the Background Assessment Concentration (BAC), slightly elevated if above the BAC but below the Environmental Assessment Criteria (EAC) and of concern if above the EAC.

The general trend in Scottish waters for metal contaminants is that the input in disposed waste is declining and these downward trends for mercury, cadmium and lindane are reported in Charting Progress 2 and Scotland's Marine Atlas (see Figure 4.2). In a recent study by Webster *et al.* (in press) PAH, PCB and PBDE concentrations were found to be significantly higher in sediment and fish liver from the Clyde compared to all other sea areas around Scotland. The PAH data from this study showed that all PAHs in all sea areas were at acceptable concentrations (green) except for the Clyde.

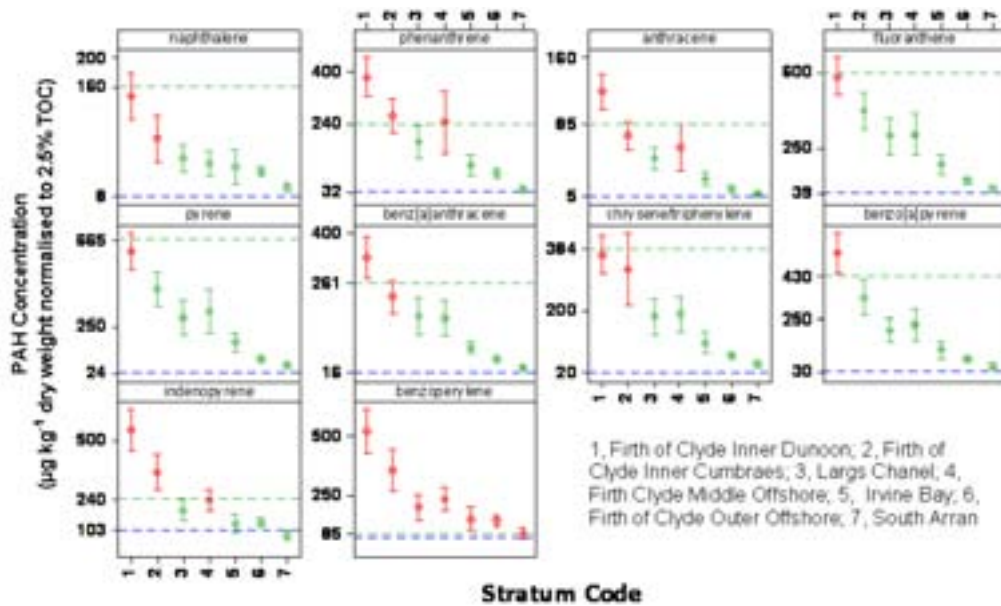
The Clyde Sea area is sampled at seven different stratum from north to south; 1 Firth of Clyde Inner Dunoon; 2 Firth of Clyde Inner Cumbræ; 3 Largs Chanel; 4 Firth Clyde Middle Offshore; 5 Irvine Bay; 6 Firth of Clyde Outer Offshore; 7 South Arran (Figure 5.3). Although PAH concentrations in the sediment were found to be above assessment criteria in the areas of the inner Clyde, a downward trend was detected. PAH concentrations also showed a significant gradient going from north to south stratum with the lowest concentrations being in the strata closest to the open sea (Webster *et al.*, in press) see Figure 5.4.



**Figure 5.2** Source, Scotland's Marine Atlas (2011) (Baxter *et al.*, 2011).



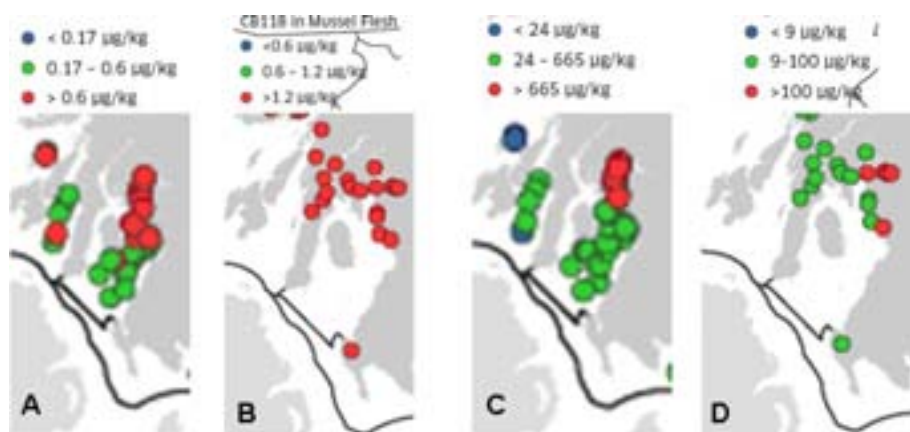
**Figure 5.3** Location of sampling sites for each stratum in the Clyde



**Figure 5.4** Interval plot of time-averaged individual parent PAH concentrations in sediment ( $\mu\text{g kg}^{-1}$  dry weight normalised to 2.5% TOC) for the strata in the Clyde. The error bars are the 95% confidence limits. Sites are highlighted 'blue', 'green' or 'red' on the basis of the concentration relative to assessment criteria. (Source, Webster *et al.*, in press)

The accumulation of mercury in fish flesh has been investigated in relation to the disposal sites in the Clyde (Clark, 1989). Mercury is of particular interest as it can be transmitted through the food chain and can be potentially passed on to humans. However, fish from the Clyde have not accumulated mercury above background concentrations (Roger, 1992).

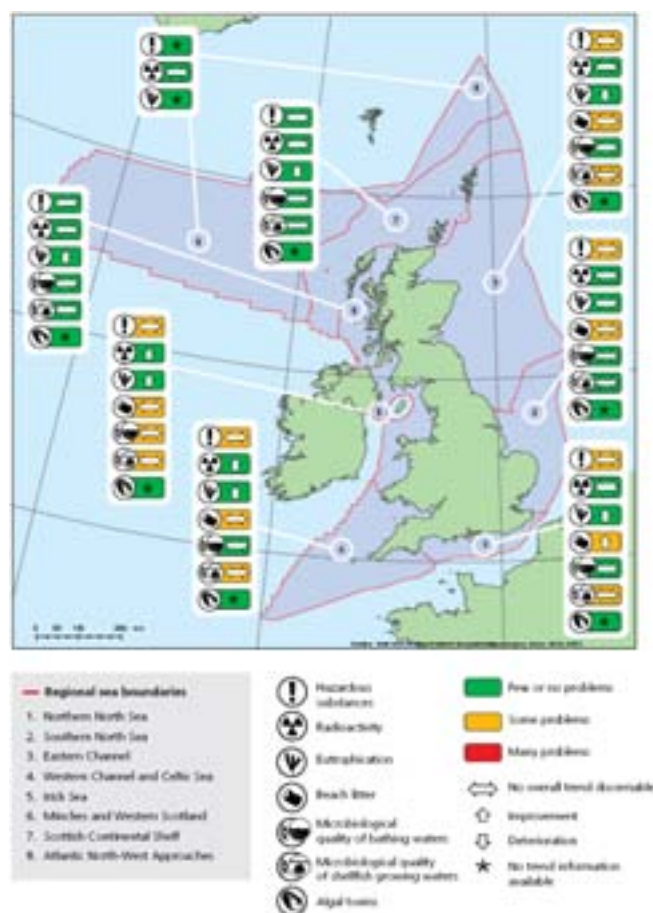
The most toxic PCB (CB118) is present above the EAC in mussels and one sediment site in the Firth of Clyde and it is of concern that adverse biological effects may be seen in marine biota in the area (see Figure 5.5).



**Figure 5.5** A - CB118 in sediments normalised to 2.5% TOC. B – CB118 in Biota. . C- Pyrene in sediments normalised to 2.5% TOC. D – Pyrene in Biota. Source, Scotland's Marine Atlas (Baxter *et al.*, 2011)

In order to determine the biological effects of hazardous substances bioassays of two species, the crustacean *Corophium volutator* and the polychaete worm *Arenicola marina*, are used (Baxter *et al.*, 2011). Toxicity is determined by the number of test organisms which survive in the test sediments compared to uncontaminated control sediments. The sediments from two sites in the inner Firth of Clyde were found to contain the highest level of contaminants from the coastal areas around Scotland and the bioassays indicated that adverse effects are possible at these sites (Baxter *et al.*, 2011). However analysis of the sediments does not show any adverse impacts at present.

The overall status of the sea areas around Scotland assessed for persistent organic pollutants (POPs) are considered to be acceptable as concentrations were below those likely to result in chronic effects except for in the *Clyde Sea* area. However, a downward trend in PAH in sediments in the Clyde has been detected and in comparison to other seas around the wider UK the environmental status of the Clyde has few problems (see Figure 5.6).



**Figure 5.6** Pollution status of the seas around Scotland Source, The State of UK Seas, Charting Progress 2, (UKMASS, 2010).

### **5.3 Marine Litter**

Marine and beach litter is a significant issue in the Firth of Clyde and around Scotland. Marine litter has been an ongoing problem for many years and originates from many different sources such as recreation and tourism, fishing debris, sewage related debris and shipping waste (Somerville *et al.*, 2006). In addition, the litter in Scottish seas may be derived locally or have travelled thousands of miles from well outside Scotland's influence. Some sea lochs around Scotland act as a natural collecting funnel (known as litter sinks) such as at the head of Loch Long at Arrochar in the Clyde Sea, which collects large accumulations of litter on the beach even though the population of the surrounding area is quite small.

It has been estimated that approximately 80% of marine litter originates from land-based sources and that up to 90% of the waste consists of plastics which can persist for a significant amount of time (Davison, 1996). Litter in the marine environment gives rise to a range of adverse ecological impacts, including; entanglement, smothering, ingestion, disturbance of habitat, transport of invasive species and poisoning by the breakdown of products. The major impacts of marine litter on fishery interests results from damage to nets and fouling of fishing grounds (MaLITT, 2002). Fishing itself remains one of the worst sources of marine litter. The most significant impact of litter from fisheries is ghost fishing where lost fishing gear, particularly from creel fisheries, continues to capture target and non-target species. However, in the Clyde the effects of this have been shown to be minimal with most species able to escape from creels over time (Adey, 2007).

In general there is little known about the extent and composition of marine litter around the Firth of Clyde. This is mainly due to the lack of a systematic monitoring programme being in place in Scotland and no agency that has overall responsibility for tackling marine litter (Donnelly *et al.*, 2010). However, Marine Scotland is currently leading the development of a Scottish marine litter strategy.

### **5.4 Shipping**

Historically the ports of the Firth of Clyde have played a vital role in the prosperity of Scotland. The Clyde is a major international shipping location, which has several major ports, busy shipping lanes and a BP oil terminal in Loch Long. The major ports of the Clyde are Glasgow, Greenock, Hunterston, Ardrossan and Stranraer. The contribution of ports and water transportation to business and Scotland's economy is quite significant. About 95% of UK imports and exports are transported by sea. Clydeport itself is the third largest port in Scotland and the eleventh largest in the UK by volume of traffic. Figure 5.7 illustrates the shipping infrastructure in the Firth of Clyde.





**Figure 5.7** Shipping and transport infrastructure in the Firth of Clyde (Source, SSMEI Clyde Pilot, Donnelly *et al.* 2010).

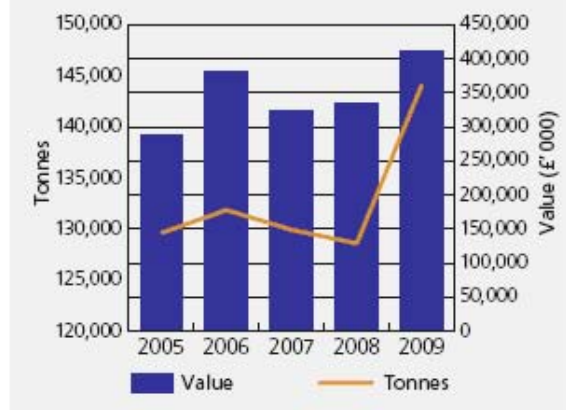
## 5.5 Aquaculture

Aquaculture has been the fastest growing food production sector in the world and currently Scotland is the largest aquaculture producer in the European Union (Hall-Spencer *et al.*, 2006). Scotland's fjords provide sheltered cool waters and high water exchange well suited for the farming of salmon (Hall-Spencer *et al.* 2006). The industry in Scotland is dominated by salmon production but also has significant rainbow trout and mussel production. Scotland Highland and Island salmon farming has grown dramatically and is an increasingly important industry helping to underpin economic growth in rural coastal communities (Baxter *et al.*, 2011). The Firth of Clyde has in recent years, like many other areas on the West Coast of Scotland, become an important focus of aquaculture processes. There are a number of salmon farms to the North of the region, such as in Loch Fyne and Loch Striven, and some further south at Arran. Figure 5.8 shows the trends in salmon and shellfish (particularly mussel) aquaculture for Scotland since 2005.

There are growing concerns over the environmental effects of the aquaculture industry (Fernandes *et al.* 2001). Aquaculture generates considerable amounts of effluent from nutrients, waste feed, faeces and from the by-products of pesticides. In shallow waters with weak under currents, waste products from marine cages settle on the bottom accumulating and smothering organisms on the sea floor. This can result in alterations to the infaunal community structure and lowered species diversity. In deeper waters and where there are stronger currents effluents released should be dispersed over a larger area. Fish farms located over maerl beds; although in a tidally strong location can get particulates trapped within the complex matrix of the thalli. Marine fish farming can thus have harmful effects on the surrounding environment. In semi-enclosed sea lochs, cage aquaculture of Atlantic salmon is the most common source of organic enrichment. The area of sea floor impacted by fish faeces and uneaten food will depend on the size and tonnage of the farm, on water depth, and on the local hydrodynamic conditions (Hughes, 1998).



### a) Atlantic salmon production and turnover (2005-2009)



### b) Mussel and other shellfish – production and turnover (2005-2009)



**Figure 5.8** Trends in production and turnover from 2005-2009 for a) Atlantic salmon b) Mussel and other shellfish. Source, Scotland's Marine Atlas, 2011.

## 5.6 Scotland's Marine Atlas – Overall Assessment

The following is adapted from Scotland's Marine Atlas, Regional assessments, Solway, North Channel and Clyde (Baxter *et al.*, 2011)

### 5.6.1 Activities and Pressures

The Clyde hosts a wide range of human activities and consequently is subject to a number of pressures. Aquaculture, particularly salmon and shellfish production, takes place in a number of sea lochs and there is widespread fishing, mainly for *Nephrops* and scallops.

There are significant ports, shipping and ferry activities with 20% of Scottish cargo volume passing through the Clyde ports. The Clyde is one of the busiest areas for ferry traffic with key links to various islands and peninsulas, as well as Northern Ireland, accounting for ~60% of overall Scottish passenger traffic.

Scotland's only Naval base is on the Clyde.

The Clyde is popular for recreational sailing, supporting ~40% of Scottish boat berths. There are also popular bathing beaches on the Ayrshire coast.

The Clyde Estuary and Ayrshire coast are relatively urbanised and industrialised compared with other parts of Scotland. This results in discharges from waste water treatment works and industrial effluents to estuary and coastal waters, as well as water abstraction, mainly for power generation.

Pressures resulting from these activities include the introduction of contaminants from industrial effluents and sewage works and dumping of dredge spoil from harbour maintenance. Fishing using trawls and dredges results in the abrasion of the seabed. There

are also local effects of aquaculture on seabed ecology. Recreational boating and commercial shipping activities have probably led to the introduction of non-native species.

#### 5.6.2 *Clean and Safe*

At the area level (i.e. all Clyde Sea) there are few concerns in relation to hazardous substances, radioactivity, oil and chemical spills and algal toxins.

Contaminant loadings to the Clyde Estuary are lower now compared to historical discharges but a legacy of localised contaminated sediments remains. These in turn have caused elevated concentrations of contaminants in mussels in the Clyde Estuary.

Water quality in the Clyde Estuary is compromised by discharges of industrial effluent and treated sewage although effluent treatment has improved resulting in returning populations of residential and migratory fish.

The quality of bathing and shellfish waters in the Firth of Clyde is affected by inputs of bacteria from diffuse sources, which increase during periods of high rainfall.

Local accumulations of litter are observed on some beaches possibly being transported by the prevailing currents. The source is not always possible to identify.

#### 5.6.3 *Healthy and Biologically Diverse*

The status of habitats within the Clyde is mixed. Intertidal habitats (rock and sediments) are deteriorating. In relation to rocky intertidal habitats this is due to invasion of non-native species, in particular wireweed. Shallow subtidal sediments are relatively degraded while shallow, subtidal rocky habitats appear to be in a better state.

In general, mobile species such as cetaceans, seals and seabirds also show a mixed picture but overall are stable at the area level.

In contrast, the reduced populations of commercial fish are a major concern.

The introduction and establishment of a number of invasive non-native species, for example, intertidal wireweed (*Sargassum muticum*) and the subtidal carpet sea squirt (*Didemnum vexillum*), first found at Largs in 2009, is very concerning.

#### 5.6.4 *Response / Forward Look*

Many of the concerns associated with the Clyde result from historical practices and management approaches. Enhanced scientific knowledge, improved regulation and greater environmental awareness have resulted in significant reductions in inputs of contaminants and improvements in water quality.

Pressure on coastal and inshore habitats is increasing from industry such as the proposed Hunterston power station (with a possible change in cooling water requirements), aquaculture and recreational activities.

The Clyde may have a potential resource to support the generation of marine renewable energy, mainly offshore wind and tidal. Growth of the industry and development of associated infrastructure, including seabed cables, is anticipated. Further work will be

required to understand the effects on seascapes and landscapes, communities, tourism and recreation.

Increasing shipping activity, possible new container facilities at Hunterston, and recreational sailing will risk the further introduction of non-native species.

Underwater noise associated with industrial and recreational activities is expected to increase. There is also the possibility of increased ferry traffic to Northern Ireland with facilities in Loch Ryan due to expand.

## **5.7 Concluding Remark**

As Europe, the UK and Scotland prepares to implement the Marine Strategy Framework Directive, the Clyde Sea offers a potentially exciting test area, where indicators and targets describing Good Environmental Status (GES) could be developed, an integrated ecosystem monitoring scheme devised involving cross-organisational working (i.e. Marine Scotland, SEPA, SNH) and a series of management measures implemented to take the Clyde towards GES by the target date of 2020. The Clyde offers: a pragmatic scale; a solely national management regime; a varied mix of status and pressures; diverse habitats; a representative range of stakeholders.

## 6. HUMAN IMPACTS - FISHERIES

### 6.1 Introduction

The fishing industry has had a major impact on the image and character of the Firth of Clyde and many of its coastal towns. It is a complex, traditional industry and holds great economic importance for many rural communities around Scotland's coast, including the Clyde, as well as political influence (SSMEI, 2010). In the Clyde, fishing occurs throughout the area and the main landing ports are Campbelltown, Tarbert, Ayr and Troon and some smaller fishing ports, Greenock, Largs and Rothesay. The Clyde had once been a productive fishery for demersal, pelagic and shellfish but is now primarily a shellfish fishery. The locations of the main fishing ports in the region where landings have been recorded are shown in Figure 6.1.



**Figure 6.1** The locations of the main Clyde fishing ports where landings have been recorded. Also shown are 1 nm (orange) and 3 nm (red) limits from the coast.

### 6.2 Legislation

In Scottish Inshore waters the principle legislation for fisheries management is the Inshore Fishing (Scotland) Act 1984. The principal fisheries management legislation Acts that are applicable to the Clyde are included in Table 6.1. The list should not be considered a comprehensive list and does not include the statutory instruments implemented under the different acts throughout the years.

