Bycatch of Harbour Porpoise (*Phocoena phocoena* L.) in the North Sea: a case study of the Grimsby gillnet fleet

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Abstract

The problem of estimating bycatches of harbour porpoise (*Phocoena phocoena*) in gill-net fisheries and the impact of this bycatch on management in the North Sea was examined. A case study of the Grimsby UK gillnet fleet was selected since bycatch levels from this fleet had not been analysed before. The study was based on interviews with gill-netters fishing for cod and using bottom-set and wreck-netting methods. Detailed fisheries analyses, including examination of effort, landings and bycatch statistics were undertaken for the whole fleet, consisting of 27 vessels during 1985-1999. For comparison, interviews with gillnet skippers were undertaken in Denmark in the summer of 1998. Interviews took place in the ports of Esbjerg, Hvide Sande and Thorsminde. Data from 30 licensed gillnetters (approximately 10% of the total fleet) were used. The bycatch for the UK gill-net fleet in Grimsby, using observer data in conjunction with a detailed spatio-temporal analysis of the fishery, was estimated to range from 149-297 animals per year. Estimates for the Danish fleet from interviews in 1998 ranged from 3500-4500 animals. From these studies it was concluded that interviews represent a cost-effective method of assessing levels of bycatch.

The development of more effective management structures requires the identification of areas, times and fishing-operations that are associated with a high-risk of bycatch. These were determined from spatio-temporal analyses of fishing effort by the Grimsby fleet, in relation to oceanographic features such as fronts, information from interviews and previously published studies.

In order to estimate levels of bycatch, a complete programme incorporating interviews, observer programmes, population models and increased research surveys is proposed.

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Declaration

This thesis is my work unless otherwise stated. Parts of this thesis have appeared in publications, these include:

- J. McGlade and K. Metuzals (1999) A governance framework for the assessment and reduction of the bycatch of harbour porpoises *Phocoena phocoena* in the North Sea and surrounding areas based on the principles of responsible fishing. Chapter 17. EU BYCARE, Final report, contract number FAIR-CT05-0523.
- McGlade, J. and K. Metuzals (1999) Options for the reduction of bycatch of harbour porpoises *Phocoena phocoena* in the North Sea J. McGlade and K. Metuzals *in* The effects of fishing edited by M. Kaiser and S. de Groot (2000) Blackwell, Oxford. 394 pp. Chapter 22: 332-353.
- Hall, M., D. Alverson and K. Metuzals (2000) Bycatch: Problems and Solutions in 'Seas at the Millennium' Chapter 116 edited by C. Sheppard, Elsevier.

Introduction

The bycatch issue is one of the main fisheries problems today, yet it remains largely unknown and unassessed. This thesis is the outcome of a study to examine the extent of the bycatch of harbour porpoises in the North Sea in the Grimsby fleet.

Bycatch is the catch taken by a fisherman which is not the directed catch. For example, a cod fisherman may catch some plaice and turbot as well as cod. The plaice and turbot are the bycatch. Sometimes, a marine mammal may also be caught accidentally. Why should this be a major problem? Incidental mortality happens in all fisheries but if it happens to a high degree, it may endanger the population caught as bycatch. For example, marine mammal populations, with their slow reproductive rate, are not able to withstand high levels of fishing mortality indefinitely. There is also the issue of public perception and the influence of environmental groups in raising awareness of this highly emotive issue.

The porpoise bycatch problem lies within two policy arenas. One concerns whaling and the use of a moratorium by whaling organisations such as the IWC, the International Whaling Commission, and the other involves fisheries regulations and the issues of overexploitation.

Since porpoises are not fish, they are generally not managed under the aegis of national fisheries management regimes or such bodies as the FAO (Food and Agricultural Organisation) of the UN. But as cetaceans, they are too small and unimportant to be covered under the auspices of the IWC. Bycatch is however very much a fisheries problem, and so until fisheries management attempt to solve it, the IWC will not assume the responsibility. This thesis is an attempt to try to resolve and reconcile the two approaches of fisheries and whaling, by providing, for the first time, substantiated evidence of the degree of bycatch in specific fisheries.

In the first chapter of the thesis I define the bycatch problem and describe the extent to which it occurs in the North Sea. My approach is to synthesise the data and present a new, interdisciplinary approach to an old problem. This approach uses a variety of data and different analysis to achieve a type of 'consilience' (*sensu* Wilson 1998). This involves linking facts and fact-based theory across disciplines to create a common groundwork of explanation. Data sources are fisheries (catch and effort) data, together with *in situ* fishermen's interviews plus strandings and observers' data.

In Chapter 2, the biology of porpoises, *Phocoena phocoena* L. is investigated to see why porpoises are susceptible to different fishing gears. A summary of the life history traits of the porpoise in the North Sea is presented with special emphasis on trying to understand the reasons why animals get caught. The question posed is why do intelligent animals that can see well (sideways) and echolocate (with sonar) still get entangled in bottom set gillnets? It seems from experimental and observational studies that porpoises become entangled in fishing gear after they follow fish when diving to the bottom.

In order to determine how serious the problem of bycatch is in the North Sea, a comparative analysis of methods currently used including observer programmes, interviews and dockside monitoring are examined in Chapter 3. These methods provide an estimate of incidental mortality which is then applied to the estimates of population size. Different criteria such as the Potential Biological Removal (PBR) can then be used to determine a population at risk. PorpSim, a population model, is used to simulate different dispersal patterns and to derive a critical upper limit of bycatch in Chapter 4. Other methods and models of assessment of marine mammal stocks in the Atlantic are also described.

In Chapter 5, the two case studies that form the basis of the thesis are described; one in Grimsby, UK and the other near Esbjerg, Denmark. Both ports have fishing fleets with high bycatch levels of porpoises in the North Sea. Differences in the origins of the specific type of fishing used by the industry are traced. The characteristics of the local gillnet fishery in each community is also described. The Danish fishermen are more concerned and open about the bycatch issue than their UK counterparts. Fisheries management in Grimsby and Esbjerg fall within the Common Fisheries Policy (CFP). But while fishermen in Grimsby are very unhappy with the current system, the Danish fishermen are not too displeased.

In order to seek solutions to the bycatch issue, it is important to assess the relative importance of natural versus anthropogenic factors. A description of the biophysical environment of the North Sea is thus presented in Chapter 6 to explore what makes the North Sea such a rich fishing ground and an area where porpoises occur. In particular, the role of fronts, and tides are examined in relation to oceanographic parameters. Given that there has been a warming tendency, the potential effect on fishing patterns and hence the bycatch problem is also discussed.

An analysis of the spatio-temporal distributions of the main species of pelagic (herring and mackerel) and demersal, (cod and flatfish) fishes in the North Sea is presented and the main locations, gear types and resulting gear conflicts determined.

In Chapter 7, the bycatch estimates and an assessment of areas and times of the highest risk of bycatch are presented. The results from an analysis of the distribution of fishing effort in the North Sea by the Grimsby fleet, in the form of fishing maps of gillnet effort by ICES (International Conseil pour l'Exploration de la Mer) rectangles for at least 15 years are presented. From these data it is evident that certain areas are 'hotspots' of fishing and consequently, can be used to detect sensitive zones in relation to the risk of bycatch.

In Chapter 8, solutions and views about bycatch are presented. New ideas about governance, such as how active local committees interact with regional, national institutions and international institutions are examined, including an assessment of observer programmes, and the effectiveness of strong environmental lobbies.

In the last chapter, I summarise and discuss what can be concluded from the analysis. Firstly, I address the question of whether there is a real problem in the North Sea and make a comparison with other areas of the world to determine if the situation in the North Sea is similar or different. I then look at The Precautionary Approach and policies on responsible fishing and conclude that they need to be emphasised, alongside Marine Protected Areas (MPA) or 'no take zones'. The results of bycatch estimates from the case studies are presented and a discussion of the benefits and shortcomings of using interview techniques as opposed to observer programmes to estimate levels of bycatch and areas of high risk.

The thesis ends with suggestions for future research to reduce the problem of bycatch of porpoises in the North Sea.

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Chapter 1

Breaching the Bycatch issue

> *The kingdom of heaven is like a net that was thrown into the sea and caught fish of every kind: when it was full, they drew it ashore and put the good into baskets but threw out the bad.* *Matthew 13:47- 48*

The purpose of this chapter is to review one of the most significant issues affecting fisheries management today, the bycatch, especially bycatch of porpoises in the North Sea. Although it is very difficult to assess, the bycatch issue is at present a globally important and a very controversial one (Alverson *et al.* 1994, Alverson and Hughes 1996, Hall 1996). Recent reviews on bycatches of marine mammals, sea birds and sea turtles have indicated that bycatch is one of the most serious environmental impacts of modern fisheries (Hall 1998, Read 2000).