Year	Title
1885	Sea Fisheries Scotland Act
1891	Fisheries Act
1893	North Sea Fisheries Act
1915	Fishery Harbours Act
1934	Illegal Trawling Act
1955	Fisheries Act
1962	Sea Fish Industry Act
1964	Fishery Limits Act
1966	Sea Fisheries Regulation Act
1967	Sea Fisheries (Shellfish) Act
1967	Sea Fish (Conservation) Act
1968	Sea Fisheries Act
1970	Sea Fish Industry Act
1973	Sea Fisheries (Shellfish) Act
1976	Fishery Limits Act
1984	Inshore Fishing (Scotland) Act
1992	Sea Fisheries (Wildlife Conservation) Act
1992	Sea Fish (Conservation) Act
1994	Inshore Fishing (Scotland) Act
2000	Sea Fisheries (Shellfish) Amendment (Scotland) Act
2005	The Registration of Fish Sellers and Buyers
2009	Marine and Coastal Act
2010	Marine Scotland Act

**Table 6.1** The principal fisheries management legislation Acts that are applicable to the Clyde. The list should not be considered a comprehensive list and does not include the statutory instruments implemented under the different acts throughout the years.

Some of the legislation changes have had a profound effect on the behaviour of the fisheries such as following the introduction of the Buyers and Sellers registration in 2005 which resulted in an almost complete stop to black landings around Scotland. However, since the Buyers and Sellers regulation there has also been a dramatic increase in the levels of discarding of finfish across all age groups suggesting that the legislation has controlled landings rather than catch.

A ban on trawling in the Clyde was originally introduced in the late nineteenth century after fishery scientists at the time suggested that the Firth of Clyde fisheries were becoming depleted due to excessive trawling (Thurstan and Roberts, 2010). The Act was then amended in 1934 to include beam and otter trawling under the Illegal Trawling (Scotland) Act 1934. The closure remained in place until 1962 when the Sea Fisheries (Scotland) Byelaw (No.65) came into effect which permitted summer (1 May to 30 September) otter trawling within the Firth of Clyde except within a 3 nautical mile limit (Figure 6.1). Further legislation in 1968 (Sea Fisheries (Scotland) Byelaws no.'s 80 and 83) enabled fishing to take place throughout the year. The 3 nautical mile limit remained until 1984 (Inshore Fishing (Scotland) Act) when it was repealed under pressure from the industry during a time when demersal finfish landings were in decline.

Recently there has been a call to re-instate the 3 n.mile limit, most strongly from the Scottish Sea Angling Conservation Network (SSACN). Sea angling was at one time a major sport and tourist attraction in the Clyde, which began in the 1960s. However, with the decline in

catches sea angling in the Clyde is not what it used to be. SSACN blame poor fisheries policies and practices combined with political ineptitude, resulting in the removal of many gear and access restrictions in the 1980's, to be the reason that the quality of sea angling has drastically declined. This suggestion was further supported by Thurstan and Roberts (2010) which linked the collapse of the demersal fisheries in the Clyde with the removal of the 3 nautical mile closure.

With regards to legislation applicable to the herring fishery in the Clyde, it was also prohibited to pelagic trawling for herring until 1962. In the same year a Byelaw was passed which prohibited fishing for herring by any method between midnight on Fridays and midnight on Sundays. The spawning ground for herring located on the Ballantrae Bank had originally been closed in 1860 but this was repealed in 1867. The bank stayed open to fishing until 1972 when a seasonal closure was introduced from 15 February until the 30 April each year. There was an exemption for anchored drift nets but they became included in the seasonal closure in 1977 (Bailey *et al.*, 1986).

The measures which remain in force in order to protect the spring-spawning herring are as follows;

- a complete ban on herring fishing from 1 January to 30 April
- a complete ban on all forms of active fishing from 1 February to 1 April on the Ballantrae Bank spawning grounds
- a ban on herring fishing between 00,00 Saturday morning and 24,00 Sunday night.

### **6.3 Stock Assessment**

ICES provides scientific advice on the management of the important commercial species of fin fish and some shellfish stocks in all areas of the north-east Atlantic. For the purpose of assessment, ICES divide sea areas into sub areas and divisions. Annual Total Allowable Catch (TAC) quotas are agreed for each of the fisheries in each division. Ideally these are based on scientific advice which is given in accordance with the precautionary approach and aimed at keeping stocks above the reference point of Bpa (if this is defined for the stock). This work is summarised in the annual ICES advice. ICES is responsible for providing scientific advice on TACs and other conservation measures to the international fisheries commissions, including the EU. In addition, since 2010 ICES has given advice in relation to Maximum Sustainable Yield (MSY).

The Firth of Clyde falls into Division VIa which stretches from the North Channel of the Irish Sea to 60°N and west to 12°W including the coast of Scotland as far east as 4°W including the Clyde. For the main demersal species stock assessments are carried out at the level of VIa. Thus assessment and setting of Total Allowable Catches is carried out at the level of the 'West of Scotland' rather than the Clyde. The main exceptions to this are Clyde herring, *Nephrops* and scallops, which are assessed locally.

### **6.4 Pelagic Fisheries**

#### **6.4.1 Herring**

The Firth of Clyde was once the centre of a major herring fishery which had been prosecuted in Scottish inshore waters since the 15th century (Rorke, 2005) although it has been subject to major fluctuations (Bailey *et al.*, 1986). The biology of the Clyde herring stock has been

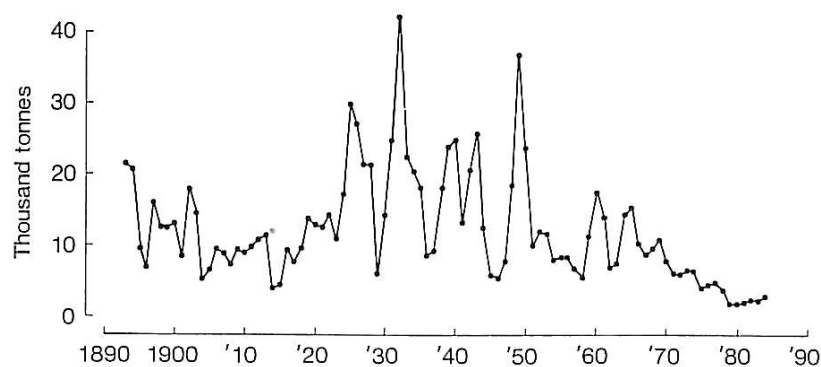
studied since the late 1800's following the opening of a temporary laboratory at Tarbert, Loch Fyne (Gordon and De Silva, 1980). In the past the fishery was almost entirely dependent on spring-spawning herring which spawn locally on Ballantrae Bank in the Firth of Clyde until about 1969 when a new component of autumn-spawning herring gradually increased in importance in landings and was predominant by 1972 (HAWG, 1978). Although autumn-spawned herring formed a greater part of the Clyde population, there was no evidence of autumn spawning occurring within the Firth (Wood, 1960; Saville, 1962).

Although there had been no significant change in the abundance of the total herring population, the spring-spawners had decreased in the early 1970s which was accompanied by an increase in the absolute abundance of autumn-spawners. In 1979 TAC regulations were imposed on the stock in addition to a closure of the fishery from October through till May in response to the clear evidence of a decrease in the abundance of spring-spawning herring (Bailey *et al.*, 1986). The cause of this decline may be natural as it can be attributed with the reduced recruitment of the local spring-spawning stock, but the effects of intensive exploitation cannot be ruled out (Bailey *et al.*, 1986).

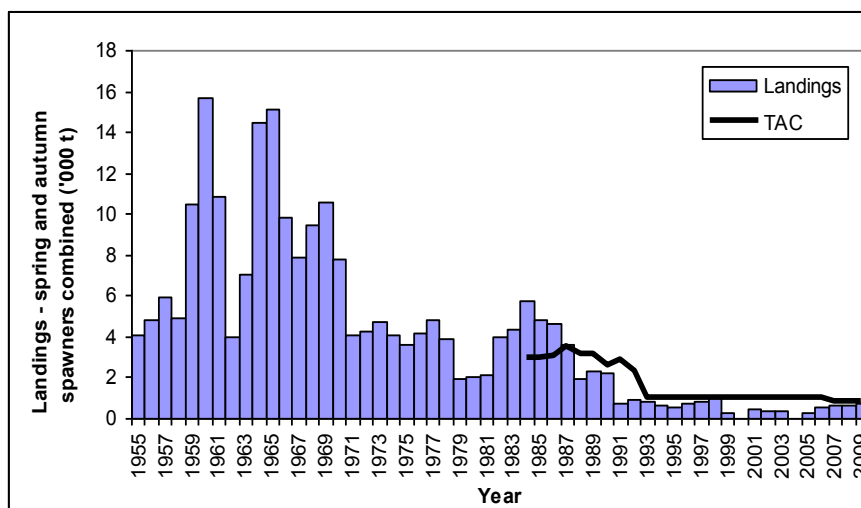
In Scotland, records of herring landings were kept even before the Fishery Board for Scotland was formed in 1882. The fishery was prosecuted by anchored drift net and ring-netting until pair trawling arrived in 1968 and became the predominant method by 1973 (Bailey *et al.*, 1986). Catches increased to a peak between the late 1950s and mid 1960s averaging around 14,000 t per annum after which the stock began to collapse (Bailey, 1986) (see Figure 6.2).

The Firth of Clyde is part of ICES Division VIa and in the 1970s all the herring stocks in the adjacent areas to the Clyde were at a low level. This led to Division VIa herring fishery being closed in 1978 but because of the complex origin of the Clyde herring population, ICES advised that the area be treated as a separated management unit. A small TAC of 2000t was agreed in 1979 for the area (Bailey *et al.*, 1986) and the first analytical assessment was carried out in 1982 (Hatfield *et al.*, 2007). Management of the Clyde has remained separate since 1979.

Landings of herring from the Firth of Clyde fluctuated about a long-term average of 14,200t in the period 1893-1960, from 1960-1978 the average landings were down to 8300t and only 2400t from 1978-1984 when landings became regulated. Since 1991 catches in the Clyde have exceeded 1,000 t only once (see Figure 6.3). The reasons for the collapse of the Clyde herring are not clear cut however declining spawning stock biomass, high fishing mortality and lack of recruitment to the local spring-spawning stock may well have been causative (Bailey *et al.*, 1986).



**Figure 6.2** Herring landings in the Firth of Clyde (1000 tonnes) 1890-1984 (Source, Bailey *et al.*, 1986).



**Figure 6.3.** Herring landings (1000 tonnes), 1955 to 2009. Spring and autumn spawning herring combined. Agreed TAC 1984 – 2009.

Today herring in the Clyde are exploited by a small number of local trawlers and by pair trawlers from Northern Ireland. There is not much information on the current status of the stock as catch and sampling data availability has been minimal since the early 2000s. Thus, the precise status of the stock is uncertain; the stock is low but there is currently no evident downward trend. The Clyde herring stock is recognised as a separate stock but is not currently assessed analytically.

In 2011 under the provisions of the TAC and Quota Regulations (57/2011), the European Commission has delegated the function of setting the TAC for certain stocks which are only fished by one Member State, to that Member State – setting out a mechanism for how the TAC should be determined. This provision currently applies only to the Clyde Herring stock. However, as mentioned, Clyde Herring is a very data poor stock which makes this task more difficult. It has been proposed, in the absence of a detailed assessment, to set the TAC for 2011 based on the recent stability of the fishery at an average of the TAC set for the last 3 years.

Despite the management measures imposed on the Clyde herring fishery such as the closure of the spawning fishery, there is so far no evidence of recovery of the recruitment to this stock.

## 6.5 Demersal Fisheries

In the Clyde yields of demersal fish increased rapidly after the repeal, in 1962, of the long standing ban on trawling in the area up to 3 nautical miles from the coast. The demersal fish landings continued to increase up until 1973 when landings reached a maximum before starting to decline (Hislop, 1986). In 1984 the 3 nautical mile ban was also lifted in order to try and maintain catch levels. This proved ineffective and demersal fin fish landings continued to decline until the early 2000's when the directed fishery effectively ceased (Heath and Speirs, 2010). In addition, the total demersal fishing effort in the Clyde had risen since the 1960's almost entirely due to an increase in trawling for *Nephrops* from which there was a large by-catch of whitefish. According to the Scottish Sea Fisheries Statistical Tables (SSFST), which were published annually by DAFS, the annual weights of all demersal species landed at Clyde ports, in the early 1980's, ranged from 4,000 to 10,000 tonnes, valued at £2-5 million. In terms of value, cod and hake were the most important species in



the Clyde fishery; these species composition of landings in the Clyde are unusual for a Scottish inshore fishery in that the proportion of haddock is rather small, while that of hake is relatively large.

The demersal fishery was seasonal on the Clyde grounds and most of the fishing effort took place during the winter and spring, partly because catch rates were relatively high at this time of year and partly because the area provides shelter from the winter weather. The Clyde fishery depends to a large extent on young fish and the relative importance of the principle species fluctuates from year to year in response to variations in the strength of the recruiting year class. Although there was no conclusive evidence that the Clyde populations were self-contained, all the major species are known to spawn within or close to the area and tagging experiments had shown that there was not much mixing between Clyde fish and those from surrounding areas. Historically, the most important single species in the Clyde demersal fishery in terms of landings has been whiting (Gambell, 1965).

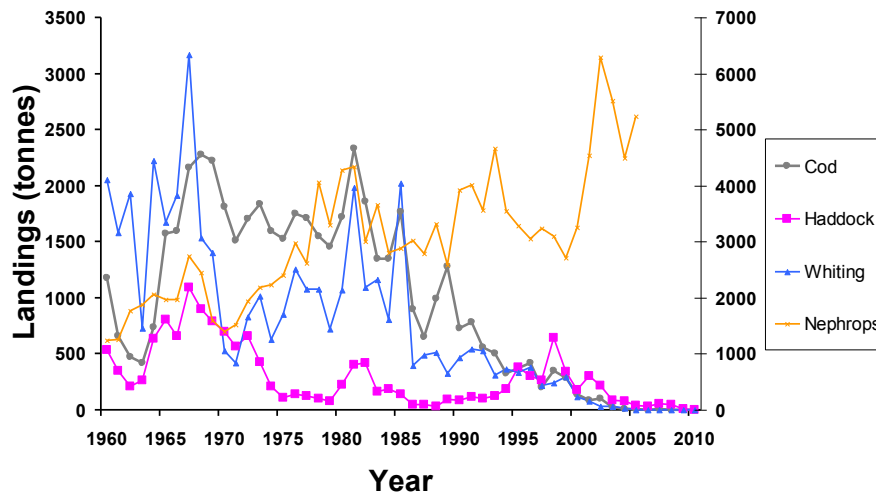
In 1986, the demersal fish stocks in the Clyde were considered to be exploited intensively with the fishery there depending to a large extent on the younger age groups and thus the fishery was highly sensitive to variations in the strength of the recruiting year class (Hislop, 1986).

Demersal fishing in the Clyde Sea has changed dramatically since the 1986 review by Hislop. Since the mid 1980's, as mentioned previously, there has been a collapse in the stocks of the main commercial demersal species, cod, haddock and whiting and a transition to a *Nephrops* dominated fishery in the Clyde (see Figure 6.4.). Although the target fishery is *Nephrops* the demersal fisheries in the *Clyde Sea* area are a mixed fishery and as a result of this all groundfish stocks are exploited. Cod, haddock and whiting are the predominant roundfish caught in this mixed fishery with highest catches in the winter, although there can also be important by-catches of other species such as hake and saithe (WGNSDS, 2008). A mixed fishery by its nature is difficult to determine appropriate management strategies for and in recognition of this, ICES has given the following advice for fisheries in the west of Scotland, they should fish,

- without catch or discard of cod and whiting in Division VIa
- with minimal catch of common skate and undulate ray
- within the biological exploitation limits of all other stocks

Thurstan and Roberts (2010) used historical records and anecdotal information to describe changes in the fisheries of the Clyde. It has been asserted by this study that the record of demersal fish landings demonstrates that the Clyde is an ecosystem in 'ecological meltdown'. However, fisheries landings data alone are insufficient to support such a strong claim. For example, discard data can form an important component of the total species catch in demersal fisheries and often render landings data inadequate for monitoring trends and assessing the state of an ecosystem (Stratoudakis *et al.*, 1999).

For the purpose of this review it is useful in the first instance to reproduce the trends in landings for the fisheries in the Clyde using historical landings data. Figure 6.4 shows the trends in landings (taken from the Fisheries Management Database at MSS) for the three main demersal fish species cod, haddock and whiting and for the *Nephrops* fishery. The arguments made by Thurstan and Roberts (2010) is evident from the plot; the decline in demersal fin fish landings corresponds with the increase in *Nephrops* landings and the transition to a *Nephrops* dominated fishery in the Clyde.



**Figure 6.4** Landings from 1960-2010 for cod, haddock, whiting and *Nephrops* in the Clyde (ICES Stat Rectangles 39E4 + 39E5 + 40E4 + 40E5. Source, MSS).

### 6.5.1 Cod

The Atlantic cod (*Gadus morhua*) is found in all Scottish waters from shallow coastal areas to waters deeper than 200m. It is a key species as it is an important marine predator and a highly valued commercial resource providing one of the major fishery resources in the North Atlantic dating back centuries (Hughes and Nickell, 2009; Hutchinson *et al.*, 2001). They are fished throughout the North Sea and West Coast of Scotland. However, high exploitation rates in the 1980s and 1990s have depleted the cod stocks off the west coast of Scotland, like many other Atlantic cod stocks, to an all time low and these stocks are now showing some signs of recovery (Wright *et al.*, 2006).

In response to the depleted state of the cod stocks the emphasis of recent management has been to help their recovery with the implementation of the Cod Recovery Plan in 2001 (ICES, 2001). Under the recovery plan the immediate requirement was to allow as many cod as possible to spawn before the end of April when the spawning season finishes. The seasonal closure remains in the Clyde from February 14th – April 30th when all bottom trawling is prohibited in the outer closed area shown in Figure 6.5 and only trawling for *Nephrops* is allowed in the inner closed area. ICES have previously advised a zero catch of cod which would provide the highest probability of stock recovery in the context of the precautionary approach. However, this would effectively mean a closure of all the mixed demersal and *Nephrops* fisheries on the West Coast and, due to social and economic issues, fisheries managers have never fully implemented the recommendation of ‘zero catch’.

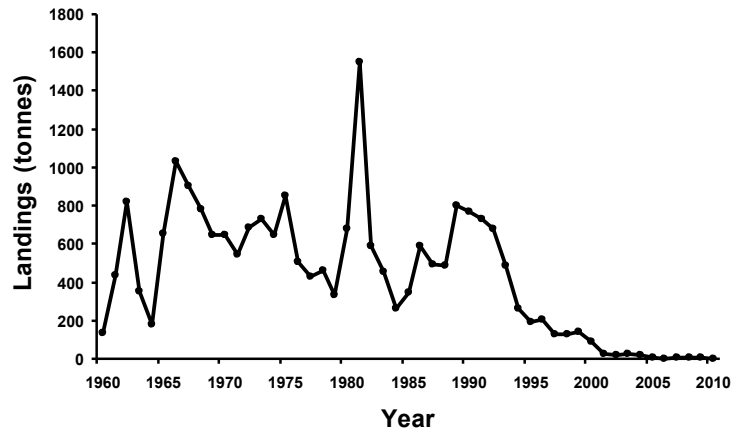


**Figure 6.5** Clyde closed areas to fishing for cod.

Understanding the Clyde cod structure and migration habits is important for the local management of the stock. Cod in the west of Scotland have shown a high degree of fidelity to their spawning grounds with recent studies estimating that between 67-97% of inshore cod remains within 100 km of their spawning ground (Wright *et al.*, 2006). The scale of juvenile and adult movements indicated by recent studies suggests that there are sub-stocks within ICES division VIa which may be reproductively isolated due to limited movements. Therefore, recovery within the Clyde is likely to be dependent on self-recruitment in this area and movements into the region from the nearby Inner Hebrides. Although the closed area contains an important spawning aggregation, the spatial scale and seasonal limit is too small to protect this local sub-stock (Wright, 2010).

### 6.5.2 Hake

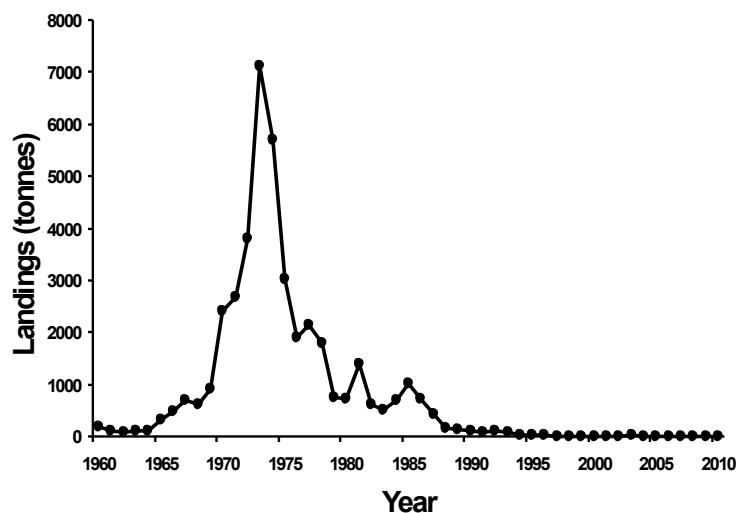
The deep waters of the Firth of Clyde are known to have provided excellent fishing grounds for hake (Hislop, 1986). ICES provides advice for the Northern hake stock as a widely distributed migratory stock which can be found in the Kattegat and Skagerrak straits adjoining Norway, Sweden and Denmark, in the North Sea, the Channel and also in the waters to the west of Scotland. Currently the state of the stock is unknown but trends based assessment indicates an increase in SSB for the Northern hake stock (ICES, 2011). Information specific to hake in the Clyde is limited but discarding rates of juvenile hake is substantial in the area (Stratoudakis *et al.*, 2001). Figure 6.6 shows the landings of hake in the Clyde from 1960-2010, which show a significant decline in landings since the early 1990s to virtually zero.



**Figure 6.6** Landings of hake in the Clyde from 1960-2010 (ICES Stat Rectangles 39E4 + 39E5 + 40E4 + 40E5. Source, MSS).

### 6.5.3 Saithe

Saithe in the Clyde has been described as a boom-and-bust fishery (Thurstan and Roberts, 2010) which was discovered in the late 1960s and peaked in 1973 with landings of over 7000 tonnes; however the catch quickly collapsed to very little by the 1990s (see Figure 6.7).



**Figure 6.7** Landings of saithe in the Clyde from 1960-2010 (ICES Stat Rectangles 39E4 + 39E5 + 40E4 + 40E5. Source, MSS).

## 6.6 Shellfish fisheries

### 6.6.1 Nephrops

The Langoustine, Norway Lobster, Dublin Bay Prawn, or *Nephrops norvegicus* (L) is the most commercial shellfish resource in UK waters and is extensively exploited throughout

Europe. Up until the early 1950's *Nephrops* attracted little commercial attention in Scotland and was rarely on sale in the region. However, in the last 50 years an important fishery for *Nephrops* has developed in Scotland and is now the largest in Europe. These developments were delayed in the Clyde by the Herring Fishery (Scotland) Act 1889, which prohibited otter and beam trawling in the Clyde until 1962 when otter trawling for *Nephrops* in the Firth of Clyde was permitted in the summer (Bailey *et al.* 1986). Shellfish such as *Nephrops*, scallops, lobster, edible and velvet crab are now the most important resource to the inshore fleet of the region. The majority of the inshore trawling fleet are dependent on *Nephrops* which are landed all year.

During the summer *Nephrops* are exploited by the Clyde fleet to the west of the Kintyre peninsula and in the more sheltered and accessible waters of the Firth of Clyde in the winter months. *Nephrops* are targeted by small demersal trawlers of no more than 30 m and are allowed to use a mesh size of 70mm, prior to 2009, and 80mm from 2009 onwards in the cod-end provided provided that *Nephrops* constitute a certain minimum proportion by weight of the total landings (Tuck *et al.*, 1997; ICES, 2011).

In more detail, the changes in technical measure regulations applying on the West of Scotland (ICES VIa) were designed to improve the selectivity and reduce unwanted catches of small fish. The minimum mesh size in the *Nephrops* fishery was increased from 70mm to 80mm as part of the 2009 EU emergency measures to deal with reduced gadoid populations. A second measure was the requirement for *Nephrops* vessels operating on the west coast to use a square mesh panel with a mesh size of 120mm as part of the Scottish Conservation Credits scheme (in place since 2008).

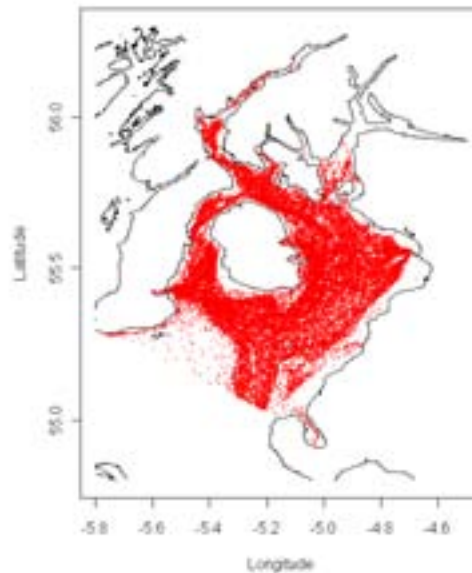
Owing to its burrowing behaviour, the distribution of *Nephrops* is restricted to areas of a particular sediment type; mud, sandy mud and muddy sand. Burrow density and animal size are related to sediment characteristics and hydrography (Chapman and Bailey, 1987). Around Scotland it has been found that areas of fine sediments are characterised by large *Nephrops* occurring in low densities and areas of coarser sediments are characterised by smaller *Nephrops* at higher densities (Tully and Hillis, 1995). In the Clyde, burrow densities are higher in the south and the average size of *Nephrops* is smaller. This is particularly evident from the differences in discard composition between the north and the south of the Clyde. Catches from the south have a higher proportion of small *Nephrops* resulting in large proportions of undersized *Nephrops* and *Nephrops* heads (Bergmann *et al.*, 2002). Trawls in the south also generate larger quantities of roundfish discards (35%), including the important commercial species whiting, cod and haddock (Bergmann *et al.*, 2002)

*Nephrops* stocks have been identified on the basis of population distributions which are defined as separate functional units (FU) and are the level at which ICES Working Groups collect fishery data and performs assessments. The Clyde Sea area (FU13) is one of three distinct functional units within ICES area VIa where Scotland's *Nephrops* stocks are assessed, although the stocks are considered to be functionally separate they are currently managed under the West of Scotland single stock definition.

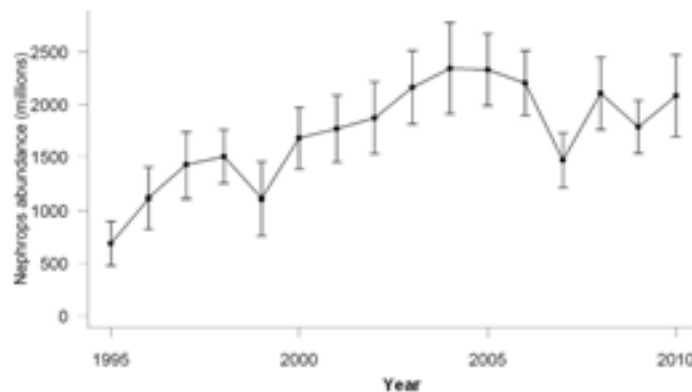
Survey assessments of the stock are carried out annually by an underwater TV survey (UWTV) which determines *Nephrops* burrow density on the seabed. The information gathered provides an index of stock abundance which is independent of the fishery and together provides information on the status and predicted stock level.

The *Nephrops* fishery has also developed in recent years due to an increase in catches by static gear such as creeling. Almost all of the Clyde including the sealochs is targeted by bottom trawlers fishing for *Nephrops*; VMS data linked to landings shows the areas which are targeted by boats greater than 12m in length (Figure 6.8). This figure suggests that the area covered by the UWTV survey is slightly smaller than the area covered by fishing activity

(WGCSE, 2010). The perception of the state of the stock in the Firth of Clyde is that it is stable and with the recent high catches by trawlers it is perceived to be a sustainable fishery. However, a reduction in abundance in 2007 coupled with the increase in landings has led ICES to advise a more precautionary approach in recent years (Figure 6.9).



**Figure 6.8** The distribution of VMS pings (shown in red) recorded from *Nephrops* trawlers >12 m length in 2010.



**Figure 6.9** *Nephrops*, Clyde (FU13), Firth of Clyde subarea. Time-series of revised TV survey abundance estimates (not adjusted for bias), with 95% confidence intervals. (Source, ICES, 2011).

For most analytical models used for assessment purposes, it is assumed that the population is homogenous in terms of its biological characteristics. The *Nephrops* stock in the Firth of Clyde has been shown to consist of a mixture of sub-unit populations differing from each other in growth, size composition and density which invalidates the assumption of homogeneity.

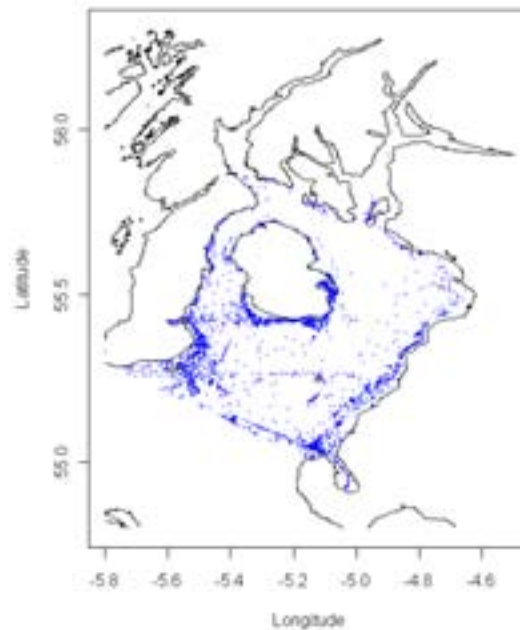
The north-east Atlantic *Nephrops* trawling fisheries have been ranked as having the fifth highest discard ratio in the world (number of by-catch to number of target species) (Catchpole *et al.* 2005). Unsurprisingly the discarding rates are also high in the Clyde *Nephrops* fishery with the proportion of the catch discarded being estimated between 66 and 80% in the Clyde Sea (Bergmann *et al.*, 2002; Stratoudakis *et al.*, 2001). The discards mainly consist of small demersal fish particularly young whiting (*Merlangius merlangus*) (Stratoudakis *et al.*, 2001 and see Section 7). The use of more selective gear can help reduce by-catch levels such as the use of the Swedish selection grid (Nordmore grid) which may allow the *Nephrops* fishery to be decoupled from cod and other demersal fish species (Valentinsson and Ulmestrand, 2008). The Swedish grid has been adopted by the Swedish *Nephrops* fishery and has recently been trialled for the west coast of Scotland *Nephrops* fishery (MSS, 2011). The trials resulted in a significant loss in the smaller *Nephrops* (< 41-45mm carapace length) attributed to the selection of the 80mm cod-end and no significant loss of larger *Nephrops* (MSS, 2011). There has, however, been a reluctance to adopt this method in the Clyde *Nephrops* fishery due to handling difficulties and the decrease in retention of the larger size classes of *Nephrops*.

### 6.6.2 Scallops

The most important commercial molluscan species in the Clyde Sea are the scallop (*Pecten maximus*) and the related but smaller queen scallop (*Chlamys opercularis*). Both species occur wherever the sea bed consists of sand, fine gravel or sandy gravel. The distribution of suitable sediments results in the species being found in a narrow strip of sea bed on each side of the Clyde and around Arran in depths no greater than 40m (Mason and Fraser, 1986). Both the scallop and the queen are filter feeders, the scallop lies recessed in the sediment, the queen, however, do not recess into the sediment and will swim sporadically for a short time.

A dredge fishery for the scallop started in the Clyde Sea in the 1930's but remained small during the 1940s and 1950s with landings averaging 112t (Mason, 1983) but the scallop fishery provided a useful income for a few boats between other fisheries. In the 1960s there was a radical change in the fishery; a large demand for scallops had developed in continental Europe resulting in a huge expansion of the fishery. The advent of processing factories in Scotland also allowed fishing for scallops to occur throughout the year (Mason and Fraser, 1986). Scallops are now exploited in the Clyde by a fleet of dredging boats which developed in the area in the late 1960's. The Ayr and Campbeltown Fishery District, includes the Clyde Sea Area and has been the major locus of the fishery in Scotland since the fishery began.

The traditional method of catching scallops is by dredge which basically consists of a rigid metal frame and toothed bar that digs into the sea bed at an angle of 60-70°; this is towed along the sea bed and the scallops are scraped into a netted bag (Mason, 1983). In the early days of the Scottish scallop fishery. A small percentage of the catch is also taken by hand by SCUBA divers along the coast. Figure 6.10 shows the distribution of Vessel Monitoring System (VMS) pings from scallop boats greater than 15m, this plot indicates that scallop dredging by larger vessels occurs mostly along the coast of the Clyde.



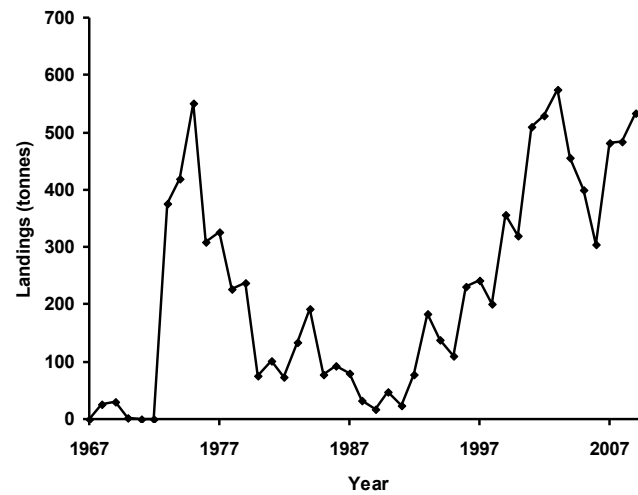
**Figure 6.10** The distribution of VMS pings (shown in blue) recorded from scallop vessels >12 m length in 2010.

Many fisheries are controlled by one or more of a number of types of measures such as quota restrictions, mesh regulations, minimum landing size, closed areas and seasonal closures. Not all of these measures are suitable for scallops due to the fragmented nature of the fisheries which is prosecuted in remote areas and landed in many isolated harbours. The most applicable measure for conserving scallop stocks is the minimum landing size and is the most commonly practised (Mason, 1983). In September 2003 The Prohibition of Fishing for Scallops (Scotland) Order 2003 was implemented. This put in place new measures for scallop conservation that limited the number of dredges a scallop vessel can tow to a maximum of 8 per side for Scottish Inshore waters (FRS, 2006). Currently there is no catch limit on UK scallop fisheries. They are mostly managed through minimum sizes, restriction on dredge numbers and seasonal closures in some areas. Scallop stocks are highly susceptible to overfishing due to their limited mobility and confinement to a particular type of sea bed. However, scallop stocks have largely held up well on all grounds, even in the Clyde where fishing has gone on the longest.

The historical landings series shows marked fluctuations resulting from a combination of variable recruitment and changes in fishing effort (ICES, 2006). After the rapid development of the fishery in the late 1960s, landings declined sharply in the early 1970s, only to increase again reaching a peak in the late 1970s. Following the high reported landings of 1984, landings declined to a low point in 1988 after which they increased fairly steadily until 1998 and have fluctuated since then, probably influenced by the effect of area closures (ICES, 2006). The historical landings show that until recently annual landings have been, typically, between 200 and 300 tonnes. However, since 1999, there has been an upward trend with the 2003 landings exceeding 500 tonnes for the first time since the mid 1970's (see Figure 6.11). The most recent assessment for scallops was done in 2006 which is mainly due to a lack of data and the fact that sampling of Clyde scallop landings is quite limited and irregular. Because of limited port sampling, the age composition data are insufficient to carry out a



VPA assessment for the Clyde and no survey data is available (ICES, 2006). Catches are reported by individual ICES rectangles and in recent years rectangle 40E4 has accounted for almost all of scallop Clyde landings. All recorded landings are taken by dredge and the main landing ports are in Campbeltown, Troon and Ayr.



**Figure 6.11** Landings of scallops in the Clyde from 1967-2010 (Source, MSS).

### 6.6.3 Other Shellfish

There are small creel fisheries for crabs, lobsters and shrimp mostly on a part-time basis. Gathering mussels was a flourishing industry in Scotland at the end of the nineteenth century and accounted for 29% of the total shellfish landings, but now only a few are taken, mainly in the lochs and mainly for human consumption. Beds of cockles are found in several parts of the Clyde, including the Isle of Bute, the Ayrshire coast and at Stranraer (Mason and Fraser, 1986). The native oyster was once abundant and widespread in Scottish waters and now it is scarce with the only commercial fishery remaining in Scotland is in Loch Ryan (SNH, 2011; Mason and Fraser, 1986)

Around the Arran coast electric fishing for razor fish is known to occur. Fishing for razors using electricity is reported to be a very effective method. However, there is limited knowledge of the effect of the electric field on other species (Breen *et al.*, 2011). The legality of using electricity as a fishing method is an issue of concern.

## 6.7 Sea Angling

Sea angling is a long established leisure activity in the Clyde and the area once had a reputation of being one of the best sea angling destinations in the UK. The Upper Clyde has experienced a significant decline in sea angling. Large number of anglers were attracted and fished from both boat and the shore and there is evidence that some travelled on a fairly regular basis from as far afield as the English Midlands.

The governing body is the Scottish Federation of Sea Anglers, which has approximately 64 affiliated clubs (Murison and Robson, 1997). Sea Angling has three main forms, angling from the shore; inshore fishing; and deep sea fishing. Sea angling occurs throughout the Clyde and the area once held major competitions including the Scottish Open Shore, the European

Boat Cod Festival and the Saltcoats Sea Angling Competition. In their prime (1970s), these competitions attracted up to 1300 entrants and visiting anglers enjoyed unparalleled sport (Donnelly *et al.*, 2010; SSACN, 2010).

In response to sharp falls in angler number, and the poor catches in the 1988 White Horse Whisky competition, the Scottish Tourist Board commissioned the Clyde Sea Angling Study (CSAS). After reviewing the available evidence, the CSAS study concluded that the Clyde fish stocks declined as a result of the increased commercial fishing effort, much of which resulted directly from the Inshore Fishing (Scotland) Act 1984 which opened up the zero to three mile zone to all mobile gear fishing activity). There was, however, no policy response and a great many sea angling dependent jobs were subsequently lost, as CSAS had predicted. The angling charter fleet has now gone and angler numbers are much reduced (Marine Scotland, 2009).

## 6.8 Environmental Effects of Fishing

It is clear that the primary objective of all fishery management strategies must be to determine fishing pressure on fish stocks in order to manage this pressure and maintain a sustainable industry. However, additional consideration should be given to the conservation of habitats and the protection of biodiversity which includes monitoring the damage caused by the impacts of fishing to target species, discards, benthic infauna and sediments (Hauton *et al.*, 2003).