1.1 DEFINITION OF BYCATCH

It is important to differentiate 'bycatch' and 'discards'. *Bycatch,* or the unintended mortality of nontarget species, is that 'portion of the catch returned to the sea as a result of economic, legal or personal considerations plus the retained catch or non-targeted species' (McCaughran 1992 *cited* in Hall 1996). This definition can be inaccurate since it lumps together a waste product with an additional source of income. Sometimes fishermen target non-target species. The definition of 'bycatch' according to Hall (1996) is that part of the catch that is discarded at sea, dead (or injured to an extent that death is the result). But for clarification, 'bycatch' is anything that a fisherman catches which he did not initially target, whereas 'discards' are everything that is thrown overboard. Bycatch is simply the term that encompasses discards plus non-targeted catch or incidental catch or capture (Alverson 1977, Alverson *et al.* 1994).

1.1.1 Bycatch equation

A basic need of fisheries management is to quantify the mortality caused to the resource (review in Chopin *et al.* 1996). This value together with natural mortality, constitutes the total loss of individuals from the target population. The traditional formula is expressed below where the total fishing mortality (z) is the sum of the natural mortality (m) and mortality due to fishing is (F). That is

$$z = m + F \qquad \textit{Equation 1}$$

Fishing mortality (F) is the sum of all direct and indirect fishing mortalities. Chopin *et al.* (1996) tried to explore all the possible sources of fishing mortality, and of other uncertainties in the data. Fishing mortality was quantified as an aggregate of all catch mortalities including discards, illegal fishing and misreported mortalities (Alverson and Hughes 1996).

$$F = (F_{cl} + F_{rl} + F_{sl}) + F_i + F_d + F_o + F_a + F_e + F_g + F_p + F_h \qquad \textit{Equation 2}$$

where

F_{cl} = commercial landing mortalities

F_{rl} = recreational landing mortalities

F_{sl} = subsistence landing mortalities

F_i = illegal and misreported landing mortality

F_d = discard mortality

F_o = drop-*out* mortality

F_a = mortality resulting from fish or shellfish that *avoid* gear but die from stress or injuries

F_e = mortality resulting from fish or shellfish contacting but *escaping* gear that subsequently die

F_g = mortality resulting from fish or shellfish that are caught and die in *ghost* fishing gears

F_p = mortality resulting from *predation* of fish or shellfish escaping from or stressed by fishing gear that would otherwise live

F_h = mortality due to gear *habitat* modifications

In the case of porpoises, fishing mortality may be due to F_0, the drop – out mortality, that is, the mortality due to the porpoises dropping out of the net after it has been set. Berggren and Carlström (1999) observed that 2 of the 12 observed porpoises fell out during hauling. F_g is the mortality due to ghost nets. Although it was often feared that gillnets were continually fishing when lost on the sea bottom, it is now believed that these nets clump and do not actively catch fish. F_g is therefore probably a very low quantity. Nevertheless, the major F is the F_{cl} due to the fishing activity of commercial landing mortalities (Alverson and Hughes 1996).

1.1.2 Biological and ecological impact

Bycatch is biologically and ecologically significant, in fact bycatches may affect the structure and function of marine systems at the population, community and ecosystem level (Crowder and Murawski 1998). Long-lived species with low fecundities, such as sharks, sea turtles and marine mammals such as porpoises are particularly vulnerable to depletion from bycatches (Read 2000). In some cases, bycatches may threaten populations, and even species with extinction e.g. vaquita porpoise (Vidal 1993 *cited* in Hall 1996, D'Agrosa *et al.* 2000). The increasing number of extinctions and local extirpations suggests that the risk of extinction in marine systems is greater than assumed previously (Brander 1981, Carlton 1993, Casey and Myers 1998, Hyrenbach *et al.* 2000).

1.1.3 Porpoise bycatch in the world

Jefferson and Curry (1994) reviewed the known extent that porpoises become entangled in fishing gear. These authors documented the bycatch of porpoise in the different fisheries and have shown that harbour porpoises are taken throughout most of their range. The Black Sea and Sea of Azov area is the only major region in which there are no data for incidental takes in gillnets, but harbour porpoises may still be taken there. In the North Pacific, about 200-300 porpoises have been taken in halibut set nets. A significant (take or kill) is known from the Makah Indian set net fishery for salmon on the northern Washington coast (Gearin *et al.* 1990 *cited* in Jefferson and Curry 1994) and takes in various set and drift net fisheries throughout Alaska, though poorly documented, are probably substantial.

In the western Atlantic, the largest numbers have been taken in foreign and domestic driftnet fisheries for salmon and domestic driftnet fisheries around Greenland. Up to 2500 may have been captured in 1972. Since the foreign fishing was phased out in the mid-1970's, current catches by local fishermen are likely to be much smaller. High numbers of harbour porpoises are also taken in gillnets in eastern Canada, especially off Newfoundland and Labrador and in the St. Lawrence River. Catches in the Bay of Fundy and the Gulf of Maine have been particularly well studied. Annual catches for this region are estimated to be greater than 1350 per year (Read and Gaskin 1990).

Many porpoises are taken in the Irish and UK gillnet fleet (Hutchinson 1996, Harwood 1999a) and there are estimates of thousands in the Danish gillnet fleet (Vinther 1999). In the eastern north Atlantic area, substantial gillnet catches occur in most areas, with the highest known takes in Norway (Bjørge and Øien 1990) and Denmark (Vinther 1994, 1995a, 1995b, 1999) and Sweden (Berggren 1994, Berggren and Arrhenius 1995a, 1995b).

Although accurate data from fisheries' observer programmes are generally not available, high gill net takes throughout the rest of the Baltic and North Sea seem likely (Bravington *et al.* 1997). The main gears which may be causing problems for marine mammals bycatches in the North Sea are the purse seine fishery and the gillnet fleets (Alverson *et al.* 1994, IWC 1995).

A number of authors have claimed that the UK in particular has substantial takes of harbour porpoises in gillnets (Northridge 1988, Jefferson and Curry 1994). This study will attempt to quantify that claim.

1.2 Relationship between fishing gear, fisheries and bycatch

Read (1994) in a review of bycatch of marine mammals separated fishing gear into active versus passive gear in order to analyse more closely the relationship of bycatch and gear type. He concluded that the more passive fishing gear would be more likely to capture porpoises.

1.2.1 MAIN FISHING GEAR

Bottom, Midwater and Pair Trawling

Couperus (1997) reviewed the interactions between cetaceans and trawling and reported target fish species in the stomach of bycaught animals. Other descriptions of cetaceans feeding associated with trawls were reviewed by Fertl and Leatherwood (1997). At least 16 cetacean species all over the world are known to feed in association with fishing trawlers (Northridge 1984, 1991). Other studies such as Tregenza *et al.* (1997) in the Celtic Sea, Tregenza and Collet (1998) in the northeast Atlantic, Dans *et al.* (1997) in the Patagonia, show that incidental takes happen in many trawl fisheries of the world.

However, the trawling of fish is not generally an operation whereby very many porpoises could be caught. The trawl is usually operated too slowly and the animals are able to escape (Read 1994). In general, incidental mortality in bottom trawl fisheries is not believed to play a significant role in the dynamics of small cetacean populations (Read 1996).

Mid-water trawls have a much greater potential to capture cetaceans than bottom trawls. The nets can be towed at a much greater speed because they are not in contact with the sea floor. The largest species of such fisheries are often fish or squid that are important prey items of marine mammals. Thus, porpoises may be captured while feeding on schools of these species: in addition, they may learn to associate the presence of mid-water trawls with concentrations of potential prey, increasing the risk of capture.

However, in pair trawling whereby two vessels are used to tow a trawl between them for pelagic fish such as anchovy or sardine, the operation is more rapid and a number of large marine mammal takes have been known to occur. Recent developments in pair trawling, originally developed by the French, use nets with large spaced mesh. These pair trawls or 'pelagiques', which generally fish at night, have vertical openings of 30-40m horizontal openings of 40-80m and are towed at 3-4 knots (Prado 1991). Pair trawls have the potential to take large numbers of cetaceans because of the large size of the nets, the high speed it is towed and the areas in which the nets are fished. In both Europe and eastern US, pair trawl fisheries have developed recently to catch a variety of pelagic tuna, swordfish and sharks. Little is known about the magnitude of bycatches of cetaceans in these fisheries, but their potential for incidental mortality is extremely high (Bravington *et al.* 1997). In the case of southern France there are still no official statistics available, despite local protests against this type of trawling (J. Arocena in *le Marin* 7 Oct. 1994).

Gillnets

Gillnets are passive fishing gear, designed to capture fish that attempt to swim through them by entanglement or gillnetting (Read 1996). These nets can vary in construction, configuration and use ranging from small, handmade nets in artisanal fisheries to large driftnets that may extent for many kilometres. The nets may be constructed of monofilament nylon, multifilament nylon or natural fibres (Read 1996). Gillnets are designed to be undetectable to fish: this has also the unintended consequence of making the nets more likely to catch non-target species. Most gillnets have a buoyant float line at the top of the net and weighted lead line at the bottom and can be configured to catch fish of various sizes. In general, the larger the mesh size, the greater the risk of entanglement to cetaceans. Porpoises are captured less frequently with fine mesh (Read 1996). A major review of the mortality of cetaceans in gillnets was produced a few years ago (Perrin *et al.* 1994) and some of the proposed solutions to bycatch are considered there.