### 6.8.1 Trawling

The effects of towed fishing gear on the marine environment has attracted considerable interest recently with many studies examining this issue using various approaches (Currie and Parry, 1996; Tuck *et al.*, 1998; Thrush *et al.*, 1998;). The use of such gear affects much more than the species being caught. As the gear is dragged along the sea bed it disturbs both the sediments and the organisms and plants that live there. Many of the species affected by the fishing gear have no commercial value but they do play important ecological roles (Coggan *et al.*, 2001). Direct changes can result from the crushing of individuals while the partial excavation and damage of near surface dwelling organisms can attract mobile predators/scavengers. In the majority of cases, the immediate impacts on benthic organisms are quantitative in nature such that changes in the abundance of various organisms occur rather than their elimination. Trawling can also reduce habitat complexity by damaging the physical and biological structures of the sea floor (NRC, 2002).

The obvious impacts of trawling are the physical effects of the doors and that trawling results in a reduction of the abundance of large, fragile organisms and an increase in the abundance of opportunistic species (Tuck *et al.*, 1998; Coggan *et al.*, 2001). Trawl damaged fauna provide an artificial food subsidy to an area which, over time, generally seems to shift the species composition in favour of scavenger feeders (Ramsay *et al.*, 1997). A study on the effects of trawl disturbance was carried out in an un-fished sea loch of the Clyde, Loch Gareloch, which found that measures of diversity decreased while the number of individuals increased suggesting a disproportionate increase in a few dominant species (Tuck *et al.*, 1998). The main species that showed a consistent increase in abundance in association with disturbance was the cirratulid family which are considered to be opportunistic in nature (Tuck *et al.*, 1998).

The principle fishery today in the Clyde is a *Nephrops* fishery and as shown from the VMS data (see figure 6.8) nearly the entire Clyde is targeted by *Nephrops* trawlers. In terms of the direct effects on *Nephrops*, the passage of ground gear over the sea bed may close over the

entrance to burrows of *Nephtys* and other species. However, the animals have been observed to be able to open the burrows again easily thus the effect on uncaught *Nephtys* is minimal (Coggan *et al.*, 2001).

### 6.8.2 Dredging

The impacts of trawls and dredges are often thought to be similar as they are both towed along surface sediments where they are likely to damage organisms. However, the toothed scallop dredge, designed to dig into the sediment may be the most damaging of all demersal fishing gears to benthic communities (Jenkins *et al.* 2001; Collie *et al.*, 2000). Scallop dredging has been found to markedly change the topography of the sediment by flattening mounds and filling depressions in soft sediments directly after trawling (Currie and Parry, 1996). However the long-term effects of trawling and dredging differ greatly with dredging affecting the most vulnerable species which are slow-growing and long-lived such as sponges and coral.

Although many studies have been unable to detect the long term effects of gear impact on sedimentary habitats (Hall-Spencer and Moore, 2000), an ongoing scallop dredging study over 5 years has been shown to alter benthic communities, driving them from one state to another often causing the community to become more heterogeneous (Bradshaw *et al.*, 2001). Hall-Spencer and Moore (2000) showed that scallop dredging could kill and bury up to 70% of living maerl (a habitat of special conservation interest in EU waters) in the path of the dredge. Atlantic maerl beds are usually characterised by coarse sediment, clean water and significant bottom currents, thus tend to provide good scallop fishing grounds (Macdonald *et al.*, 1996). The difference between un-fished and fished areas confirms that maerl beds are a particularly fragile habitat. Most of the Clyde maerl grounds have been extensively modified by scallop dredge.

A hydraulic dredge fishery for razor clams (*Ensis* sp.) exists on a small scale in Scotland although increased demand from Europe and the Far East has led to a growth of interest in the fishery (Hauton *et al.*, 2003). Hydraulic dredging is another severely damaging fishing activity which has the potential to expose deep-burrowing long-lived bivalves, such as the otter shell (*Lutraria* sp.) which would otherwise rarely find itself exposed on the sediment surface (Hauton *et al.* 2003). The capacity of these deep-burrowing species to rebury is low compared to bivalves that live closer to the surface of the sediment as they bury into the sediment as juveniles.

### 6.8.3 Discards

Another significant effect of fishing results from the discards which are produced by commercial fishing worldwide. Discards are by-catch organisms which are returned to sea as they are considered undesirable. This can be for a variety of reasons such as that they have no commercial value, are below minimum landing size or are surplus to quota (Bergmann *et al.* 2002; Catchpole *et al.*, 2005). Discarding behaviour can be highly variable and depends on current legislation and market conditions (Rochet *et al.*, 2002). The rate of discarding in the *Clyde Sea Nephtys* fishery is very high and the proportion discarded has been estimated between 66-80%. Wiczorek *et al.* (2001) estimated that approximately 80 tonnes of biomass are discarded every working day by *Nephtys* trawlers in the Clyde Sea and that every year a minimum of 25,000 tonnes are discarded in the area.

Beam trawling results in two forms of potential biomass for scavengers, discarded by-catch and disturbed, damaged and dead benthic infauna (Groenewold and Fonds, 2000). Most of the discards from beam trawlers end up on the sea floor, 80% of flatfish, 90% of

invertebrates, and 20% of roundfish. The majority of the discarded material in the Clyde Sea reaches the sea bed within a few minutes where it becomes available to benthic scavengers. Invertebrate discards fall to the sea bed rapidly where they are readily consumed by megafaunal scavengers and amphipods (Bergmann *et al.* 2002). The overall impact of this is that discarding subsidises benthic populations and the food web in general, by making available food resources that would otherwise be unattainable for organisms at a particular trophic level (Kaiser and Haddink, 2007). This carrion could therefore also be subsidising the *Nephrops* population. However, the extent to which this occurs in the Clyde is unknown as there is a lack of information in the ecological energetics of the species involved locally.

Although the majority of material discarded sinks to the sea bed discards are also exploited at the sea surface by seabirds. Many seabirds especially gulls associate with fishing boats all around the British Isles and discards and offal provide a large quantity of food. This availability of large amount of discards is one of the factors which may have contributed to the rapid growth of some seabird populations (Garthe *et al.* 1996; Dunnet *et al.*, 1990). Recently there has been a concerted change in discarding practice around Scotland which could have a significant impact on the breeding populations along the coast.

## **6.9 Suggestion for further work**

While the *Nephrops* stock in the Clyde is regularly surveyed, and there is some survey data describing the demersal stocks (see next section), there is no up to date survey of the herring stock in the Clyde.

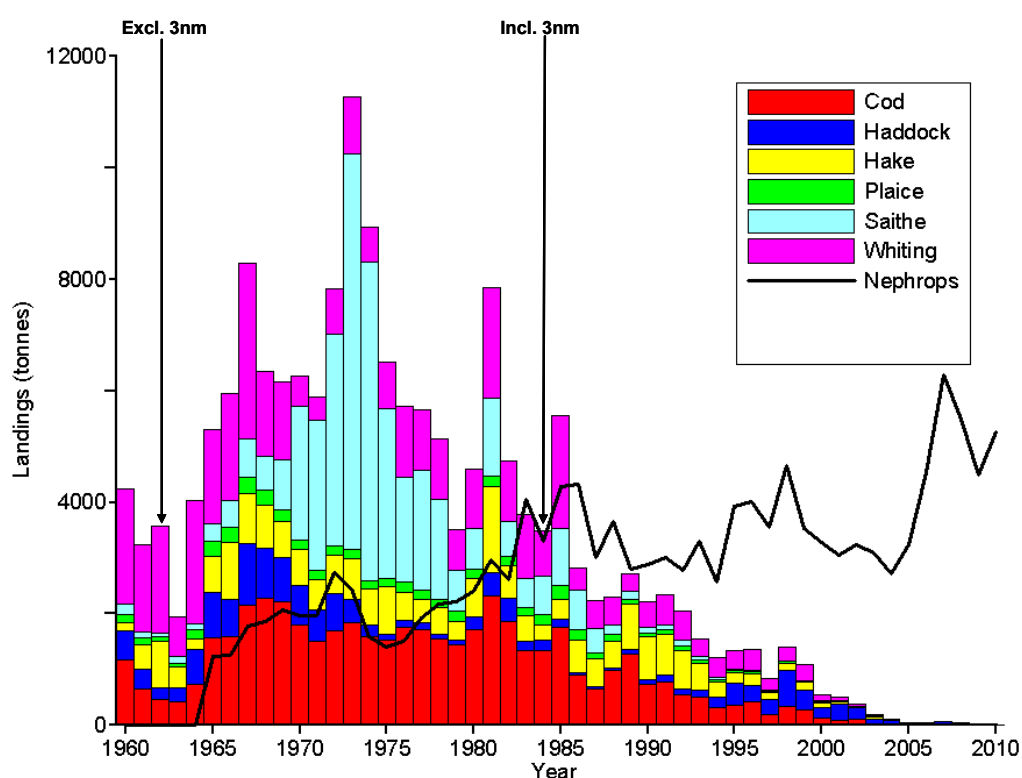
In order to estimate the current abundance and distribution of herring and sprat in the Clyde Sea, a fisheries acoustic survey should be conducted, using a multi-frequency scientific echosounder and a pelagic trawl for validation. The survey should include all areas of the Clyde Sea, as close inshore as is possible to navigate the survey vessel, and include the major loch areas (Kyles of Bute, Loch Fyne, Loch Striven, Loch Ryan) and the Clyde Estuary (to Port Glasgow). This survey should result in estimates of abundance at age for herring and sprat, and maps of their distribution.

## 7. THE CURRENT STATUS OF THE CLYDE DEMERSAL FISH COMMUNITY

The study by Heath and Speirs (2011 – for the remainder of this section this paper will be referred to as *HS2011*) provides the most comprehensive analysis of the state of the Clyde demersal fish community currently available. This section presents the results of *HS2011* in some detail as the results of this study are centrally relevant to addressing some of the concerns raised by Thurston and Roberts (2010).

### 7.1 Summary of Demersal Clyde Landings

Figure 7.1 summarises the landings of demersal fish from the Clyde, described in detail in the previous section.



**Figure 7.1** Summary of landings (tonnes) of six demersal fish species from the Clyde Sea (ICES Stat Rectangles 39E4 + 39E5 + 40E4 + 40E5. Source, MSS). Years when the Clyde opened to trawling, excluding the area within 3 nm from the coast (1962), and including within 3 nm (1984) are highlighted. Landings of *Nephrops* are also shown (black line).

The decline in landings of demersal fish is clear. *HS2011* describe the following milestones in the development of the fishing impact on the demersal fish stocks in the Clyde,

1889	Entire Firth	Closed to trawlers (>8 tonnes)	To protect inshore fishing grounds and herring
1962	Firth outside 3 nm limit	Opened to trawlers	Fish landings rise to 1973, then start to decline
1984	Firth inside 3 nm limit	Opened to trawlers	To keep up fish landings. To exploit inshore <i>Nephrops</i> grounds
2001	Parts of Clyde (see Figure 6.5)	Seasonal closures	To protect spawning cod
2000's			Fishing targeting demersal fish stops as uneconomic. Fish landings only from <i>Nephrops</i> fishery by-catch

It is clear from Figure 7.1 that, following the opening of the Clyde to trawlers in 1962, landings rose towards a maximum in the early 1970s, and then have subsequently crashed. The removal of the 3nm limit in 1984 resulted in the landings rising slightly for one year, before the steep decline continued. *Nephrops* landings, in contrast, have steadily risen since the mid-1960s.

From landings data alone it would seem that demersal fish have disappeared from the Clyde, to be replaced by *Nephrops*. However, this is far from the actual true picture of the health of the Clyde Sea ecosystem.

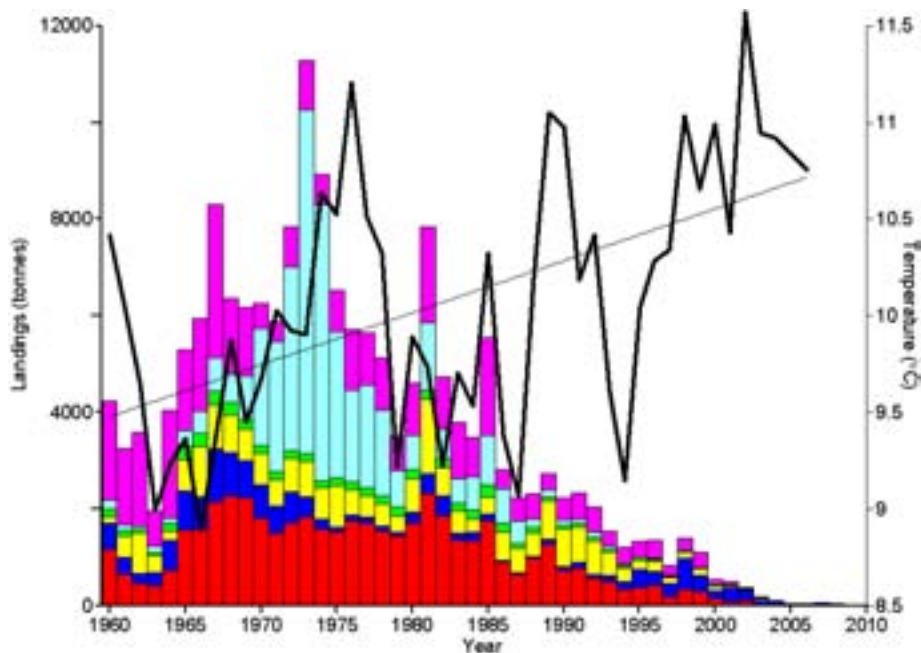
## 7.2 A Climatic Effect ?

Before moving onto how *HS2011* have developed a much more accurate picture of the current status of demersal fish in the Clyde, it is worth one final consideration of the overall picture obtained from the landings data.

It might be argued that Figure 7.1 reflects the results of climate change rather than fishing. Figure 7.2 shows the average annual temperature derived from weekly measurements performed at Millport, Cumbrae, in the Clyde, compared to the data presented in Figure 7.1.

A simplistic argument might state that in the 1960s and 1970s waters were cooler than now, and landings of demersal fish were high. Now that waters have warmed, demersal fish abundances have declined resulting in lower catches. We will see from the analysis of *HS2011* that this is not the case. However, even a comparison of temperature and landings as presented in Figure 7.2 can show that, when the detail is examined rather than the overall trends, there is much disparity from the simple idea that warm waters mean less demersal fish, as warm periods (e.g. 1974-1977) can have good landings, and cool years (e.g. 1993-1995) poor landings.

It is quite clear that overfishing has led to the decline in fish landings in the Clyde. However, landings data alone can not give the true picture of the health of the demersal fish communities in the Clyde, as we will see in the following sections.



**Figure 7.2** Summary of landings (tonnes) of six demersal fish species from the Clyde Sea (ICES Stat Rectangles 39E4 + 39E5 + 40E4 + 40E5. Source, MSS) compared to annual average temperature at Millport, Cumbrae (thick black line. Linear regression – thin black line).

### 7.3 Limitations of Landings Data

*HS2011* noted that the use of landings data alone is fraught with difficulty. Landings of a particular species can be affected by a diverse multitude of factors, including,

- the amount of the catch of a species that is not landed (discards)
- market demand for that species
- existing legislative controls including quotas and effort restrictions
- restricted access to the fishery for the species owing to weather
- fishing fleet decisions based on fuel price
- fishing fleet decisions based on skipper preferences and current trends
- decommissioning schemes reducing effort targeting that species
- by-catch of the species in other fisheries

For this reason, analyses as presented above and the analysis of Thurston and Roberts (2010) and its conclusions require significant caveats applied. The difficulties associated with using landings data resulted in *HS2011* focussing on research vessel survey data.

### 7.4 Research Vessel Survey Data

Since early in the 20<sup>th</sup> century, the Scottish Government, through its Marine Laboratory in Aberdeen, have conducted trawl surveys of the Clyde fairly consistently on an annual basis. However, it is only since 1985 that standardised survey methods have been used.

#### 7.4.1 Constructing the Time-Series

*HS2011* took a statistical approach in order to reconstruct time-series describing the demersal fish community back until 1927. Their “gold standard” data set was the standardised survey data coordinated by the International Council for the Exploration of the Sea (ICES) and conducted by MSS after 1985. These surveys used a net design called the *Grande Overture Verticale* (GOV) net. This design, based on commercial gear at that time, is considered to be efficient at catching a wide range of fish sizes and species. Although it is not as efficient as modern demersal gear at catching specific species or sizes, it is not meant to be. It’s aim is to collect a representative sample of all the fish present in an area using a standard method that does not alter one year to the next. Thus, time-series established using the GOV are comparable year on year, and the data can be used as a time-series. Stations sampled using the GOV gear after 1985 are shown as red symbols in Figure 7.3.

Although the standard surveys using the GOV net commenced in 1985, MSS and it’s predecessors have conducted demersal trawl surveys since the early part of the 20<sup>th</sup> century. In order to extend the time-series back earlier than 1985, *HS2011* used other survey data collected by MSS in the Clyde Sea, selecting trawl stations that lay within close proximity to the post-1985 GOV stations (i.e. trawls that lay within the red squares shown in Figure 7.3) and which used similar fishing gear. *HS2011* performed a range of tests to ensure that the data was comparable and of sufficient quality.

#### 7.4.2 The Basic Fish Data

For each haul performed during the surveys *HS2011* used, all fish species were identified and recorded. In addition to the species name, the length of each fish of that species was measured, or a sub-set of fish measured and statistically raised to the number of that species caught. Hence, the basic data *HS2011* used was the numbers of each species caught within 1cm length categories.

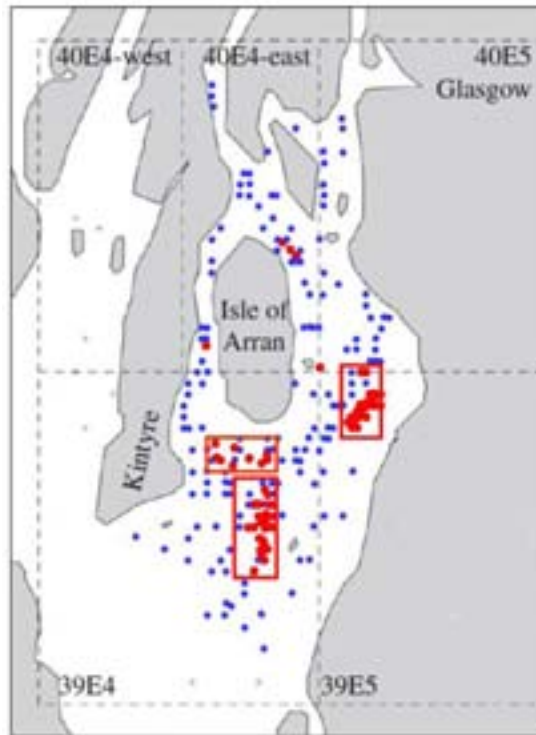
Other estimates *HS2011* used in order to derive their statistics were the area each net used in the surveys swept (since 1985 this has been directly measured using acoustic instruments prior to 1985 estimates were made – see *HS2011* for details) and a conversion between fish length and fish weight (from standard measurement for each species).

In the end, *HS2011* used data from 138 hauls collected during the 83 year period between 1927 and 2009. These hauls produced nearly 20,000 sets of species length-class records. In all, 70 different species (taxa) were identified in survey trawls in the Clyde over the recorded period, 59 of which were demersal fish species (see Annex for full species list). This compares to values of 93 and 79 demersal fish species in the Sea of the Hebrides and the Irish Sea respectively. This of course does not reflect the total number of demersal fish species in the Clyde, just those that are found offshore and can be caught by the survey gear. However, it does include all species that will be affected by commercial fishing.