Drift nets

Large-scale surface gillnets or drift nets are by definition longer than 2.5 km. (FAO 1990 *cited* in Read 1996). However, they can extend up to 50 km long. Bycatches in these large-scale drift net fisheries (fleets of Japan, Taiwan and Korea) were very high. In December 1992, when the UN passed a resolution (46/215) calling for a moratorium of these nets on the high seas, the EU also passed a ban on the use of large-scale drift nets by 1993. However, many drift net fisheries are still operating, but use nets less than 2.5 km long (Northridge *et al.* 1991).

Set nets

Gillnets are also used to capture bottom-dwelling groundfish if the nets are anchored near the bottom. Bottom set gillnets are one of the most common forms of fishing gear used throughout the world, due to their efficiency, flexibility and low cost (Read 1996). Like surface nets, this gear can be configured in many ways to capture the target species.

Entanglement is almost always fatal for small cetaceans (Bravington *et al.* 1997). Harbour porpoises, *Phocoena phocoena* are the most frequently killed cetaceans in these set nets (Read 1999a). There is some evidence that monofilament gillnets with large mesh sizes or openings, used in fisheries for hake, turbot and monkfish are the most dangerous for porpoises (WDCS 2001).

Consequently, gillnets appear to represent one of the most significant threats to porpoise populations (Jefferson and Curry 1994).

1.2.2 Temporal variation of bycatch

A recent study to quantify midwater trawl bycatch in the eastern Atlantic showed that most of the bycatch occurred during the night or close to dawn (Morizur *et al.* 1999). Some factors which may be important in the cetacean-trawl interaction include the target fish species, time of day, tow duration, level of tow, size of net opening, haul back speed and gear design. A better understanding of these factors could help provide solutions to the problem.

1.2.3 Bycatch in capture fisheries

One way to view the flow of bycatch in capture fisheries is to analyse the diagram below, which shows the different pathways of fishing activity (Figure 1-1). With any 'gear operation', there are the impacts on the habitat (such as trawling or dredging which scrape the ocean bottom). Gillnet operations can also affect the ecosystem by the loss of nets which may continue to fish or 'ghost' fish. When fishing, if there is 'capture', there is also chance of 'release' for any unwanted fish species or other animals. Porpoises, if they are caught early enough, can be released. However, according to one fisherman, after 15 minutes in a net, the porpoise drowns. The 'catch' is usually sorted into 'marketable catch', 'rejects' or discards. The marketable catch is then separated into 'yield' and 'processing waste'. The yield is the catch that goes to the consumer.

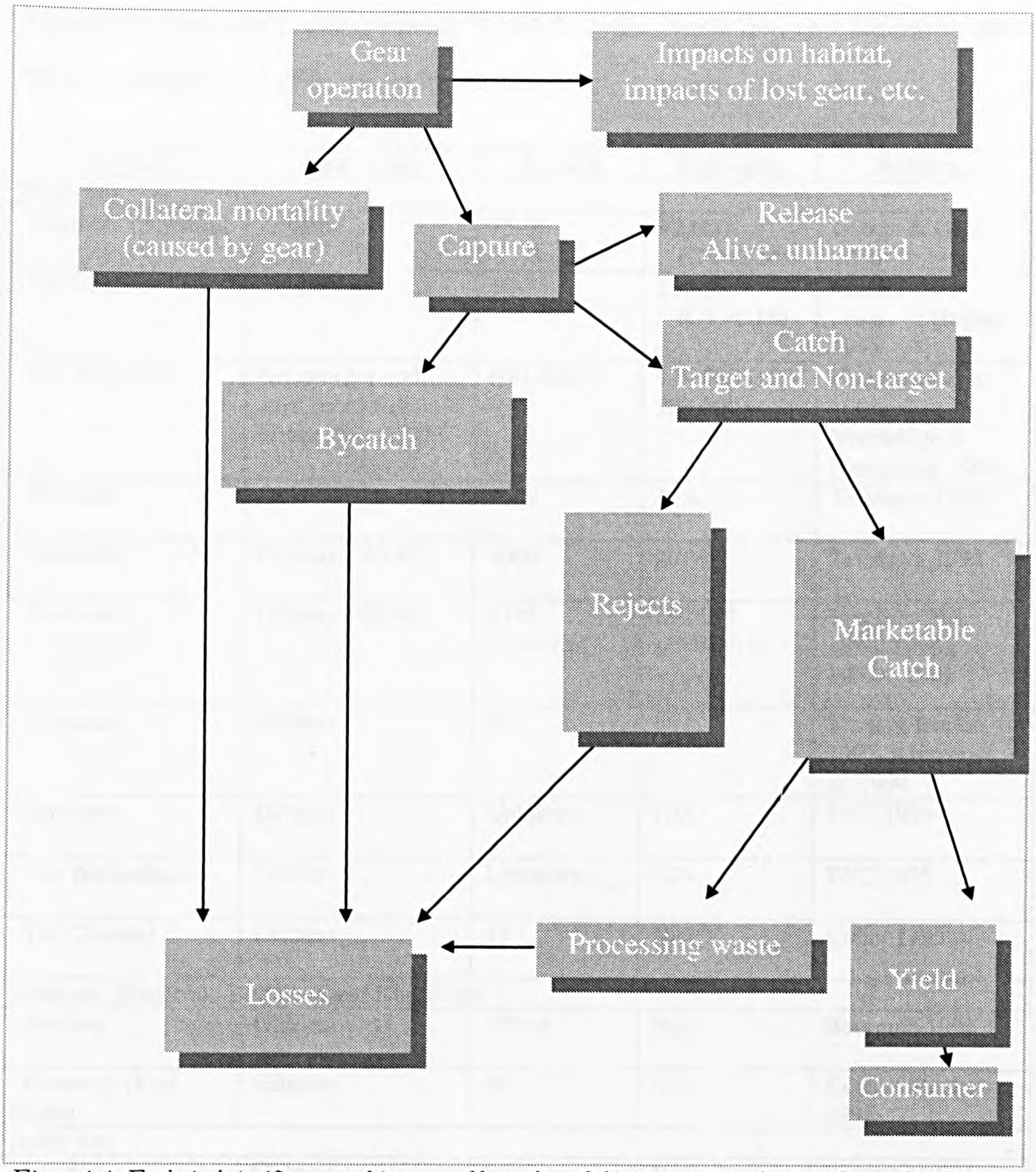

Figure 1-1. Ecological significance and impacts of bycatch on fishing operations showing the marketable catch and losses (adapted from Hall 1996)

1.2.4 Porpoise bycatch in the North Sea

Harbour porpoise bycatch in set net fisheries in the central and southern North Sea is known to be very high (Bravington *et al.* 1997) but there are few annual estimates available. Hence, systematic bycatch estimates and annual monitoring are needed from all major set net fisheries. Known estimates of porpoise population abundance and porpoise bycatch in the North Sea and adjoining seas are summarised in Table 1-1.

Region	Gear (year)	Bycatch	Population	Reference
North Sea				
Northern (Norway)	Gillnets	75-96	82,600 (CV=0.24)	Bjørge & Oien, 1995
UK Coast	Salmon nets	10-15	16,939 (CV=0.18)	Rhodes *pers. comm.* in Hughes 1998
UK North Sea	Set nets for cod, sole, monkfish, turbot	600-800/yr	170,000 (130-234,000)	Hammond *et al.* 1995 Northridge & Hammond, 1999
Denmark	Gillnets ('93-94)	4629	N/A	Teilmann 1995
Denmark	Gillnets ('80-81)	3000	N/A	Teilmann 1995
Denmark	Gillnets ('92-98)	6785 (CV=0.12)	292,995 (CV=0.16)	Vinther 1993, 1994, 1995a, 1995b, 1999
Germany	Gillnets	21	N/A	Kock & Benke 1995, Kremer *et al.* 1994
Scotland	Gillnets	Unknown	N/A	IWC 1995
The Netherlands	Gillnets	Unknown	N/A	IWC 1995
The Channel	Gillnets	13	N/A	Collet 1995
Kattegat, Skagerrak, Belt Seas and Kiel Bight				
Sweden	Gillnets	150/yr	N/A	Berggren 1995
Germany (Kiel Bight)	Gillnets	95	N/A	Kock & Benke 1995
Baltic Sea				
Sweden	Gillnets	5/yr	N/A	Berggren 1995
Germany	Gillnets	3/yr	N/A	Kock & Benke 1995
Poland	Gillnets	80/yr	N/A	Skora *et al.* 1988

Table 1-1. Summary of porpoise bycatch by gear type and population numbers for the North Sea and Baltic Sea where N/A indicates data not available

1.2.5 Spatial distribution of bycatch

Northern North Sea (Sweden)

Observers monitored Swedish cod gillnetters in 1995-1996, covering a single ICES rectangle off Gothenburg. The bycatch estimates were similar for the two years of 32 porpoises per 10,000 net km hours, or an annual bycatch estimate of 53 porpoises in this area (Bravington *et al.* 1997).