#### Statistics

In the following sections, a selection of the results presented by *HS2011* has been used in order to illustrate some key findings. The reader is encouraged to study the full results in order to obtain the complete picture as presented by the authors, who also deal with the uncertainties involved in their study. They use complex indicators of species abundance, richness, evenness and size. Values of these indicators of the health and status of the demersal fish community vary from survey to survey. In order to look at inter-annual trends, *HS2011* fit statistical models to the data, especially a loess smoother model. For simplicity, in the sections below this is referred to as “average” results.

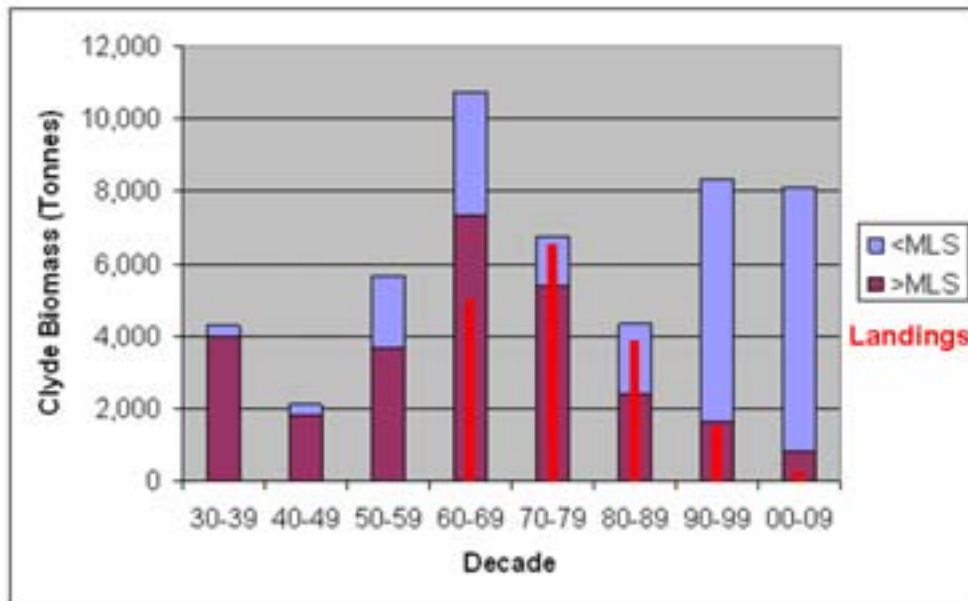




**Figure 7.3** Map showing the location of trawl sampling locations used in the analysis of *HS2011*. Also shown are ICES statistical rectangles (dashed lines) they used to obtain landings and discard data. Red symbols indicate the locations of research survey vessel trawl tows performed by Marine Scotland Science using a standard survey gear (the GOV net) after 1985. The three red rectangular cells show the sub-areas used to select other trawl stations (blue symbols) where data was obtained using non-standard fishing gear.

#### 7.4.3 Demersal Fish – Changes in Biomass

Figure 7.4 shows the average abundance (biomass) of the commercial demersal fish species (sum of cod, haddock, whiting, hake, saithe and plaice) in the Clyde Sea calculated using research vessel survey data, from *HS2011*. The data is presented as the weight (tonnes) of fish in the Clyde in an average year within the stated decades. The data is subdivided between fish that are smaller than the Minimum Landing Size (MLS) and larger than the MLS. Note that each species making up the six demersal fish has a species-specific MLS which is used in the calculation of the “greater than” and “less than” MLS percentages. Also shown in Figure 7.4 are the decadal average landings for 1960 onwards.



**Figure 7.4** Average abundance (biomass) of commercial demersal fish species (sum of cod, haddock, whiting, hake, saithe and plaice) in the Clyde Sea calculated using research vessel survey data, from *HS2011*. The data is presented as the weight (tonnes) of fish in the Clyde in an average year within the stated decades. The data is subdivided between fish that are smaller than the Minimum Landing Size (MLS) and larger than the MLS. (Note: Data has been extracted from *HS2011* Figure 4 for <MLS and >MLS loess smoothing functions, raised to the area of the Clyde Sea, i.e. 3700 km<sup>2</sup>, and averaged over relevant decades). Also shown is the decadal average landings for 1960 onwards.

The principal aspects of Figure 7.4 to note are:

- landings in the decade 1960-1969 appear to have been 46% of the total biomass. This percentage became 99% in the decade 1970-1979, 91% in 1980-1989, 18% in 1990-1999 and 2% in 2000-2009.

- the biomass of demersal fish in the Clyde in the decades 1990-1999 and 2000-2009 was over 8000 tonnes. This is approximately twice the biomass of fish in the decade 1930-1939 (~4000 tonnes) and approximately four times the biomass in the decade 1940-1949 (~2000 tonnes).

- in the decades 1930-1939 and 1940-1949, fish smaller than the minimum landings size made up on average 11% of the total biomass, whereas in the decades 1990-1999 and 2000-2009, fish smaller than the minimum landing size made up on average 85% of the biomass.

The first observation throws up some difficulties. It is not possible that a harvest ratio of 99% can be sustained for a decade without demersal stocks being completely eradicated from the Clyde. This suggests that there is a scaling factor required between the estimated total biomass and the landings data. Landings data are from official estimates derived from market sampling and log book records. The biomass is from *HS2011* using calculations involving the swept area of survey nets, the catch per unit time of a survey net, and the catchability of a species in the survey net, with the final estimated values of fish density

raised to the area of the Clyde Sea. Thus there may well be scaling issues with the estimation of total biomass. The estimates are undoubtedly too low. However, it may be assumed that this scaling factor applies equally to all years, thus comparisons between decades of estimated biomass remains valid.

It is quite clear from the Figure 7.4 that, despite the scaling issue, there was extremely heavy exploitation of the demersal fish stocks in the decades 1960-1969, 1970-1979 and 1980-1989.

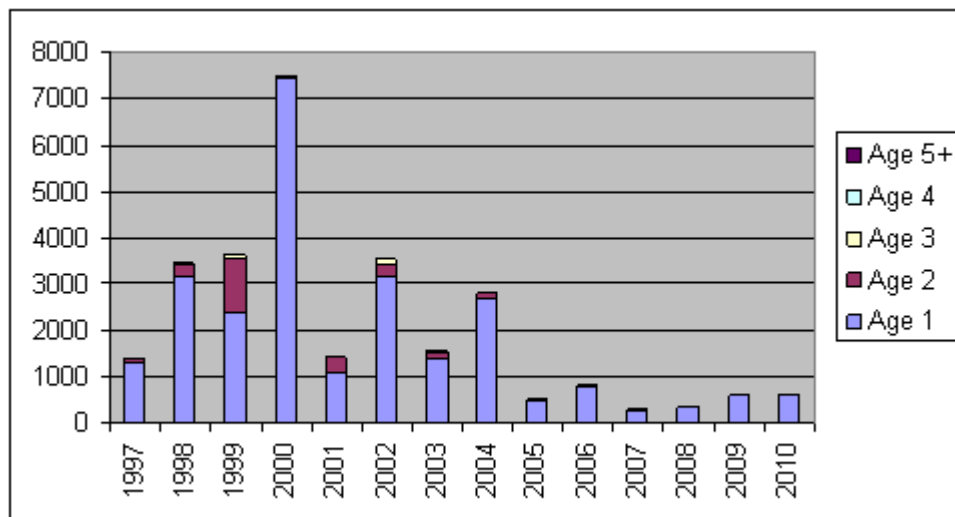
What is also clear is that, despite the intense fishing pressure on demersal stocks that took place in those decades, the biomass of demersal fish bounced back and in fact became greater than in the decades when fishing pressure was much lower, prior to the 1960s.

Although the total biomass of demersal fish recovered, the size of individual fish was much changed in recent decades compared to previous decades. While there was a recovered biomass, it was predominantly small fish, with >80% being smaller than the minimum landing size.

In terms of species, >70% of the small fish was whiting (see Section 7.4.4 below).

In terms of age, Figure 7.5 shows that the small whiting have been predominantly 1 year olds at least since the late 1990s.

These observations must imply that the Clyde is indeed productive. Primary production in the form of phytoplankton growth, and secondary production in the form of zooplankton growth each year supports a large biomass of young, 1 year old whiting.



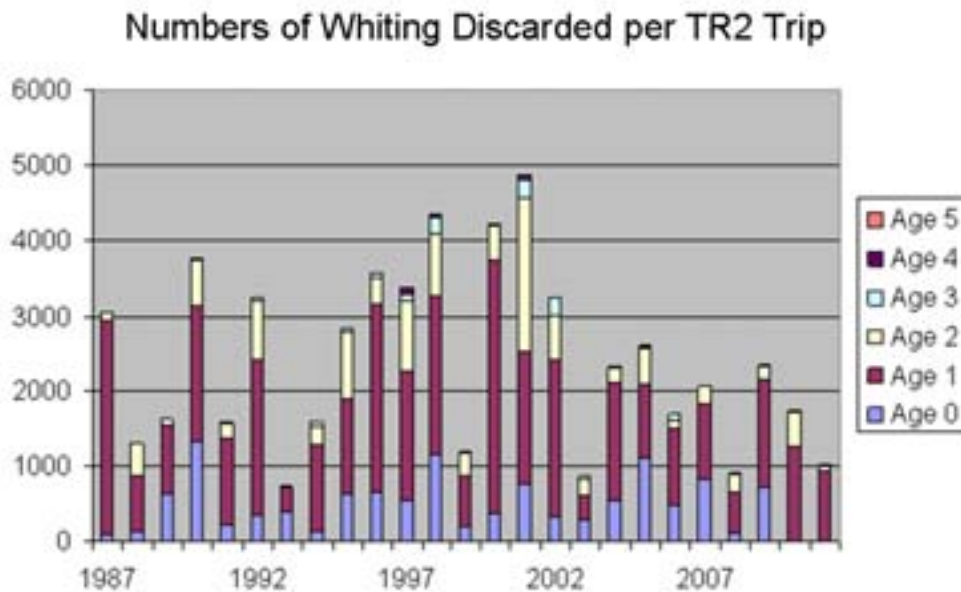
**Figure 7.5** Age of whiting caught in research vessel survey trawls in the Clyde Sea. From the Scottish Groundfish Survey Quarter 1, Marine Scotland Science. Units are a standardised index.

A valid question is where are the spawners? What fish are reproducing and producing each year an influx of new 1 year olds?

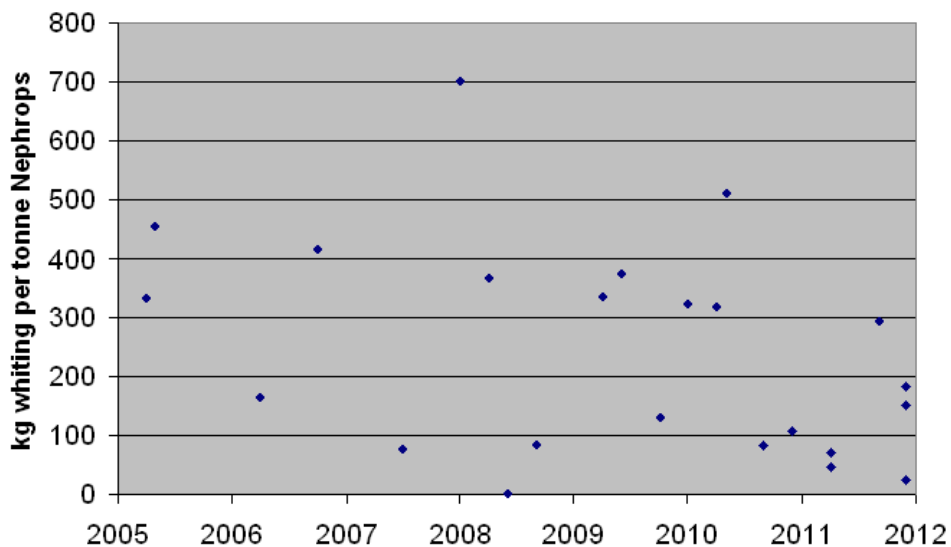
There are no comprehensive answers to these questions. Whiting can sexually mature at age 1, although no maturity data has yet been examined for Clyde whiting. The surveys that

Figure 7.5 is drawn from may have missed the spawning older fish. They may be in the areas the survey did not cover, including the upper Firth, the sea lochs and the coastal zone. An alternative may be that the spawning population is not within the Clyde at all, and the population of small whiting in the Clyde is created by recruitment from a distant spawning population, although this is thought to be unlikely. In order to find the answer to these questions, a survey of small fish in the Clyde is needed, focussing on sexual maturity.

Another valid question is; what happens to the older fish? Again no conclusive answers are available. However, Figures 7.6 and 7.7 provide some clues.



**Figure 7.6** Numbers of whiting discarded from the Clyde *Nephrops* fishery, by age. Numbers are discarded fish per observed fishing trip, derived from the MSS observer programme.



**Figure 7.7** Weight of whiting discarded per tonne of *Nephrops* landed for every observed trip since 2005. Data is from the MSS observer programme.

Figure 7.6 reveals that there have been significant discards of whiting from the TR2 *Nephrops* fishery. Up until 2009, pre-recruit (age 0) whiting were caught and discarded. The absence of age 0 whiting in the discards after 2009 may be related to the increase in cod-end mesh size from 70 mm to 80mm that occurred at the start of 2009.

Also in some years (e.g. 2001) significant numbers of 2 year old fish were caught and discarded. There is evidence of even older fish, 3 and 4 years old being included in the discards, although numbers are small.

Figure 7.7 shows the amount of whiting discards in relation to the amount of *Nephrops* landed by an individual fishing trip by a *Nephrops* vessel. The average discard rate over the period 2005 to 2012 is 241 kg of whiting discarded for every tonne of *Nephrops* landed, although individual trips have much higher values.

In 2009 the landings of *Nephrops* from the Clyde was 4460 tonnes. Using the average value of 241 kg of whiting discarded per tonne of *Nephrops* landed, this implies that in 2009, 1070 tonnes of whiting were discarded from the *Nephrops* fishery. In 2009, the estimate of the total biomass of whiting is 5,300 tonnes. Hence the by-catch of whiting in the *Nephrops* fishery exerted a fishing pressure with a harvest ratio of 0.2 (i.e. 20% of the whiting biomass is discarded in the *Nephrops* fishery each year). This is very similar to that calculated using other methods by *HS2011*.

Therefore, the suggestion from this analysis is that the *Nephrops* fishery in the Clyde may be partly responsible for the current absence of older, larger fish in the Clyde.

In summary, from the estimates of biomass in the Clyde Sea the conclusions are:

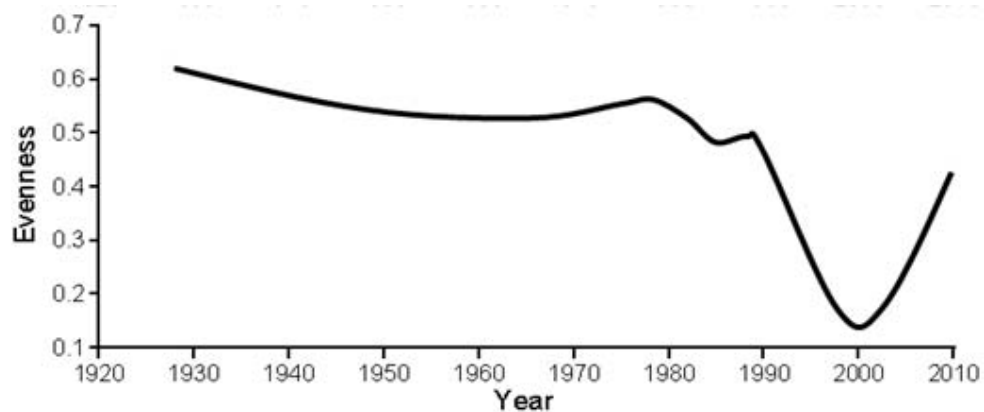
- the biomass of demersal fish in the Clyde is now greater than it was in the 1930's and 1940's. In fact more than twice as great.
- but 90% of this biomass is smaller than the minimum landing size, and 72% of it is whiting.
- the demersal fish biomass has recovered from the incredibly high exploitation rates in the 1970's and 1980's.
- hence the Clyde marine ecosystem is productive. It therefore has the potential to be restored.
- however, it is in a new regime with abundant small fish and few large fish.
- in order to recover the ecosystem towards a healthy state, we need to find measures which allow large fish to survive and increase.

#### 7.4.4 *The Mix of Demersal Fish Species in the Clyde*

Using the survey data, *HS2011* show how the mix of fish species in the Clyde has altered. To do this they use a measure called "evenness". This measure has a value of close to 1 when all species are equally present, but reduces to very low values if a few species dominate. A healthy ecosystem is generally thought to have an even mix of species, and the evenness should not alter drastically.

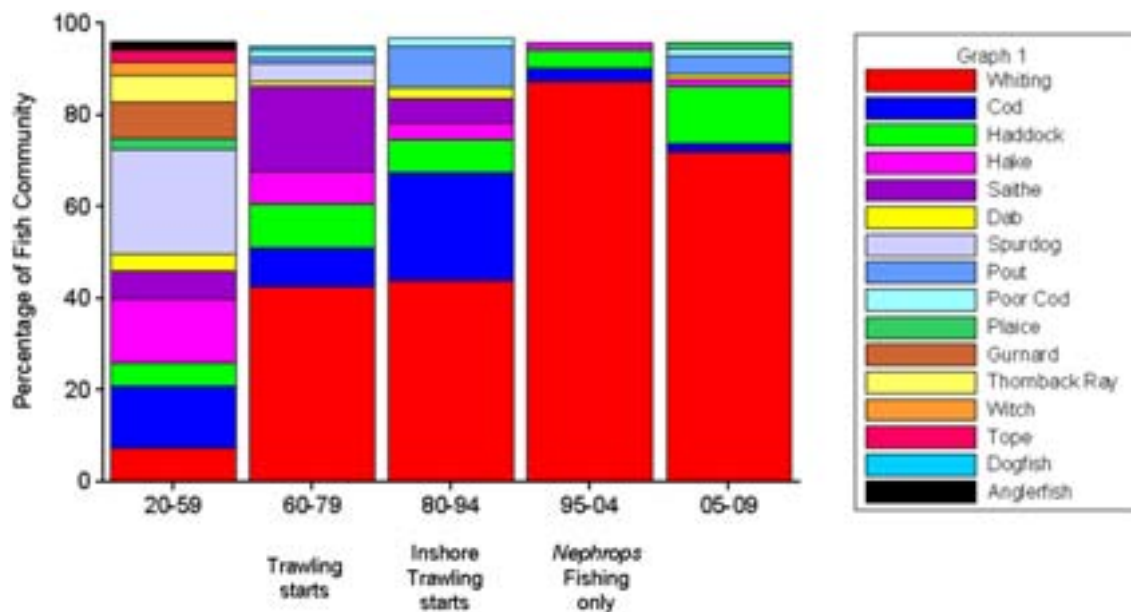
In the Clyde, *HS2011* found that the average evenness factor declined significantly between 1980 and 2000, although has since started to recover (Figure 7.8). This can also be seen in

Figure 7.9, which presents the species mix which makes up 95% of the demersal fish biomass during five different fishing “regimes” in the Clyde:



**Figure 7.8** The average (loess smoother) value of the species evenness indicator, calculated using research vessel survey data for the Clyde demersal fish community *HS2011*. This indicator has a value of 1 when all species are equally present, and reduces towards zero as fewer species dominate a community.