Northern North Sea (Norway)

A large number of gillnet vessels operate in the coastal area here. In 1996, a total of 5561 vessels used gillnets. Incidental catches of 96 porpoises were recorded in 1988 in the drift net fishery for salmon: this averages 0.8 porpoises per 1000 net km hours (Bravington *et al.* 1997). However, there is no recent bycatch estimate for the Norwegian fleet (Northridge and Hammond 1999).

Northern North Sea (UK)

A large number of UK gillnetters operate around Orkney and Shetland. While porpoises are numerous in the northern North Sea and in neighbouring waters, there appears to be considerable gillnet effort in this region. Thus, there is the potential for substantial bycatch (Bravington *et al.* 1997). No bycatch estimate is available for the large freezer–netter fleet nor the German and Faroese fleet that are reported to land in Scottish ports and which have yet to be assessed (Northridge and Hammond 1999).

Central North Sea (Denmark)

The Danish fleet is the largest in the European Community (Lowry and Teilmann 1994) and the annual bycatch has been estimated by a number of observer programmes from 1992 - 1998. The bycatch estimate can be as high as 4450 to 7000 porpoises per year (Vinther 1999).

Central North Sea (UK)

There are several UK set net fisheries with substantial effort (Bravington *et al.* 1997). The largest component, the English wreck net fishery (with currently 12 boats working out of Grimsby) is the present case study. The Grimsby fleet accounts for 34% of days at sea by English boats in the North Sea in 1994 (Northridge and Hammond 1999). There is also a variety of inshore gillnet fisheries along the east coast of Britain. A small fishery off the east coast of Scotland, was reported to be taking 1-20 animals per year in 1960-1970 (Bravington *et al.* 1997).

South-eastern North Sea

Very little set netting is prosecuted off the Netherlands or Belgium (Bravington *et al.* 1997). However, since 1988 at least 24 harbour porpoises have been stranded in Belgium and six had bycatch markings. In recent years there have been small German set net fisheries for cod and sole in the North Sea. Of 565 porpoises found stranded only a few could be classified as bycatch (Kock and Benke 1996).

The Channel

Gill and trammel nets are deployed off France and England. Bycatch has not been studied systematically (Bravington *et al.* 1997) and only two porpoises were recorded in 1980 as bycatch.

Celtic Shelf

An observer programme for the English and Irish hake gillnet, tangle and wreck net fishery was established to monitor dolphin Bycatch (Berrow *et al.* 1994) Harbour porpoise bycatch was estimated to be 2300 (Tregenza 2000). The programme did not cover trammel nets or smaller boats which may contribute substantially to overall bycatch. In the southern Celtic shelf, where porpoise densities may be lower there are large French set net fisheries (Morizur *et al.* 1999).

Northwest Scotland

Data collected by observers on a small number of gillnet vessels operating in the waters west of the Outer Hebrides, showed that bycatch of porpoises does occur in this area (Northridge and Hammond 1999). The region is also exploited by Spanish vessels. However, the level of bycatch is unknown (Parsons *et al.* 2000).

Summary

From these estimates, it is evident that more research is still needed. Currently there are observer programmes which operate in Denmark (Vinther 1999), Norway and the UK (Harwood 1999a) for the gillnet fleets but other gear sectors have not yet been studied in detail.

Nevertheless, there is cause for concern about bycatch rates in the Skagerrak/Kattegat/ Belt seas region, where estimates of bycatch are thought to be high (Bravington *et al.* 1997). The porpoise population structure is unclear and it is thought that the animals migrate to the Baltic Sea, mix in the northern North Sea and in the Channel. The very high bycatch rates in the Celtic Shelf may thus pose a problem for the recovery of the depleted Channel population (Bravington *et al.* 1997).

Pelagic trawls, as mentioned above, with the high overall effort may also be a potentially high risk for porpoise bycatch. Moreover, there are no estimates available in the North Sea (Bravington *et al.* 1997). Drift nets in the North Sea are currently few in number and the overall cetacean bycatch may therefore be probably low compared with other fisheries (Bravington *et al.* 1997). The overall scale of fisheries is low except for the Norwegian mackerel driftnets.

The other common fishing methods employed in the North Sea are bottom trawling, beam trawling, seining and longlining. There are records of cetacean bycatches from some of these fisheries, but bycatch rates appear very low and at present it seems likely that any bycatch from these fisheries is small in comparison to that from set nets and pelagic trawls (Bravington *et al.* 1997).

1.3 REGULATING BYCATCH

1.3.1 FAO CODE OF CONDUCT FOR RESPONSIBLE FISHERIES

The first and most obvious set of regulations and guidelines is the FAO Code of Conduct for responsible fisheries (FAO 1995). This code encourages nations to establish principles and criteria for the elaboration and implementation of national policies for responsible conservation of fisheries resources and fisheries management and development, and states precisely that bycatch should be discouraged to reduce post harvest losses and waste as well as improve the use of bycatch to the extent that this is consistent with responsible fisheries management practices. In another regulation it is required that:

12.4 States should collect reliable and accurate data, which are required to assess the status of fisheries and ecosystems, including data on bycatch, discards and waste. Where appropriate, this data should be provided, at an appropriate time and level of aggregation, to relevant State and sub regional, regional and global fisheries organisations.

The Kyoto Declaration and Plan of Action

The states that met in Kyoto for the International Conference on the sustainability contribution of fisheries to Food Security in December 1995 endorsed the provisions of the FAO Code of Conduct and in Declaration 15 stated that 'they would promote fisheries through research and development and use of selective, environmentally safe and cost effective fishing gear and techniques'. This resulted in the following being included in the plan of action agreed at (Clucas 1997):

To increase efforts to estimate the quantity of fish, marine mammals, sea birds, sea turtles and other sea life which are incidentally caught and discarded in fishing operations: assess the effect on the populations or species: take action to minimise waste and discards through measures including, to the extent practicable, the development and use of selective, environmentally safe and cost effective fishing gear and techniques, and exchange information on methods and technologies to minimise waste and discards.

1.3.2 ESTABLISHMENT OF BYCATCH POLICY

As Alverson and Hughes (1996) point out, the emergence of bycatch as a major management issue of this decade can be traced to the rapid growth of world fisheries and their increasing competition, the rise of environmental groups and the resulting efforts to protect populations of marine mammals, birds and turtles affected by commercial fisheries. One of the best known examples was the dolphin bycatch in tuna purse seine nets (Hall 1998). Next, there was the case of marine mammals and birds in the north Pacific salmon net fisheries (Hall *et al.* 2000). Another example was the marine turtle bycatch in the shrimp fisheries of the Gulf of Mexico (Bache 2000). Recovery efforts for the sea turtle are underway and include regulations on TEDs or Turtle Excluding Devices, which are simple devices that can be inserted into existing trawl nets to allow the turtles to escape with little or no shrimp loss.

Marine mammals, birds, turtles and other species in the high seas drift net fisheries in the North Pacific were also part of the debate. And it was this latter issue that served to put bycatch policy to the highest level of collective governments, the United Nations (UN) (Alverson and Hughes 1996).

1.3.3 Present management and implications

The main regimes covering the management of porpoises in the North Sea are the OSPAR (Oslo-Paris) and ASCOBANS (Agreement on the Conservation of Small Cetaceans in the Baltic and North Seas) under the UN Convention on the Conservation of Migratory Species of Wild Animals also known as the Bonn Convention. In the role of ASCOBANS, the UK government has an obligation to protect the harbour porpoise, through both the Habitats and Species Directive (Council Directive 92/43/EEC) and reduce bycatch. It also chose the porpoise as a flagship species when it launched its Biodiversity Action Plan.

Under ASCOBANS at the meeting of parties in Bristol 2000, the UK and several EU member States have made a commitment 'to achieve and maintain a favorable conservation status for small cetaceans' (ASCOBANS 2000b).

The IUCN (The World Conservation Union) has classified the porpoise as having a 'vulnerable' status (see www.phocoena.org). Vulnerable is defined when a taxon is not critically endangered or but is facing a high risk of extinction in the wild in the near future (see www.iucn.org).

1.3.4 Mitigation measures

Some successful measures to prevent bycatch include placing 'pingers' or acoustic deterrents on nets (Kraus *et al.* 1997, Trippel *et al.* 1999). However, there is recent evidence that porpoises may get accustomed to these devices (Read 2000). In addition, it seems that the fishermen themselves in the Bay of Fundy are reluctant to use pingers (Read 2000). Another measure that is currently being tested with more success is the use of acoustically 'reflective nets' (Read 2000).

Further aspects of bycatch regulation

Although progress is made towards responsible fishing and lowering of bycatch rates, the problem is not generally perceived in the context of more generic fishery management issues i.e. discerning mortalities resulting from resource harvesting, evaluations, their consequences on affected populations and controlling the rate of fishing mortality in relationship to specific management goals. In many instances, bycatch constitutes a topical discussion set apart from the basic question of population dynamics, yet it is an integral part of ecology.