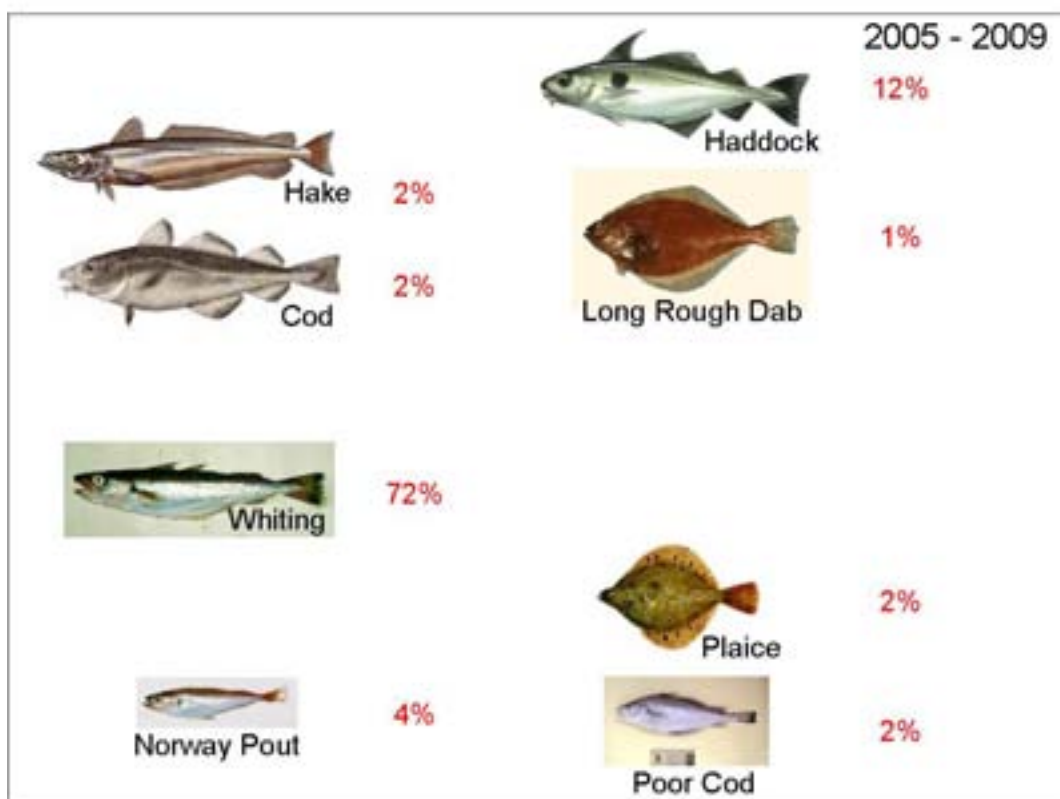
Period	Fishery Regime
1920 - 1959	Clyde closed to large trawlers
1960 - 1979	Clyde opened to large trawlers beyond 3 nm (opened in 1962)
1980 – 1994	3 nm limit removed (1984) – PEAK EXPLOITATION AND COLLAPSE
1995 – 2004	<i>Nephrops</i> fishery commences – demersal vessels convert
2005 – 2009	<i>Nephrops</i> fishery continues (by-catch of demersal fish)



**Figure 7.9** The species in the Clyde that make up 95% of the biomass of Clyde demersal fish (from Table 1, *HS2011*).

From Figure 7.8 the species change that resulted in the decline of the evenness indicator is evident. Whiting increased from just 7% of the species mix in 1920-1959, to a maximum of 87% in 1995-2004. In the earlier period there were 13 species making up 95% of the biomass, whereas by 2004 there were just 4 species in the mix. The large predator fish spurdog, which made up 23% of the demersal fish biomass in the earlier period, vanished from the top species list by 1980. In contrast, small fish such as poor cod and Norway pout, which were present in the earlier period but did not make it into the top species list, increased in significance and after 2005 represented about 4% and 2% respectively of the demersal fish biomass. Figure 7.10 presents this changing species mix pictorially.





**Figure 7.10** Pictorial representation of the change in the species mix making up 95% of the demersal fish biomass between 1920-1959 and 2005-2009 in the Clyde Sea (from Table 1, *HS2011*). Pictures and photos from FishBase.



Conclusions from the study of the mix of species in the Clyde can be summarised as follows:

- Fishing has significantly altered the mix of species in the Clyde.
- The fish community has changed from an even one, with many large predator species, to one dominated by whiting and other small fish.
- Along with other indicators and tagging data, the fact that species evenness changes in the Clyde very differently than that observed in nearby waters in the Sea of the Hebrides and the Irish Sea, confirms that the Clyde fish populations respond locally to fishing pressure.
- This also suggests that the Clyde can be managed separately from the Scottish west coast, with a good chance of recovery using local restoration measures irrespective of what happens elsewhere.
- Indeed, conservation measures applied to the west coast as a whole may not be sufficient for the Clyde, as it responds differently and independently from the adjacent coastal waters.
- *HS2011* found that there was a lag of about 20 years between the maximum average relative removal of fish from the Clyde (the Harvest Ratio peaked in about 1980) and the maximum effect on the mix of species (which reached a minimum in 2000). Such a lag is found in other indicators *HS2011* use of the health of the demersal fish community in the Clyde. It is typical of the complex interactions which exist in an ecosystem, and shows that we can not expect restoration measures to have immediate effects. This is particularly true if we have forced the Clyde ecosystem from one stable state to another.

## 7.5 Concluding Remarks

There are already positive signs of change in the Clyde Sea demersal fish populations.

Since 2000 the species evenness index is increasing. In the period 1995-2004 just 4 fish species made up 95% of the biomass of Clyde demersal fish, whereas in 2005-2009 this had increased to 8. In the earlier period 87% of the biomass was whiting, while in the later period this had decreased to 72%. Possibly the most positive sign is in the size of the biomass itself, which has shown a significant increase since 1990. All of these indicators of improving conditions in the Clyde should be strong arguments supporting the prospect of a restored Clyde.

The changes in technical measures in the Clyde *Nephrops* fishery (change from 70mm to 80mm mesh size, introduction of square mesh panels) potentially assist in reducing catches of small fish and may have contributed to some of the early signs of improvement recorded in this study. For this improvement to continue, further developments are required in order to allow higher proportions of medium and large size fish to escape and grow.

If we are to design optimum restoration plans for the Clyde Sea, they must be built on sound science. However, we can not wait indefinitely for the results of further scientific studies. An integrated science / policy approach is needed so that progress can be made on both fronts at the same time. To be successful, this should intimately involve all sectors of society with an interest in the future of the Clyde Sea.

It could be argued that the Clyde gives Scotland an opportunity to demonstrate leadership in terms of ecosystem restoration. It is our own inland sea, over which we have significant management control. We will be required to bring the Clyde to Good Environmental Status

by 2020 by the Marine Strategy Framework Directive. Currently the Clyde would certainly fail tests such as the Large Fish Indicator, and measures of biodiversity health. A restored Clyde ecosystem could bring market advantages to the fishing industry, through ecolabelling and headline conservation achievements. However, fishing sectors will have to work together in an open and transparent way. The allocation of blame is an entirely wasteful activity. Conservationists must also accept that the Clyde is not a pristine ecosystem and never will be. It is heavily used by society for many legitimate purposes, of which food extraction is one. Focus must always be on the best way forward for all. Compromises will be possible if all stakeholders approach the challenges in a constructive way.

## **7.6 Suggestions for Further Work**

A comprehensive survey of demersal fish in the Clyde is required, including small fish. The survey should include a focus on the sexual maturity and stock identification of whiting. The survey could be accompanied by increased observations of the discards of demersal fish in the *Nephrops* fishery.

## **8. ECOSYSTEM COMPARISONS**

Changes in the Clyde Sea ecosystem are similar in many aspects to those which have occurred in marine ecosystems the world over as a result of natural and anthropogenic impacts. Each source of impact may induce different patterns of response in marine ecosystems that reflect the different biological production characteristics of the ecosystem. In addition, coastal, shelf and marginal sea ecosystems which are heavily subjected to human induced perturbations are thought to experience more complicated regime changes under multiple forcing than oceanic ecosystems (Oguz and Gilbert, 2007). Understanding the structure and function of marine ecosystems and their response to such perturbations can be aided by a comparative approach (Megrey *et al.*, 2009).

### **8.1 Black Sea**

The Black Sea is a marine ecosystem which has also experienced a collapse in commercial fisheries and has undergone dramatic changes in its ecological properties from the early 1970's – 1990's. The Black Sea, although on a larger scale, is similar to the Clyde in that it is a semi-enclosed ecosystem with a history of intense commercial fishing pressure and heavy organic pollution. The two ecosystems also share similar trophic characteristics which at one point supported stocks of small pelagic fish.

The Black Sea receives extraordinarily high nutrient loading and contaminants from rivers that drain half of Europe and parts of Asia (Oguz *et al.*, 2001). Uncontrolled, industrial fisheries for pelagic species (bonito, mackerel, bluefish, and dolphins) started on a huge scale in the early 1970s and within 20 years the stocks became severely depleted (Daskalov, 2002). A study by Oguz and Gilbert (2007) illustrated the existence of regime-shift events, from ecological data (1960-2000), due to the synchronous forcing of marked nutrient enrichment, overfishing and climatic cooling/warming. The first major change in the food web of the Black Sea was the decline of large predator fish populations and the subsequent increase of small pelagic fish stocks. The second shift corresponded to the collapse of the small pelagic stocks followed by an immediate rise of gelatinous stocks in the late 1980s. It was concluded by Oguz and Gilbert that the regime shifts in the Black Sea supports strongly the assertion that the combination of eutrophication and extreme overfishing can induce hysteresis in marine ecosystems if they exert sufficiently strong forcing on the system.

Heath and Speirs (2010) have suggested a similar hysteresis has occurred in the Clyde ecosystem where there has been a transition to an alternative stable state dominated by small fish (see Section 7).

### **8.2 Gulf of St Lawrence**

Northwest Atlantic ecosystems have historically supported the largest and densest cod stocks. However, many of these cod stocks have steeply declined (Hamilton *et al.*, 2004; Christensen *et al.*, 2003; Myers *et al.*, 2001). Biological analyses point to overfishing as the primary cause of the collapse with environmental conditions being a contributing factor (Hutchings and Myers, 1993; Drinkwater 2002). In the Gulf of St Lawrence a fishing moratorium was put in place by the Canadian government in 1992 to promote the recovery of these stocks. Despite this moratorium on Northern cod in 1992 and subsequent strict management efforts the stock has failed to rebound and in April 2003 the Northern cod fishery was closed (Hamilton *et al.*, 2004). Similarly the cod stocks to the west of Scotland have not shown any significant signs of a rebound despite the strict management strategies in place to protect cod.

Similarly to the Clyde fisheries, since the collapse of cod and other groundfish species in the Gulf of St. Lawrence, fishing effort has been more directed towards shellfish fisheries (Morissette *et al.*, 2007). As cod catches declined in the early 1970s and 1980s effort was redirected towards invertebrate fisheries, most notably northern shrimp (*Pandulus borealis*) and American lobster (*Homarus americanus*). Much like the Clyde, the total value of the new invertebrate fisheries exceeded that of cod when catches were at their maximum (Hamilton *et al.*, 2004).

### 8.3 Mediterranean

The Mediterranean fishery has experienced a decline in catches over the past 20 years due to an excessive increase in effort (Sarda *et al.*, 2004). Hake is the most important target species of the mixed demersal fishery in the western Mediterranean and landings have been decreasing from a maximum since the early 1990s. In addition, an increasing share of the catch has been immature individuals (Sarda *et al.*, 2005). Discarding is a major problem, similar to the Clyde, and in the Mediterranean small juvenile hake are the hardest hit. As a result, a lot of research effort has been invested to improve selectivity and reduce by-catch levels (Cheret *et al.*, 2002; Alemany and Alvarez, 2003; Sarda *et al.*, 2004; Sarda *et al.*, 2005).

Studies and simulations of escape systems for Mediterranean hake suggest that allowing the escape of small fish could bring about a 30-50% increase in catches of larger individuals four or five years later after implementation of the system (Cheret *et al.*, 2002). Selectivity studies for the hake fishery have shown that in general the use of sorting grids results in high escape rates for individuals that are immature or under minimum landing size (Sarda *et al.*, 2004). The use of a square mesh cod-end in this fishery has also been shown to allow more fish to escape but is much less efficient than the sorting grid (Sarda *et al.*, 2004).

Recently the General Fisheries Commission for the Mediterranean (GFCM) incited the Mediterranean countries to substitute the diamond meshes of the trawl cod-end by 40 mm square meshes for the bottom trawling fleet (GFCM, 2011). In addition, GFCM has encouraged the Mediterranean countries to develop more selectivity studies in various situations and to include bio economical analysis of their use. This has been a significant step towards the implementation of sorting grids in commercial trawl gears in the demersal fisheries of the Mediterranean Sea.

## 9. CLYDE MANAGEMENT EVALUATION MODEL (CMEM)

### 9.1 Introduction

Recently there has been a call to re-instate spatial management measures in the Clyde, including the 3 nautical mile limit which had been in place in this region from 1962-1984. The limit is thought to have provided important refuges for many commercial whitefish species and may allow for fish stock recovery in the Clyde (Thurstan and Roberts, 2010). Since the removal of the 3 mile ban the fisheries in the Clyde have changed considerably to a *Nephrops* dominated fishery, and policy changes now need to consider wider ecosystem impacts in addition to the ecological status of fish and shellfish stocks and the economic status of the fishery.

Effective fisheries management is nearly always hindered by uncertainties which can be particularly problematic for rebuilding fisheries when trying to balance the need to reduce fishing effort and to ensure rebuilding, with the need to meet social and economic needs of fishery stakeholders, both in the short term and the long term (Holland, 2010). Scientific support is required at key steps of fisheries management; for monitoring, assessment and decision making. Scientific tools that evaluate the potential outcome of management strategies are therefore required to support their practical implementation.

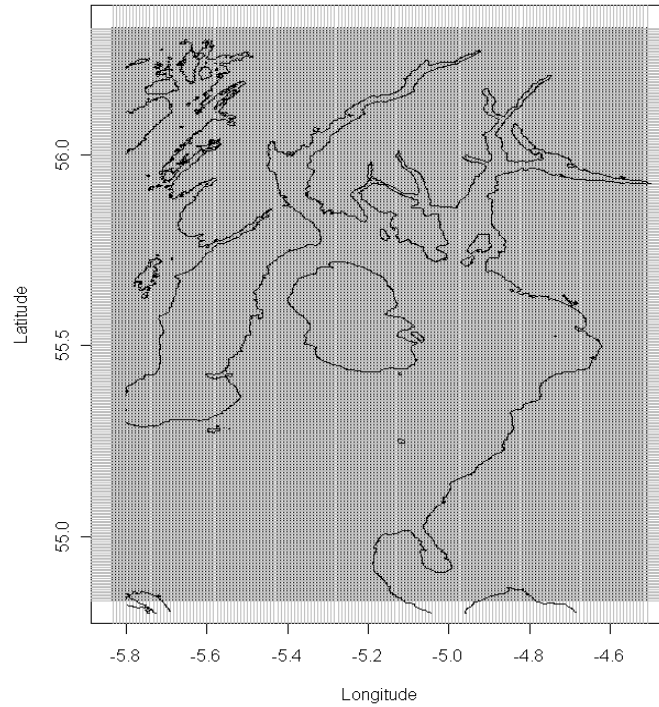
Spatial and temporal closures are common practice in the Clyde (e.g. Ballantrae Bank and the cod seasonal closure) and, with the possibility of re-instating a 3 mile limit, tools that look at the spatial and temporal dynamics of the Clyde fisheries are particularly valuable. In addition, it is useful to create a tool that looks at wider ecological impacts by assessing potential effects on habitats. The aim of this section of the report is to describe the development of a spatial management evaluation tool that aims to have practical application for assessing fisheries management options and policy initiatives for the Clyde Sea area. The tool will incorporate data on the topography and sedimentology of the sea bed in addition to analysing fishing activity patterns using Vessel Monitoring Systems (VMS) data. This management evaluation model developed for the Clyde is intended to be used to inform an exploratory and adaptive decision-making process. In this section we address a small range of questions. However, it is available to the community to provide quantitative evidence for any suggested spatial measure.

### 9.2 Methodology and Model Data Layers

Development of the evaluation model was built using the statistical programming software R, version 2.13.1.

#### 9.2.1 *Create grid*

The first step in developing the model was to implement a basic model grid that provides information at a relevant spatial resolution. This was chosen as 0.25' latitude x 0.5' longitude (approximately 500m x 500m) per grid cell in order to be able to spatially resolve known management measures. The outside limits of the model grid were longitudes 5° 50' W to 4° 30.5' W and latitudes 54° 50'N to 56° 20.25'N. This gave a model grid of 161 grid cells and 361 grid cells in the east and north directions respectively. An illustration of the grid created can be seen in Figure 9.1.



**Figure 9.1** Evaluation model grid - 0.25' latitude x 0.5' longitude (approximately 500m x 500m) over the Clyde Sea area.

The longitude ( $x_i$ ) of the left hand, bottom of a grid cell  $i,j$  is calculated as,

$$x_{i=1,161} = -5 - (50 - 0.5 \cdot (i - 1)) / 60$$

And the latitude ( $y_j$ ) of the left hand, bottom of grid cell  $i,j$  is calculated as,

$$y_{j=1,361} = 54 + (50 + 0.25 \cdot (j - 1)) / 60$$

The distances involved in this model grid are as follows,

Width of 0.5° longitude grid cell at southern limit (54° 50'N) = 533.7m

Width of 0.5° longitude grid cell at northern limit (56° 20'N) = 513.7m

Height of 0.25° latitude grid cell = 463.3m

A central-point grid cell area of 523.7m x 463.3m =  $2.43 \times 10^5 \text{ m}^2$  (0.243 km<sup>2</sup>) is used for all area calculations

### 9.2.2 Masks

The resulting 161 x 361 grid covered both land and sea so that a mask was needed to determine which grid points were on land and which grid points were marine. This was achieved using the GEBCO coastline data (GEBCO, 2011). The resulting mask ( $M_{all\ i,j}$ ) had a grid-cell value of 1 for water grid cells, and 0 for land grid cells.

Additional masks representing one, two and three nautical mile limits (domains) from the coast were created using the buffer tool in ArcGIS which were then exported for use in R,

$$\begin{aligned} M_{one\ i,j} &= 1 \text{ for cells in between the coast and 1 nm seawards, otherwise } 0 \\ M_{two\ i,j} &= 1 \text{ for cells in between the coast and 2 nm seawards, otherwise } 0 \\ M_{three\ i,j} &= 1 \text{ for cells between the coast and 3 nm seawards, otherwise } 0 \end{aligned}$$

Using the series of masks, the evaluation model can be used to investigate the potential implications, impacts and benefits of enforcing different spatial limits.

### 9.2.3 Bathymetry

Bathymetric data for the Clyde was obtained from BGS/SeaZone (2011a). The data set was then interpolated by linear interpolation onto the model grid so that each 161 x 361 grid cell had an associated depth value ( $d_{i,j}$ ), where  $d_{i,j}$  was a real value for marine grid cells and zero for land grid cells. The method used a bivariate linear interpolation in the triangles bounded by the data points which is based on algorithms developed by Akima (1978).