Conclusion

It can be seen that the global bycatch problem is far more extensive than originally thought possible. FAO summarised the known extent of the various fisheries with the bycatch levels (Alverson *et al.* 1994). In the North Sea especially, there are still many problems and bycatch estimates are not available for certain sectors of the fishing gear. With the problems of underreporting, misreporting and the low number of observer programmes, the data are not there to obtain reliable quantitative estimates of the bycatch problems (ASCOBANS 2000a). It should be emphasised that the lack of a bycatch estimate for a fishery does not necessarily imply that bycatch is negligible.

Bycatch is considered to be one of the greatest threats to populations of small cetaceans (Bravington *et al.* 1997) especially the porpoise in the North Sea. As well, environmental groups have recently begun to protect the porpoise and the issue is highly emotive. The Royal Society for the Prevention of Cruelty to Animals, (RSPCA) has initiated a plan to protect the porpoise from fishing nets (CNN 18 July 2000). The RSPCA has released a report: 'Haul of Shame' in the UK claiming as many as 20,000 porpoises which died off the UK coasts in the last six years. The WWF-UK has also launched a programme to protect the harbour porpoise from gill nets by supporting changes in legislation to halt the damage by promoting protected areas (The Times 17 Sept. 2000). Bycatch has become a serious environmental issue.

Chapter 2

Review of Porpoise Ecology and Behaviour

> *...the common porpoise found almost all over the globe... for there are more than one sort of porpoises, and something must be done to distinguish them ... he always swims in hilarious shoals, which upon the broad sea keep tossing themselves to heaven like caps in a Fourth-of- July crowd. Their appearance is generally hailed with delight by the mariner. Full of fine spirits, they invariably come from the breezy billows to windward. They are the lads that always live before the wind. They are accounted a lucky omen... A well-fed, plump Huzza Porpoise will yield you one good gallon of good oil. But the fine and delicate fluid extracted from his jaws is exceedingly valuable. It is in request among jewellers and watchmakers... Porpoise meat is good eating, you know. It may never have occurred to you that a porpoise spouts. Indeed, his spout is so small that it is not very readily discernible. ...*
>
> *Moby Dick, Herman Melville (1851)*

This chapter provides a review of porpoise ecology and behaviour, with special reference to North Sea porpoises. The smallest cetacean found in the North Sea is called the common porpoise, *Phocoena phocoena* L. or harbour porpoise in the US, *Meerschwein* or *Tummler* in German, *nise* in Norwegian, *bruinvis* in Dutch and *marsouin* in French, and *marsvin* in Danish (Connor and Peterson 1994). Emphasis is given to aspects having relevance to porpoise bycatch.

2.1 Distribution in the North Sea

I examine the distribution of porpoises in the North Sea and some of the factors influencing their distribution. While much of the research was undertaken in the western Atlantic, it seems likely that many of the factors will also affect the distribution of porpoises in the North Sea. Changes in the presence of harbour porpoises in the North Sea, in particular the southern North Sea, are probably due to alterations in prey availability and incidental catches (Reijnders 1992). Porpoises moved out of the coastal areas because of lack of prey, but incidental catch in fishing gear reduced their overall abundance. Prey availability such as herring and mackerel as the major food source, was influenced initially by overfishing, and followed by a shift further north in spawning and feeding areas influenced by environmental factors. It is now believed that bycatch is the only other major threat (Reijnders 1992).

Porpoises are distributed around the British islands and in the North Sea (Klinowska 1991, IWC 1995). The majority of information comes from the SCANS (Small Cetacean Abundance in the North Sea and Baltic) survey and the Sea Watch Foundation (SWF) (Hammond *et al.* 1995). The population ranges from southern Norway, west to the Shetland Islands and to the Dutch coast. Concentrations along the Danish coast and the north German coast still occur, whereas total numbers have decreased in the southern North Sea (Evans 1995b, Evans 1990). During the first part of the year (January to March), porpoises form two groups, one off Denmark and the other, more scattered in the deeper waters of the northwestern North Sea. Individuals distributed inshore along Britain's east coast possibly link the two groups (Northridge *et al.* 1995) until they disperse again during April-May. From April to September, the porpoises tend to be abundant along the west coast from Yorkshire to Shetland. Small numbers of porpoises are known to be resident in some areas along this coast, such as near Flamborough Head (Hughes 1998). The harbour porpoise was regularly seen along the coast of East Anglia earlier this century, but is now rare in the English waters of the southern North Sea (Evans and Scanlan 1989). It is not known but it is possible that animals from the eastern North Sea, as well as those from further north, aggregate along this western margin during calving season. Concentrations of harbour porpoises occur off Flamborough Head in July to October (Evans 1996a).

In the winter, the two groups in the North Sea reform once again. Therefore, there appear to be two aggregations based in Danish and Scottish zones during the winter and spring. In the spring, these disperse and there is a general movement of porpoises into coastal waters of eastern Britain, especially during the calving season.

Many biological and physical oceanographic factors (depth, sea floor relief, and tidal currents and sea surface temperature) affect the distribution of cetaceans. Increased availability of prey in deep waters may be a factor affecting the distribution of harbour porpoise (Raum-Suryan and Harvey 1998). Gaskin *et* *al.* (1984) found a significant positive correlation between abundance of mother and calf pairs and bottom depth and copepod (*Calanus* sp.) density. Abundance of harbour porpoises was positively correlated with depth and physiographic features that concentrated Atlantic herring (*Clupea harengus*) in near surface waters (Watts and Gaskin 1989, Evans 1997). In New Brunswick, Canada, harbour porpoises were associated with reduced sea surface temperatures that coincided with a large influx of juvenile herring (Gaskin *et al.* 1984). Tidal state affected movements of harbour porpoises in the Bay of Fundy: Harbour porpoises were observed more often during flood tide than ebb tide and moved inshore during flood tides and off ashore during ebb tides (Gaskin *et al.* 1984).

From the SAST (Seabirds At Sea database) data it is evident that harbour porpoises were widely distributed across the north and central North Sea with important concentrations off the west coast of Scotland and in the Irish Sea (Northridge *et al.* 1995). The overall distribution shown by these sightings does not conform completely to the popular belief that porpoises are predominantly an inshore or coastal species. Sightings were made in the deep waters of the Norwegian Rinne, in deep water areas between Iceland and the Faeroe Islands. In contrast the shallow waters of the North Sea had fewer sightings.

Porpoises were most often associated with deeper waters along coastal regions of North America. Most harbour porpoises observed off the coast of California occurred at shallow depths and sightings decreased with increasing depth. Aggregations of surface schooling fish and associated harbour porpoise were rarely seen within the study areas, indicating that harbour porpoises were likely feeding on prey in deep water. Raum-Suryan and Harvey (1998) believe that harbour porpoises and their prey are associated with deeper waters, which have shallow slopes.

Water temperature may influence the distribution of harbour porpoises. Sightings were reported in water temperatures ranging from 9 to 16°C off Washington. In the Bay of Fundy, Watts and Gaskin (1989) found a negative correlation between harbour porpoises and mean August temperatures. They reported that porpoises occurred in less than 15°C in the Bay of Fundy. It is unlikely that temperature alone would influence harbour porpoise distribution. Most porpoises entered the harbour when the sea surface temperature or SST was between 9 and 10°C, a period when large numbers of juvenile herring were also entering the region (Watts and Gaskin 1989). Within the Bay of Fundy, these authors also found that herring associated with vertically mixed waters and reduced surface temperatures. This association was due to increased concentrations of zooplankton, which also occurred along convergent zones. Occurrence of harbour porpoise appears to be closely associated with the strength of tidal currents. The authors found that in their sightings, the relation between the

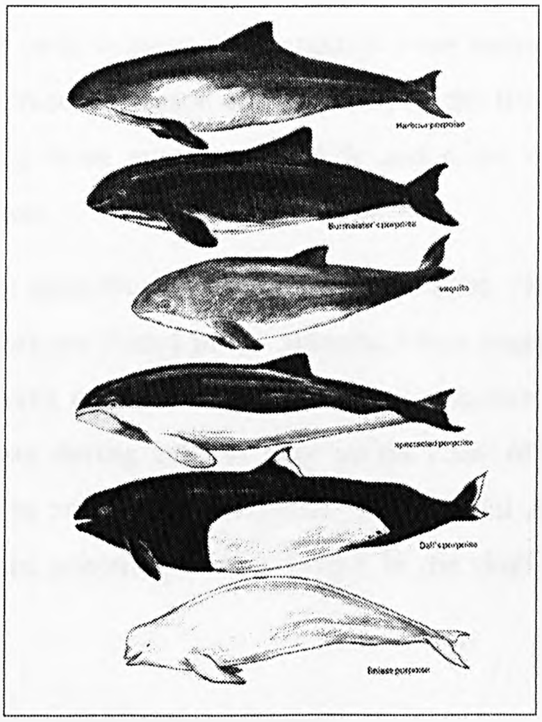

Figure 2-1. The family Phocoenidae: Harbour porpoise, Burmeisters's porpoise, vaquita, spectacled porpoise, Dall's porpoise and finless porpoise (reproduced with permission from Evans 1987)

occurrence of harbour porpoise with the tide and time of day indicates that porpoise movements may have been associated with concentrations of prey in flood currents and tide rips. Evans (1996b) also observed that tidal factors are more important than diurnal factors in determining suitable foraging conditions.