### 9.2.4 Areas and Volumes

Areas within the model can be calculated by summing grid cells within the chosen domain and multiplying by the area of a single cell ( $A_{cell}$ ),

$$A_{domain} = A_{cell} \sum_{i,j} M_{domain\ i,j}$$

Where *domain* can be *one*, *two*, *three* or *all* and  $A_{cell} = 0.243 \text{ km}^2$

Volumes can be similarly calculated by summing the product of the depth of each individual cell and the cell area,

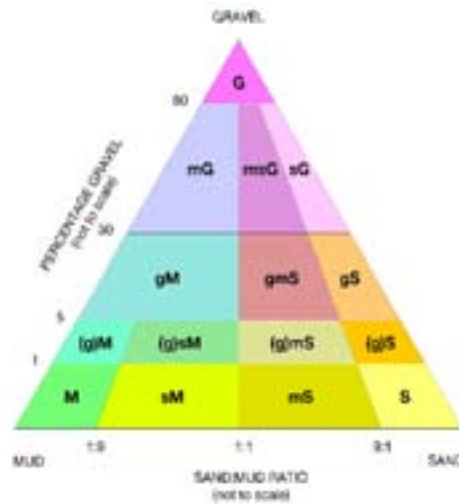
$$V_{domain} = A_{cell} \sum_{i,j} M_{domain\ i,j} d_{i,j}$$

Where again domain can be one, two, three or all.

### 9.2.5 Habitat Type

Sediment type is indicative of where certain habitats occur and where particular fishing grounds are located, for example *Nephrops* are found on mud, sand and sandy mud sediments but not found on gravel sediments. This data is particularly useful for the evaluation model to determine potential habitats affected by spatial closures. Sediment type data was obtained from BGS/Seazone (2011b). Sediment type associated with each 161 x 361 model grid cell ( $SedType_{i,j}$ ) was then determined in ArcGIS and coded based on the folk triangle classification of gravel percentage and sand to mud ratio (Figure 9.2) the data was

then exported for use in R. Land grid cells held a null value, as did cells where no sediment data was available such as within smaller sea lochs and very close to the shore.



**Figure 9.2** Folk triangle classifications of sediment gravel percentage and sand to mud ratio.

### 9.2.6 Fishing Activity Data (VMS)

For control and enforcement purposes, all fishing vessels above 15m in length are equipped with satellite-based Vessel Monitoring by Satellite systems (VMS) recording their position at regular time intervals. This VMS data is a valuable source of information and can be used to study spatial and temporal patterns of fishing activity (Mills *et al.*, 2007) which can in turn inform fisheries and environmental management. However, due to their low resolution, at 2 hour intervals, these data may provide a biased perception of fishing activity (Hintzen *et al.*, 2010). Applying an interpolation technique between VMS data points provides higher resolution gear-specific data on fishing activity in the Clyde.

#### Data Extraction

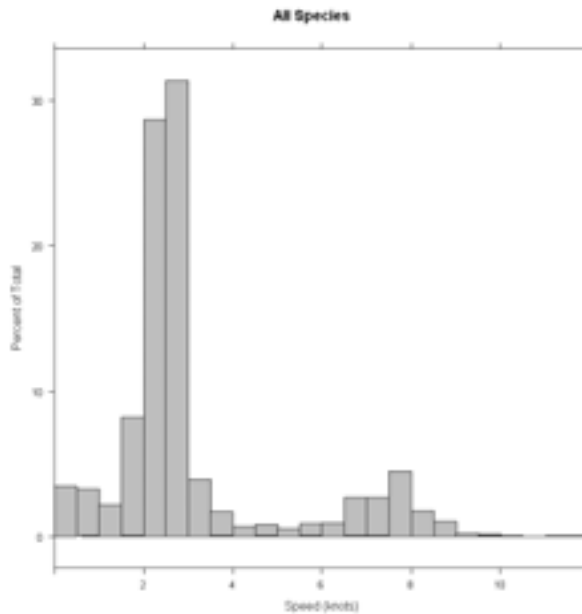
VMS and landings data in 2010 for the *Clyde Sea* area were extracted from the Scottish Government Fisheries Information Network (FIN) database. This data was then linked by vessel PLN number within R routines. Raw VMS data included latitude, longitude, date, time, vessel identification, vessel speed and other data quality and checking parameters. The duration since the last ping in seconds ( $T_{ping_{kboat}}$ ) was calculated and added as an additional parameter to each raw ping data record. If  $T_{ping_{kboat}}$  exceeded 4 hours, the data was rejected.

The integer *kboat* identified each vessel which had recorded VMS pings within the Clyde. For 2010 this was a total of 90 vessels (66 targeting *Nephrops* and 24 scallops)

#### Fishing Time

The speed range used to determine if a vessel is fishing was established as 1-4 knots based on a frequency analysis of the Clyde VMS data (Figure 9.3).





**Figure 9.3** Histogram of fishing vessel speeds from VMS data in the Clyde 2010. From this analysis fishing is determined as VMS pings where speed is between 1 and 4 knots, inclusively.

#### *Data Interpolation*

In the raw data,  $Tping_{kboat}$  varies between a few minutes and 4 hours, although the majority were approximately 2 hours. In the worst case scenario, a vessel travelling at 4 knots will move 29km in 4 hours. Obviously this is much greater than the model grid spacing. Therefore some interpolation is required. At 4 knots it takes a vessel 4 minutes to traverse 500m. Therefore, in order to obtain at least one interpolated VMS position within each grid cell a vessel passes through, each raw VMS track needs to be interpolated with a time resolution of <4 minutes.

The method used for interpolating vessel trajectories from the extracted VMS data points to obtain higher-resolution data was the cubic Hermite spline (cHs) interpolation method described by Hintzen *et al.* (2010). The cHs method uses position, heading and speed to interpolate the track of a vessel between two succeeding data points and was shown by Hintzen *et al.* (2010) to approximate the real vessel track markedly better than a straight line interpolation. The 'vmstools' package created in R allows the use of the cHs interpolation function based on the fishing speed associated with the particular fisheries in the Clyde. Interpolated pings that fell on land grid-cells (e.g. when traversing around a headland) were removed (this was less than 0.2% of the interpolated data).

#### *Final VMS Data Sets – Fishing Time*

The final data sets were 161 x 361 values of total grid cell fishing time ( $Tfish_{i,j}$ ), calculated as the sum of all values of  $Tping_{kboat}$  which fell within the grid cell  $i,j$ .  $Tfish_{i,j}$  can be calculated for vessel trips which land any fish or shellfish, or for individual species landed, such as *Nephrops*, Scallops, cod or haddock.  $Tfish_{i,j}$  can also be calculated either for raw VMS data, or for interpolated data. Both are used in the results section.

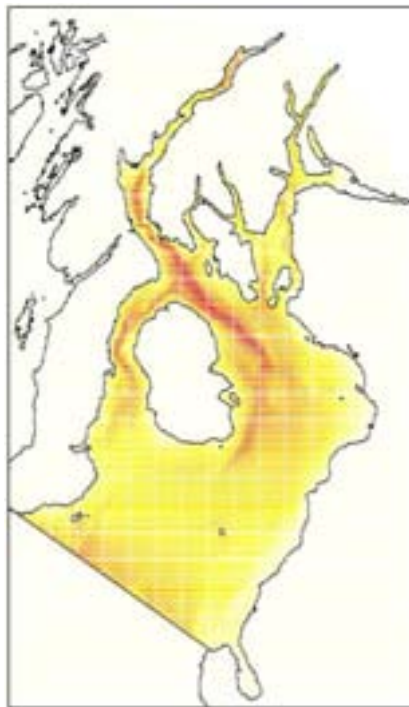
#### *Final VMS Data Sets – Landings*

It should be noted that landings could be allocated to model grid cells if an assumption is made that the landings of a vessel is distributed across its fishing pings linearly proportional to fishing time. This has not yet been done with this data set.

### 9.3 Results

#### 9.3.1 Bathymetry

The interpolated bathymetry is shown in Figure 9.4. For this section a standard map projection is used throughout.

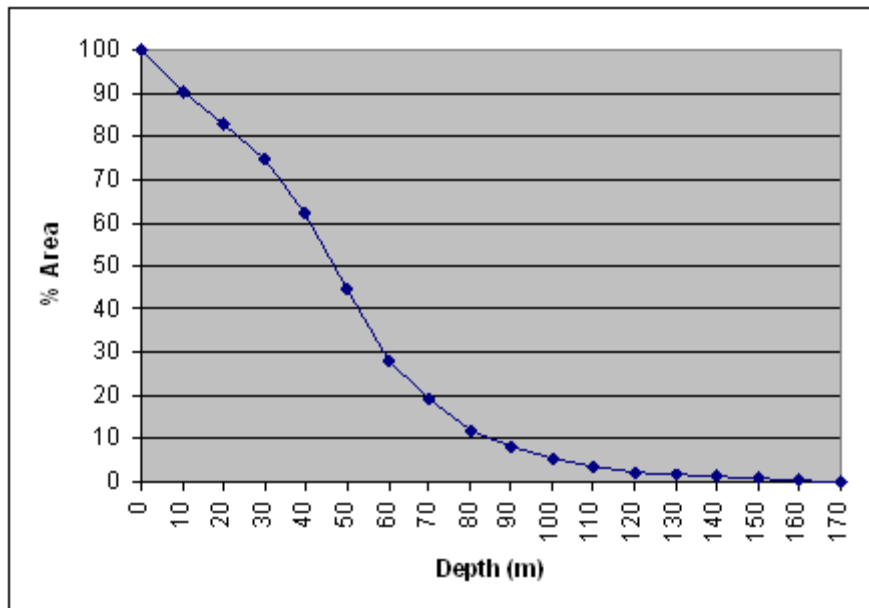


**Figure 9.4** Bathymetry data values interpolated onto the 161 x 361 management evaluation grid using linear interpolation.

#### 9.3.2 Depth Distribution

The distribution of depth, by area is shown in Figure 9.5, and tabulated below.

Depth	Area	Percentage Area
0	3671.0	100.0
10	3323.1	90.5
20	3046.5	83.0
30	2742.9	74.7
40	2277.3	62.0
50	1633.9	44.5
60	1026.1	28.0
70	707.5	19.3
80	438.7	11.9
90	305.2	8.3
100	209.9	5.7
110	132.0	3.6
120	92.2	2.5
130	68.7	1.9
140	45.6	1.2
150	29.4	0.8
160	8.7	0.2
170	0.0	0.0



**Figure 9.5** Distribution of depth by area in the Clyde.

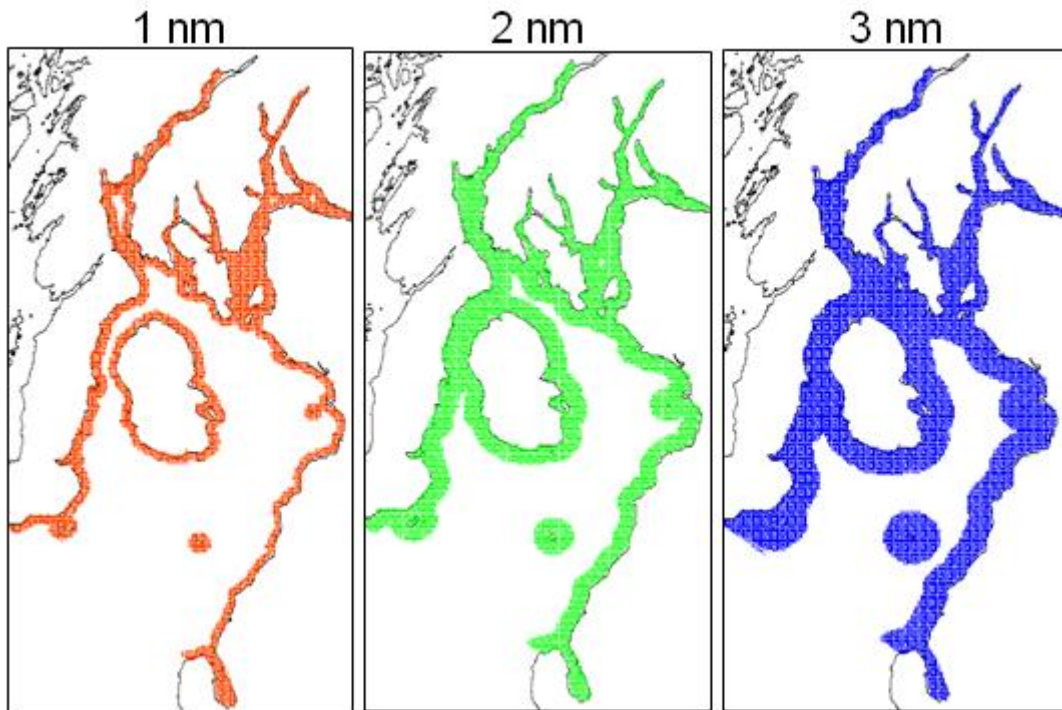
*Potential Maerl Habitats*

One use such data can be put to is to determine what habitats potentially maerl might inhabit in the Clyde. Hall-Spencer (1995) suggested that maerl is located between 6-18m in the Clyde. Using the depth distribution shown above, it can be estimated that there is 360 km<sup>2</sup> of

sea bed in the Clyde in this depth range, i.e. approximately 10% of the Clyde Sea area. The majority of this lies within the 1nm zone (see below).

### 9.3.3 Spatial Limit Masks

The spatial masks derived for the domains 1nm, 2nm and 3nm from the coastline are shown in Figure 9.6.



**Figure 9.6** Spatial masks derived for the domains 1nm, 2nm and 3nm from the coastline. All coloured grid cells have a value of 1, all others 0.

### 9.3.4 Areas and Volumes of the Clyde Spatial Domains

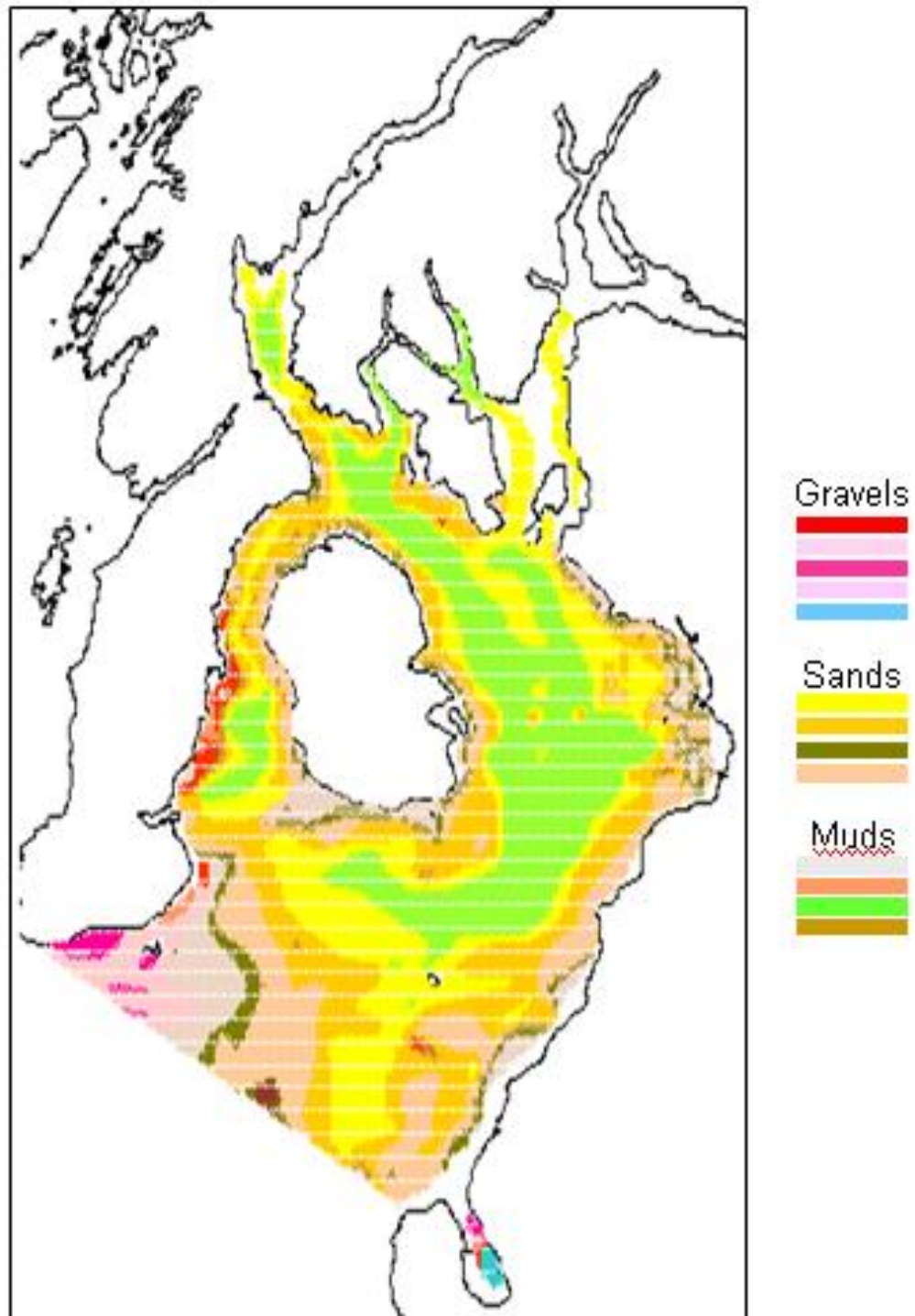
The spatial limit masks, combined with the data grid of bathymetry, provide the following details concerning the Clyde Management Area,

Spatial Domain	Surface Area (km <sup>2</sup> )	Surface Area (%)	Volume (km <sup>3</sup> )	Mean Depth (m)	Max. Depth (m)	Min. Depth (m)	No. of Valid Grid Points
Clyde Sea	3671	100%	179	48.66	170	3	15,129
Coast to 1 nm	1206	33%	36	30.22	165	3	4,971
Coast to 2 nm	1858	51%	72	38.97	170	3	7,659
Coast to 3 nm	2354	64%	102	43.40	170	3	9,702

Hence from these figures we can see that, of the 3671 km<sup>2</sup> of the Clyde Sea, 33%, 51% and 64% lies within 1 nm, 2nm and 3nm from the coast respectively, by area.

### 9.3.5 Sediment Distribution

The gridded sediment type distribution for the Clyde Sea is shown in Figure 9.7.



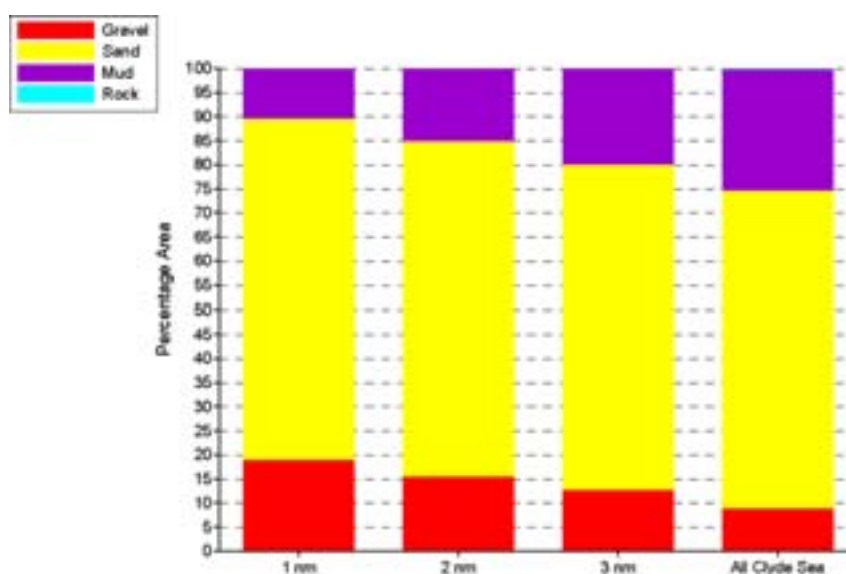
**Figure 9.7** Plot showing the gridded sediment type of the Clyde Sea area. The detailed sediment types of Figure 9.2 have been regrouped into the simpler set of gravels, sands and muds.