2.1.1 Possible reasons for strandings

Many reasons have been postulated as to the cause of strandings. One was that the cetaceans, and hence porpoises, are lost, cannot use their echolocation. It was recently discovered that particles of magnetite exist in the brain of several cetaceans, among them common dolphins, humpback whales, Cuvier's beaked whales and Dall's porpoises (Connor and Peterson 1994) and the humpback whale (Evans 1987). Klinowska (1986) found correlations between whale strandings and local magnetic field lines intersecting the coast although no hard evidence exists. However, most strandings do occur in areas of magnetic abnormalities. It has therefore been hypothesised that the earth's magnetic field is used by cetaceans for normal echolocation.

Stranded specimens in Danish waters are mainly young males. Lockyer and Kinze (1999) noted that peak seasons of strandings were summer and autumn. This coincides with the breeding season and thus may be the time that the young of the year are becoming more numerous, mobile and more vulnerable to the hazards of nearshore waters.

Another reason given for strandings is disease and starvation. Often at autopsies a high number of parasites are found in the animals. Most stranded animals are very young and some have empty stomachs. The *post mortem* findings in 38 stranded harbour porpoises during 1983 to 1986 on the coast of the Netherlands as well as observations in animals described by Clausen and Andersen (1988) concur. They observed the presence of roundworm in the skull sinus (Van Nie 1989).

2.1.2 Why porpoises get entangled in gear

Why do animals that are intelligent, and use echolocation get entangled in fishing nets? It seems that porpoises dive for their prey, and probably dive too close to bottom set nets (Read 1999a). Another reason may be that porpoises are too small in comparison to the nets. The larger whales can usually escape and take the major portion of the net with them, but a porpoise whose appendages, flukes or fins may get caught, does not have the strength to free itself (Read 1999a).

2.2 BEHAVIOURAL ECOLOGY

2.2.1 SOCIAL ORGANISATION

Harbour porpoises are usually found in small groups or pods of fewer than ten animals (Connor and Peterson 1994). Evans (1996a) observed groups of three and four porpoises off the Shetland Islands. Lockyer and Kinze (1999) in a recent study determined that the overall average pod size of porpoises in Danish waters was 2.1, while the largest aggregations of porpoises, containing calves, consisted of 17 individuals. Females and calves are seen in groups of three. During the summer months these groups are sedentary, whereas the largest shoals form in March, April and November, and these are migrating animals (Lockyer and Kinze 1999). Read (1999a) reports that porpoises in the Bay of Fundy are seen either in very small groups of females with their young or separate groups of males. From recent tagging studies, it was shown that porpoises form groups and then within a few days disperse. The tendency to occur alone or in small groups is reflected in strandings records. Porpoises tend to strand alone, not *en masse* like the larger whales (Read 1999a).

2.2.2 SWIMMING AND FEEDING

The Norwegian scientist Scholander first measured the dive of a porpoise by attaching a harness to it, and found that the animal did not go lower than 35 m (Slijper 1962). Evans also observed foraging porpoises in 20-40 m depths in the North Sea (Evans 1996a). In more recent studies, mean dive depth and duration were measured and these ranged from 14 ± 16 to 41 ± 32 m to 44 ± 37 to 103 ± 67 sec. and the maximum recorded dive depth and duration was 226m and 321sec. (Westgate *et al.* 1995).

Observed porpoises demonstrated a diel pattern in their diving, making fewer, but deeper dives at night. Read and Gaskin (1988) noted that harbour porpoises may have feeding periods during the day related to the tidal cycle, with little feeding activity at night. Evans observed porpoises off the Shetlands, and he found that foraging and feeding occurred in the early morning and evening. Porpoises were observed to forage against the tidal flow. Feeding occurred at the turn of the tide approximately two hours before and two hours after high water, when the current was at a maximum. Foraging activity peaked approximately two hours after high water (Evans 1996a).

Comparison of the diving behaviour of harbour porpoises with data on the depth of porpoise entanglements in gill nets in the Bay of Fundy showed that porpoises made up to 70% of dives to depths (range 20-130m) where the majority of entanglements were reported (Westgate *et al.* 1995). Read reported on the satellite tagged porpoises, who dove rapidly, spent a minute or two near the bottom and then returned quickly to the surface (Read 1999a).

Experimental studies on captive porpoises

Can harbour porpoises detect nets in the water? There are no field studies to investigate this problem but some experimental observations are available. Porpoises that were found stranded off the Dutch coast were rescued and then confined to a tank. From these experimental studies (Nachtigall *et al.* 1995) the following conclusions were made. Juvenile porpoises act in a more inquisitive way and this may be why, in the wild, a disproportionately large amount of harbour porpoises are yearlings (Andersen 1975, Smith *et al.* 1993).

The fact that porpoises prefer swimming *under* ropes, to over ropes is significant. Since predators attack harbour porpoises most often from below, porpoises may be more afraid of objects below them. In addition, porpoises may usually hunt their prey from below and may be used to dealing with objects above them. Detection of prey may be done by each individual eye and thus provides a large visual field (Kastelein *et al.* 1995).

When live fish were introduced in the tanks, the swimming pattern of the porpoises changed. Swimming became more irregular and the animals crossed the ropes more frequently. Evidently, the urge to forage made the animals less cautious, a condition which may be lethal near fishing nets. While swimming around the ropes, porpoises used more click trains (click repetitions rate < 25 Hz) and less click bursts (click repetition rate >25 Hz), than they had used while swimming in the same pool. According to Kastelein, it is possible that click trains are used for navigating around the ropes, and that click bursts are for investigating close objects (Kastelein *et al.* 1995).

There are currently new experimental studies being undertaken in Kerteminde, Denmark. Again these are studies of porpoises confined to an outdoor pool rather than studies of porpoises in the wild (Lockyer *pers. comm.*).

2.3 PORPOISES IN THE MARINE ECOSYSTEM

2.3.1 TROPHIC LEVEL OF PORPOISES

What is the trophic level of a porpoise? In order to answer this question, the diet and stomachs of porpoises can be examined. Pauly *et al.* (1995, 1998) studied the trophic level for marine mammals in the marine ecosystem using available literature and the model 'Ecopath II' (software to estimate trophic levels) in order to calculate area-specific global food consumption. Harbour porpoises are primarily fish eating and they are known to eat Ammodytidae. They are also known to prey on cephalopods. Recent studies have indicated that demersal and deepwater fish may be more important than published records suggest. The level of benthic invertebrates (BI) is very low 0.05, the SS (small squids) 0.1 LS (large squids) are 0.1 and SP (small pelagics) and MF (mixed fish) are 0.3 and 0.45 respectively. The calculated trophic level is 4.1 (Pauly *et al.* 1998). This level is identical to the Black dolphin, Dall's porpoise, spectacled porpoise (Figure 2-1) and Franciscana. It is the same as that of the California sea lion, Galapados fur seal, New Zealand fur seal, the Hawaiian monk seal, the Ross seal and the Leopard seal (Table 2-1). The same level is obtained for Arnoux's beaked whale, northern and southern bottlenose whale, rough toothed dolphin, Atlantic and Pacific white sided dolphin, the Hour glass dolphin. High levels of (MF) mixed fish for the harbour porpoise, are very similar to the spectacled porpoise and also similar to the dolphins (Rough toothed and Atlantic white sided dolphin but not as high as the Hawaiian monk seal). It is evident that SP (small pelagics) such as herring, and mackerel and MF (mixed fish) fish are important to the porpoise. These results are not new knowledge but can be used to detect changes in trophic levels and diets for marine mammals.