The sediment type codes, combined with the various domain masks, provided the following information about percentage area cover of each sediment type,

Sediment Type		All Clyde Sea (%)	Coast to 1 nm (%)	Coast to 2 nm (%)	Coast to 3 nm (%)
GMSD	Gravelly Muddy Sand	1.1	4.7	2.7	1.9
GRSS	Gravel, Sand and Silt	3.3	8.7	7.3	5.7
GV	Gravel	0.8	2.6	1.7	1.4
GVSD	Gravelly Sand	3.5	1.8	3.2	3.3
GVMD	Gravelly Mud	0.2	1.2	0.6	0.4
MDGV	Muddy Gravel	0.1	0.2	0.2	0.1
MSGR	Muddy Sandy Gravel	0.4	1.8	0.9	0.7
MUD	Mud	24.0	7.6	12.8	18.2
MUSD	Muddy Sand	0.8	0.9	1.2	1.0
SDGV	Sandy Gravel	2.9	4.2	4.1	4.1
SDMD	Sandy Mud	23.6	22.8	24.1	24.2
SGMS	Slightly Gravelly Muddy Sand	21.2	19.1	21.5	21.0
SGSA	Slightly Gravelly Sand	3.8	6.6	5.7	4.7
SND	Sand	14.1	17.8	14.0	13.3
ROCK	Rock	0.2	0.0	0.0	0.0

It should be noted that the sediment data, collected by vessel-based methods such as grab samples and acoustics, do not include the near-shore sub-tidal littoral or inter-tidal zone. Hence some shoreline rock areas are not included.

The sedimentary make up of the three spatial limits, and the Clyde as a whole, differ slightly. This is summarised in Figure 9.8. The coastline – 1nm zone has relatively higher percentage areas of sand and gravel, and less of mud, than the rest of the Clyde.



**Figure 9.8** Percentage area cover in the three spatial zones (1nm, 2nm and 3nm from the coastline, and the Clyde as a whole) of the summary sediment types, mud, sand, gravel and rock.

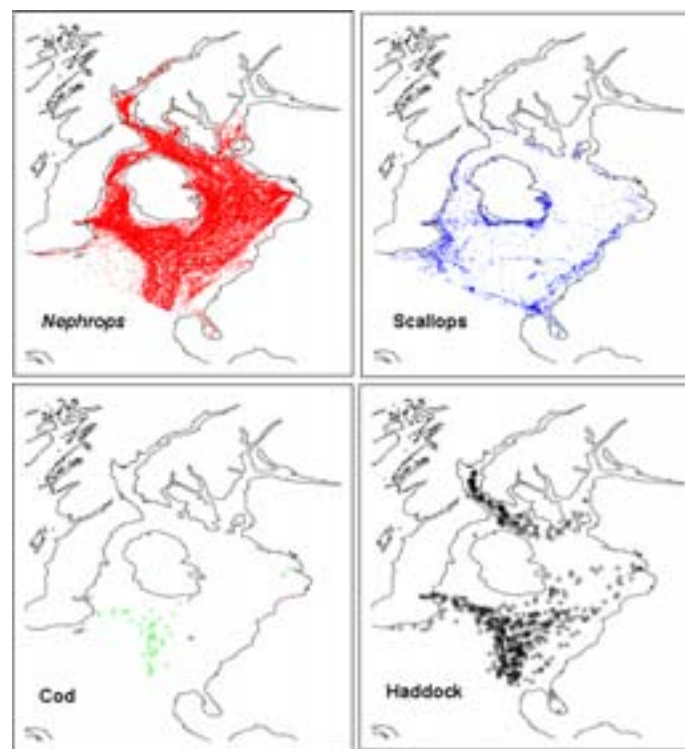
Another summary of this data is presented in table form below,

Spatial Domain	Gravel		Sand		Mud	
	Surface Area (km <sup>2</sup> )	% of Clyde Total	Surface Area (km <sup>2</sup> )	% of Clyde Total	Surface Area (km <sup>2</sup> )	% of Clyde Total
Clyde Sea	327	100	2408	100	929	100
Coast to 1 nm	229	70	850	35	127	14
Coast to 2 nm	288	88	1289	54	281	30
Coast to 3 nm	299	92	1584	66	471	51

From these figures we can see that 70%, 35% and 14% of all Clyde gravelly, sandy and muddy sediments, respectively, lie within 1nm from the coast. Similar figures are presented for the 2nm and 3nm zones.

### 9.3.6 Fishing Activity – Raw VMS

In total, using 2010 VMS and FIN data, 66 vessels were found which landed *Nephrops* in the Clyde, and 24 landed scallops. Figure 9.9 shows the raw VMS data for these vessels. VMS pings from *Nephrops* vessels which also resulted in landings of cod and haddock are also shown.



**Figure 9.9** Raw 2010 VMS pings associated with landings of a) *Nephrops*, b) scallops, c) cod and d) haddock.

In relation to possible spatial management measures in the Clyde, a summary of fishing activity of the following type may be of relevance,



	Hours				Percentage			
	All Clyde Sea (Hours)	Coast to 1 nm (Hours)	Coast to 2 nm (Hours)	Coast to 3 nm (Hours)	All Clyde Sea (%)	Coast to 1 nm (%)	Coast to 2 nm (%)	Coast to 3 nm (%)
<b>ALL</b>	56,802	13,652	20,881	25,801	100	24	37	45
<b>NEP</b>	53,520	13,298	19,902	24,536	100	25	37	46
<b>SCL</b>	3,223	336	956	1,239	100	10	30	38
<b>HAD</b>	814	156	210	231	100	19	26	28
<b>COD</b>	60	17	19	19	100	28	32	32

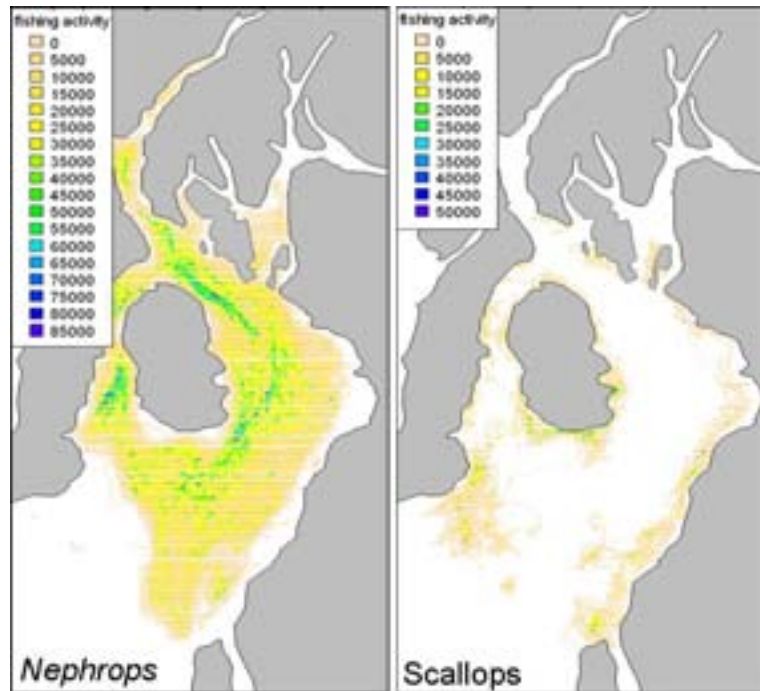
From these figures we can see that of the total 56,802 fishing hours that took place in the Clyde Sea in 2010, 53,520 hours (94%) resulted in a landing of *Nephrops*, 3,223 (6%) hours landed scallops and just 814 hours and 60 hours landed haddock or cod respectively, most probably as by-catch in the *Nephrops* fishery. Hence the 66 boats which landed *Nephrops* from the Clyde in 2010 spent on average 810 hours fishing through the year, and the 24 scallop vessels spent, on average, 134 hours.

In terms of where fishing takes place, of the total 56,801 fishing hours of 2010, 24% occurred within 1 nm from a coastline, 37% within 2 nm and 45% within 3 nm. Therefore 55% of the total fishing activity occurred outwith 3 nm from a coast. This distribution of fishing activity is virtually identical for fishing which landed *Nephrops*, while it is different for fishing which landed scallops. Here, 10%, 30% and 38% of fishing activity occurred 1 nm, 2 nm and 3 nm from a coast within the Clyde Sea.

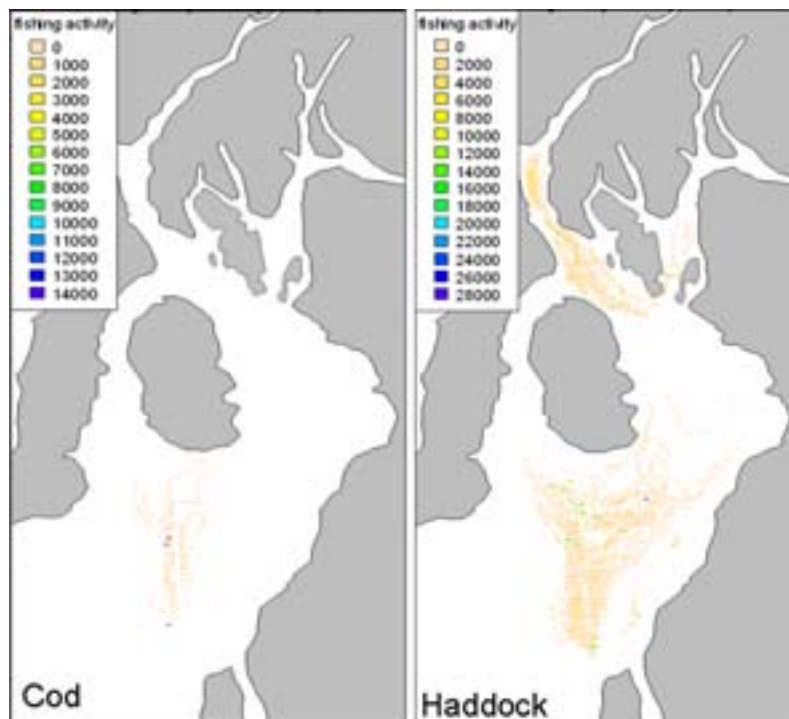
### 9.3.7 Fishing Activity – Interpolated Maps

The interpolated VMS data have been used in order map the distribution of fishing activity in the Clyde in 2010. The resulting distributions are shown in Figures 9.10 and 9.11.





**Figure 9.10** The distribution of fishing activity in the Clyde in 2010 based on the number of interpolated pings from vessels believed to be fishing (i.e. speed of vessel between 1 and 4 knots) in each model grid cell for (left) vessel trips which landed *Nephrops* and (right) scallops.



**Figure 9.11** The distribution of fishing activity in the Clyde in 2010 based on the number of interpolated pings from vessels believed to be fishing (i.e. speed of vessel between 1 and 4 knots) in each model grid cell for (left) vessel trips which landed cod and (right) haddock.

It is clear from the fishing activity maps that it is governed by the habitat types which favour the different species. Boats landing *Nephrops* principally target the areas where muddy sediments predominate, principally the deep basins of the Clyde, whereas vessels landing scallops target the harder sediments found around the shallower periphery of the Clyde as well as on the Great Plateau. The table below compares the percentage of each sediment type to the percentage of fishing activity in each of the spatial zones.

Spatial Domain	Gravel	Sand	Scallops	Mud	<i>Nephrops</i>
	% of Clyde Total	% of Clyde Total	% of Fishing Activity	% of Clyde Total	% of Fishing Activity
Coast to 1 nm	70	35	10	14	25
Coast to 2 nm	88	54	30	30	37
Coast to 3 nm	92	66	38	51	46

For *Nephrops* the percentages of muddy sediment and fishing activity within the three spatial zones of 1nm, 2nm and 3nm are comparable. However, for scallops the percentage of fishing activity outwith the 3nm zone seems excessively large. This must take place predominantly on the Plateau. Further investigations of this anomaly are underway.

### 9.3.8 Concluding Remarks

The analysis of VMS data, in conjunction with the other data layers in the CMEM databases, shows how useful this data can be to describe the current fishing practices in the Clyde and to evaluate different management options. However, more can be done.

It is possible to link actual landings to VMS pings if it is assumed each catch is evenly distributed along the vessels fishing path. This would allow summaries as above for spatial measures in terms of weight, and hence value, of landings per species per management area.

Here we have analysed the year 2010 as the most recent full year of data available to this study. However, earlier years and the more recent data can be added to look at changes over time. Similarly seasonal patterns of fishing could be examined.

Simple spatial measures involving set distances from the shore have been examined here. However, CMEM could be used to develop more complex spatial management measures based on, for example, habitat type. Temporal closures could also be examined in addition to spatial ones.

A warning should, however, be sounded. The effects of the displacement of fishing have not been touched upon here. Fishers behaviour faced with closures needs to be considered, and the impact of displaced fishing effort on other areas and habitats evaluated.

The analysis presented here only uses data from those vessels with VMS systems installed, i.e. >15m in length. Data from smaller vessels needs to be collected and analysed using CMEM.

### 9.3.9 Suggested Further Work

CMEM needs to be further developed. Data sets of habitat type can be improved using finer scale surveys, and additional environmental parameters such as sea bed temperature and sea bed water flow could be added. More years of VMS data need to be included. Seasonal patterns of fishing can be examined. Landings, by species and gear type, from each grid square, as well as value of landings, can be estimated using various methods developed at MSS. A glaring lack currently is information on fishing activity by creel boats, as well as fishing activity by all vessels smaller than 15m. This could be provided by an interview-based data gathering exercise (e.g. ScotMap, A.McLay *pers. comm.*).

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## 11. Annex – Species list for the Clyde from Heath and Speirs (2011)

Species	Common Name	Type	Percentage of years when species found	All-time Maximum Length (cm)
<i>Merluccius merluccius</i>	Hake	Demersal	100	113
<i>Hippoglossoides platessoides</i>	Long Rough Dab	Demersal	100	28
<i>Gadus morhua</i>	Cod	Demersal	97.8	98
<i>Merlangius merlangus</i>	Whiting	Demersal	97.8	51
<i>Limanda limanda</i>	Common Dab	Demersal	93.5	34
<i>Eutrigla gurnardus</i>	Grey Gurnard	Demersal	93.5	39
<i>Trisopterus esmarki</i>	Norway Pout	Demersal	93.5	27
<i>Trisopterus minutus</i>	Poor Cod	Demersal	93.5	24
<i>Pleuronectes platessa</i>	Plaice	Demersal	89.1	48
<i>Clupea harengus</i>	Herring	Pelagic	87	36
<i>Sprattus sprattus</i>	Sprat	Pelagic	87	17
<i>Nephrops norvegicus</i>	Norway Lobster	Invertebrate	84.8	5.4
<i>Gobiidei</i>	Gobies (unidentified)	Demersal	82.6	15
<i>Argentina sphyraena</i>	Lesser Argentine	Demersal	82.6	25
<i>Callionymus lyra</i>	Dragonet	Demersal	76.1	25
<i>Melanogrammus aeglefinus</i>	Haddock	Demersal	76.1	61
<i>Glyptocephalus cynoglossus</i>	Witch	Demersal	76.1	44
<i>Lumpenus lampretaeformis</i>	Snake Blenny	Demersal	71.7	30
<i>Rhinonemus cimbricus</i>	Four-bearded Rockling	Demersal	67.4	25
<i>Scyliorhinus canicula</i>	Lesser Spotted Dogfish	Demersal	65.2	76
<i>Pollachius virens</i>	Saithe	Demersal	58.7	84
<i>Microstomus kitt</i>	Lemon Sole	Demersal	56.5	34
<i>Scomber scombrus</i>	Mackerel	Pelagic	50	42
<i>Callionymus maculatus</i>	Spotted Dragonet	Demersal	47.8	15
<i>Platichthys esus</i>	Flounder	Demersal	41.3	44
<i>Lophius piscatorius</i>	Anglerfish	Demersal	39.1	81
<i>Squalus acanthias</i>	Spurdog	Demersal	39.1	105
<i>Cepola rubescens</i>	Red Band-fish	Demersal	34.8	59
<i>Trachurus trachurus</i>	Horse Mackerel (Scad)	Pelagic	32.6	40
<i>Loligo forbesii</i>	Long Finned Squid	Invertebrate	32.6	50
<i>Alloteuthis subulata</i>	Alloteuthis	Invertebrate	28.3	15
<i>Zeus faber</i>	John Dory	Demersal	28.3	36
<i>Conger conger</i>	Conger Eel	Demersal	26.1	90
<i>Leucoraja naevus</i>	Cuckoo Ray	Demersal	21.7	58
<i>Cyclopterus lumpus</i>	Lumpsucker	Demersal	21.7	30
<i>Raja montagui</i>	Spotted Ray	Demersal	17.4	63
<i>Raja clavata</i>	Thornback Ray	Demersal	17.4	74
<i>Micromesistius poutassou</i>	Blue Whiting	Demersal	13	24
<i>Pollachius pollachius</i>	Lythe Pollack	Demersal	10.9	68
<i>Gaidropsarus vulgaris</i>	Three-bearded Rockling	Demersal	10.9	22
<i>Argentina silus</i>	Greater Argentine	Demersal	8.7	24
<i>Lepidorhombus whiffiagonis</i>	Megrim	Demersal	8.7	55
<i>Ciliata mustela</i>	Five-bearded Rockling	Demersal	6.5	19
<i>Galeorhinus galeus</i>	Tope	Demersal	6.5	154
<i>Trigla lucerna</i>	Tub Gurnard	Demersal	6.5	33
<i>Psetta maxima</i>	Turbot	Demersal	6.5	47
<i>Galeus melastomus</i>	Black Mouthed Dogfish	Demersal	4.3	23

<i>Scophthalmus rhombus</i>	Brill	Demersal	4.3	47
<i>Agonus cataphractus</i>	Hooknose	Demersal	4.3	10
<i>Ommastrephidae</i>	Short Finned Squid	Invertebrate	4.3	40
<i>Dipturus batis</i>	Common Skate	Demersal	4.3	65
<i>Buglossidium luteum</i>	Solenette	Demersal	4.3	15
<i>Gadiculus argenteus thori</i>	Silvery Pout	Demersal	4.3	9
<i>Ammodytidae</i>	Sandeels (unidentified)	Pelagic	4.3	20
<i>Engraulis encrasicolus</i>	Anchovy	Pelagic	2.2	9
<i>Trisopterus luscus</i>	Bib	Demersal	2.2	14
<i>Raja brachyura</i>	Blonde Ray	Demersal	2.2	27
<i>Myoxocephalus scorpius</i>	Bull Rout	Demersal	2.2	25
<i>Cottus gobio</i>	Bullhead	Demersal	2.2	16
<i>Arnoglossus imperialis</i>	Imperial Scaldfish	Demersal	2.2	10
<i>Triglops murrayi</i>	Moustache Sculpin	Demersal	2.2	9
<i>Scyliorhinus stellaris</i>	Nurse Hound	Demersal	2.2	91
<i>Echiodon drummondi</i>	Pearfish	Demersal	2.2	8
<i>Trigla lyra</i>	Piper Gurnard	Demersal	2.2	14
<i>Chelidonichthys cuculus</i>	Red Gurnard	Demersal	2.2	22
<i>Trigloporus lastoviza</i>	Streaked Gurnard	Demersal	2.2	30
<i>Taurulus bubalis</i>	Sea Scorpion	Demersal	2.2	11
<i>Microchirus variegatus</i>	Thickback Sole	Demersal	2.2	13
<i>Alosa fallax</i>	Twaites Shad	Demersal	2.2	43
<i>Sepiolidae</i>	Bobtail Squids (unidentified)	Invertebrate	<2	15



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