Common name	BI	LZ	SS	LS	SP	MP	MF	HV
Arnoux's beaked whale	0.1	-	0.2	0.1	0.2	0.2	0.2	-
Rough toothed dolphin	0.1		0.2	0.1	0.2		0.4	
Pacific white sided dolphin			0.3	0.05	0.3	0.2	0.15	
Atlantic white sided dolphin	0.1		0.15	0.1	0.15	0.1	0.4	
Hour glass dolphin			0.5		0.2	0.1	0.2	
Bottlenose dolphin								
Black dolphin			0.2	0.2	0.4		0.2	
Dall's porpoise	0.05		0.3	0.1	0.2	0.2	0.15	
Spectacled porpoise			0.2	0.1	0.3		0.4	
Harbour porpoise	0.05		0.1	0.1	0.3		0.45	
Franciscana	0.1		0.2	0.2	0.2		0.3	
California sea Lion	0.1		0.2	0.15	0.25		0.3	
Galapagos fur seal			0.4		0.2	0.3	0.1	
New Zealand fur seal	0.2		0.2	0.1	0.1	0.1	0.25	0.05
Australian fur seal	0.1		0.3	0.15	0.2		0.25	
Hawaiian monk seal	0.2		0.1				0.7	
Ross seal	0.05	0.15	0.5	0.15			0.15	
Leopard seal		0.35	0.1		0.1		0.05	0.4
Average	*0.1*	*0.25*	*0.24*	*0.1*	*.22*		*.27*	

Table 2-1. The trophic level of the porpoise in the global ecosystem (where BI is benthic invertebrates, LZ = large zooplankton, SS = small squids, LS = large squids, SP= small pelagics, MP= mesopelagic, MF are miscellaneous fishes and HV stands for the higher vertebrates)

2.3.2 DIET OF PORPOISES IN THE NORTH SEA

The knowledge about the prey and diet of porpoises will provide more information about bycatch. Harbour porpoises are known to be primarily fish feeders. The main prey are cod, herring, mackerel and squid (Gaskin 1984). Young porpoises are known to feed on molluscs and crustaceans such as copepods (Smith and Read 1992). In the North Atlantic, their diet consists of a number of small, pelagic fish such as herring and sprat, semi-pelagic species and demersal species such as cod and flatfish (Santos *et al.* 1994).

The coincidence of porpoise distribution with those of the North Sea herring had led to the conclusion that the demise of the herring stocks was responsible for decreases in the abundance of porpoises (Jennings and Kaiser 1998). Evans (1987) also correlated porpoise distribution to herring distribution. However, harbour porpoises appear to feed on both demersal and pelagic fishes, and the number of gadoids increased in abundance as herring declined. Moreover, in some areas, porpoises remained abundant following the collapse of herring stocks. Simmonds and Hutchinson (1996) concluded that the effect of incidental capture of porpoises in gillnets was more likely to affect porpoise populations than any impact of fishing on their prey species.

The porpoises in the northeast Atlantic, in common with other marine mammal species, probably have a varied diet and feed in ecosystems where the choice of prey is varied. The diet of the porpoise in Danish waters was recorded as being composed mainly of herring, cod, and salmon (Lockyer and Kinze 1999). In more recent years (1996 to 1998) stomach contents showed that the animals had a high preference for sandeel. Gadoids are the most important prey item, then clupeoids, gobiids, and ammodytids or the sandeels. Squid was found in only 7% of the examined stomachs (Lockyer and Kinze 1999).

Female porpoises have a more varied diet in order to build up reserves for nourishing their calves (Aarefjord *et al.* 1995). The diet is diversified with age, i.e. calves tend to eat few prey species while older animals gradually broaden their range of species. In general, it can be seen that porpoise diet varies. It is interesting to note that in recent years there is more sandeel than cod in the stomach, this may well indicate the changing stock structure in the North Sea rather than any change in prey preference by the porpoise.

2.3.3 Porpoises and seabirds

Seabirds are often seen foraging in association with porpoises. Gannets, *Morus bassanus* for example, are often seen circling above porpoise groups and taking prey by plunge diving immediately ahead of porpoises as they surface (Pierpoint *et al.* 1998). These authors speculate that porpoises were driving the gannets' prey towards the surface. Gulls, *Larus* spp. are also observed following porpoises. Manx shearwaters, *Puffinus puffinus* have also been recorded feeding in association with harbour porpoises. On a number of occasions the shearwaters were observed to be feeding on sprat, *Sprattus sprattus* (Pierpoint *et al.* 1998).

Predators

The known predators of the porpoise are the large sharks and killer whales (Slijper 1962, Read 1999a). Evidence of a shark attack was noted on a harbour porpoise in the North Sea, stranded on the Frisian Island of Ameland (*cited* in Hughes 1998). There are other records of harbour porpoises found dead which had been attacked by sharks on the east coast of the Atlantic (Templeman 1963 *cited* in Hughes 1998) and in the Bay of Fundy, it is the white shark which is the most frequent predator of the harbour porpoise (Read 1999a). Bondesen (1977 *cited* in Hughes 1998) reported the stomach contents of a killer whale, *Orcinus orca* found floating in the Kattegat. It contained 14 seals and 13 harbour porpoises. Harbour porpoise predation by transient killer whales is regularly recorded off British Columbia, Canada (Read 1999a).

2.3.4 INTERACTIONS WITH OTHER MARINE MAMMALS

There is evidence of violent interactions between bottlenose dolphins and harbour porpoises. These interactions have recently been documented in the North Sea, off the Moray Firth (Ross and Wilson 1996). Porpoises that were stranded were also found to have been subjected to skin cuts and teeth marks as well as multiple skeletal fractures and damaged internal organs.

These findings challenge the benign image of dolphins and provide another unrecorded cause of natural mortality in porpoises. Dolphins and porpoises may compete for food and space. Observations showed that the interaction was undertaken by a group of dolphins (two or three) against a single porpoise. Adult dolphins chased a single porpoise at high speed before repeatedly diving in a small area with the porpoise hidden from sight. The porpoise was pursued and often butted clear of the surface on the head of a dolphin. These observed interactions were highly violent and non-consumptive. The evidence in two porpoises of healed injuries suggests that such interactions are not consistently fatal and hence, may be more frequent than suggested by strandings data alone.

2.4 OTHER ASPECTS OF PORPOISE ECOLOGY

Reproduction

Peak calving occurs in June in the British Isles, with high numbers of neonates and calves found stranded in June to September (Lockyer 1994). Data on testis weight suggest that the likely age at sexual maturity in males may be about 3 years onwards. Peak testis weight was observed in June-August. Peak births occur in June. Harbour porpoises in the Bay of Fundy have the most focused birth season of all, estimated to be in late June (Connor and Peterson 1994). This suggests a gestation of one year or less in porpoises (Lockyer 1994).

Harbour porpoises in Dutch waters have extended reproductive seasons in comparison with other porpoises. In a study conducted by Addink *et al.* (1994) in 1990, only four out of 15 female porpoises had both ovaries developed. All female porpoises (at least those studied in European waters) cycle exclusively using their left ovary (Jepson *pers. comm.*). The same phenomenon has also been documented in other terrestrial species such as camels. Many dolphin species appear to favour the left ovary (approximately 70% or so of ovarian activity occurring in the left ovary) and this appears to be part of their normal reproductive biology.

Current data for harbour porpoises in the North Sea supports an average age of sexual maturity of 3-4 years, although historically this may have been higher (approximately 5-6 years old) (Fisher and Harrison 1970). Many adult female porpoises studied at post mortem have also been found to be both pregnant and lactating, suggesting an annual calving index for at least some individuals within this species (Jepson *pers. comm.*). The lactation period was estimated to be eight months and the gestation period was estimated between 8 to 11 months (Evans 1987).

2.4.1 Life history parameters

Porpoises can live on average for 20 years. A maximum of 24 years has been recorded (Lockyer 1994). Some of the reasons for the decline and mortality of the harbour porpoise may be due to environmental deterioration as well as an increase in direct human activities such as overfishing, bycatches and boat disturbances.

Length weight relationship

Lockyer (1994) investigated the life history of porpoises in the North Sea and arrived at the following equation:

$$W=.000082L^{1.2401}G^{1.5524}$$

Where W is the total weight in kg and L is the total length in cm, and G is girth in cm. This relationship is used to determine the growth rate and is usually species specific. Females are usually larger then males, and on average mature males are 50kg whereas females can grow to an average of 65kg (Lockyer and Kinze 1999).

2.4.2 SONAR CAPABILITIES OF PORPOISES

Very limited data on the echolocation signal characteristics of these animals exist but porpoises are known to employ narrowband, high frequency sonar signals in contrast to the higher source level (SL) wideband pulses employed by many dolphins (Goodson and Sturtivant 1996). Porpoises produce sound over a wide range of frequencies, but most of their sounds are above the range of human hearing (Read 1999a). Many of these sounds are clicks used in echolocation. An echolocating porpoise should be able to detect and avoid nets, but many do not. It is possible that porpoises detect nets but do not perceive them as dangerous. Read (1999a) also suggests that porpoises may not detect the nets simply because they are not constantly echolocating.

2.4.3 PORPOISES AND POLLUTION

The major contaminants which have been measured in porpoise tissues are the organochlorine compounds and heavy metals (Aguilar and Borrell 1995). The organochlorine compounds include pesticides such as DDT and industrial compounds most notably the polychlorinated biphenyls or PCBs (Aguilar and Borrell 1995, Vidal 1995). The tissue burdens of PCBs in porpoises are widely reported to exceed the proposed tolerance levels and consequently must be pollutants of major concern (Hutchinson 1996). The health problems associated with these compounds relate to reproductive and immune system dysfunction but the underlying mechanisms are still unclear (Reijnders 1988, Reijnders 1996). How harbour porpoises will be affected depends on the likelihood of exposure and uptake, and their abilities to metabolise pollutants to harmless byproducts for elimination (Hutchinson *et al.* 1995).

Extremely high concentrations of PCBs, DDTs and other less frequently studied organochlorine pesticides were recorded in porpoises of the North

Atlantic basin (Holden and Marsden 1967, Duinker and Hillebrand 1979, Gaskin *et al.* 1983, Morris *et al.* 1989, Beck *et al.* 1990, Van Scheppingen *et al.* 1996). Porpoise numbers in the North Sea have been declining since the 1970s. Recent data from strandings indicate that levels of PCBs were higher in animals that had died from infectious disease than bycaught animals and this may be part of the reason for the decline (Jepson *et al.* 1999).

In the Baltic Sea, the harbour porpoise was common up to the 1940s (Kannan *et al.* 1993). Thereafter a drastic decline in its population was also suspected to be linked with high body burdens of PCBs, and DDTs (Otterlind 1976).

New information was recently published on organochlorines in harbour porpoises from the Baltic Sea, Kattegat and the west coast of Norway (Berggren *et al.* 1999, Bruhn *et al.* 1999). These analyses show that male porpoises from the Baltic have significantly different patterns from those of the other locations. The contaminant levels recorded in the Baltic Sea are 'a cause of concern and could have management implication' for the already threatened harbour porpoises (ASCOBANS 2000a).

Persistent organochlorine or persistent organic pollutants (POPs), are highly stable compounds that can be accumulated and remain in the environment for decades before breaking down (WWF 2001b). Chemicals characterized as 'persistent' resist the natural processes of degradation, by light, chemical reactions or biological processes, which would eventually render them harmless. Instead they are highly toxic, possess a special affinity for fat, are semi volatile, a property that allows them to evaporate and travel great distances.

The 12 persistent chemicals include eight pesticides (aldrin, chlordane, DDT, dieldrin, endrin, heptachlor, mirex, and toxaphene), two types of industrial chemicals (polychlorinated biphenyls or PCBs and hexachlorobenzene, HCB) as well as unintended by-products dioxins and furans. Studies have shown that these chemicals are dangerous not only at high levels, but also at low levels (WWF 2001b). All 12 POPS have also been identified as 'endocrine disruptors', chemicals that can interfere with the body's own hormones. Since every porpoise is exposed to these chemicals in the marine environment, the chemicals are readily accumulated in body tissues and are transferred to offspring during gestation and lactation.

The concern over the potential effects of metals such as mercury, selenium, lead and zinc results at least partly from their impacts on humans (Mulvaney and McKay 2000). The debilitating effects are well documented. However, relatively few studies on heavy metal contamination in harbour porpoises have been carried out and the sample sizes have been very small (IWC 1995, Joiris *et al.* 1990). Substantially higher levels of mercury compared to those in other regions were found in porpoises from German waters (Westgate and Johnston 1995). Bennett *et al.* (1999, 2001) measured higher mean liver concentrations of mercury, selenium, lead and zinc in porpoises that died of infectious diseases than in those that died from bycatch or physical trauma.

Recent studies summarised chemical pollutants in cetaceans (Reijnders *et al.* 2000, McKenzie 1999). ASCOBANS in 1999 noted the threats posed by two new groups of elements, the polybrominated compounds and the organotin compounds. Both types of compounds were increasingly being widely reported in cetaceans. British researchers reported the presence of butyltin compounds (TBT) in liver samples of harbour porpoises that had stranded on British coasts (Law *et al.* 1999, Jepson *et al.* 1999). Japanese researchers also identified organotins in liver samples from coastal porpoises in Japanese waters (Le *et al.* 1999). These data indicate the widespread distribution of butyltin residues in deep waters and food chains and potential risks to porpoises. Other researchers found that geographical differences in organochlorine contaminants in porpoises in the western North Atlantic can be used to differentiate stocks (Westgate and Tolley 1999). Male porpoises from the Bay of Fundy and Maine had significantly higher contaminant levels than those in Newfoundland.

Despite the fact that the exact effects are still unknown, there is some concern about the impact of these contaminants on the porpoise. Marine pollution may be an additional threat to this already vulnerable species.

2.5 PORPOISE STOCK STRUCTURE AND EXPLOITATION

2.5.1 STOCK STRUCTURE

An abundance of about 341,366 animals was estimated in the North Sea and adjacent waters. This estimate has a 95% confidence interval of 260,000 to 449,000 (Hammond *et al.* 1995). Preliminary studies suggest the existence of several sub populations, which could well be affected very differently by the different geographically concentrated fisheries (Teilmann *et al.* 1998). The specific impact of the bycatch on each of these sub populations is not known. The area off the coast of Denmark is however one of the most densely populated in number of porpoises per km^2 (Hammond *et al.* 1995).

The situation in the North Sea is complex since there are probably at least five genetically different populations or subgroups which exist: Irish Sea/ Wales, Dutch, British North Sea, Danish North Sea and Inner Danish Waters (Walton 1997, 1999). Moreover, porpoises from the Danish coast move to inner waters, the Skaggerat and Kattegat. Furthermore, genetic drift and gene flow are mediated by male dispersal and counterbalanced by female philopatry, the tendency of females to return to their natal breeding areas (Tiedemann *et al.* 1996, Andersen *et al.* 1999).

Genetic analysis

Gaskin in a world-wide review of porpoise populations proposed three main discrete populations, namely Ireland/west Britain, the North Sea and the English Channel (Gaskin 1982, 1984). Only later work suggested that there might have been sub populations within the North Sea (Yurick and Gaskin 1988).

In another study, on animals in the inner Danish waters, the North Sea and West Greenland, Andersen *et al.* (1995) detected deviations from the Hardy-Weinberg distributions. All the North Sea samples contained a surplus of homozygotes which could be explained by an effect of mixing of several subpopulations or non-random mating illustrated by straying males from different breeding areas in the North Sea. The study showed that harbour porpoises from West Greenland are geographically differentiated from harbour porpoises in the inner Danish waters and the North Sea. However, it was not possible with the small sample size to differentiate between harbour porpoises in the inner Danish waters and the North Sea.

Morphometric and meristic studies

In another study, 608 animals were analysed for population structure from the North Sea, inner Danish waters (Kattegat south, Belts, Oresund) and Swedish Baltic Sea, the Shetlands, east Scotland, east England, the Netherlands and Ireland. Morphometric measurements as well as polymorphic DNA microsatellite loci were analysed and the results of these tests indicate five genetically differentiated populations and subpopulations (Andersen *et al.* 1999). Since the Baltic Sea is separated from the North Sea by the narrow Kattegat and Skaggerak, Yurick and Gaskin (1988) initially suggested that there was a separate stock there. The original population size was unknown. But from historical records of the annual hunt, it is evident that the species was once very common (IWC 1995, Kinze 1995).

2.5.2 Exploitation of porpoises

The history of exploitaton

Slijper (1962) recorded the early history of porpoise exploitation. Porpoises have been caught throughout the ages wherever they approached the shore. Sometimes they were caught sporadically, and at other times so regularly that it could be called an industry. This happened in the eleventh century, and the oil was used for burning and the meat for human consumption. A fishery regularly occurred all along the coast and at the mouth of the Seine (Evans and Scanlan 1989).

Porpoise meat was in fact considered a great delicacy at the time, and a chronicle from the year 1426 reports that Henry VI of England was very fond of it. Slijper also reports that during the Coronation Dinner of his successor, Henry VII, it was served up as various guises, both as main course and also in pies. The Court continued to enjoy the meat until late in the seventeenth century (Slijper 1962).

Hunting for porpoises was recorded in the Shetland Islands (Fenton 1976 *cited* in Hughes 1998). In 1734, Fetlor had four 'pellock' boats (pellock means porpoise which is probably derived from the old Scots word 'peloka') involved in fishing for porpoises. The exact methods used are not specified although it is possible that the animals were herded, as well as shot. The Orcadians, like the Shetlanders, were involved with drive fisheries (Hughes 1998).

Porpoises used to make seasonal migrations from the North Sea into the Baltic in the spring and out again in late autumn and winter (Lockyer and Kinze 1999). For centuries, considerable numbers of porpoises were caught in a drive fishery and most of the data was obtained from the taxation of the porpoise catch. Porpoises provided food for the inhabitants of Middlefart, a small Danish town on Fyn, since the sixteenth century (Slijper 1962). However, when the oil market dropped, regular catches ceased, and in 1892 the whole industry on Fyn collapsed, though since then it has been revived on occasion, particularly during the first and second World Wars.

Berggren (1994) described direct takes of porpoises in Swedish waters during the nineteenth century. Large numbers of porpoises were driven into shallow waters, enclosed by nets and pulled ashore. Kinze (1995) reported that 47,432 porpoises were taken by the Little Belt Station alone during 1827-1892. The catches increased in the 1880's and this may have caused the decline of the Baltic stock.

More recent direct takes of harbour porpoises are known from the Faroe Islands (Larsen 1995). The annual catch averaged between 10-20 animals and it is likely that porpoises are still taken occasionally.

The porpoise has been hunted for food in Greenland for centuries, perhaps millennia (Lockyer *et al.* 2001). Nowadays harbour porpoises are taken primarily in a directed fishery by Inuit hunters and fishermen from West Greenland settlements, and usually shot from small dinghies. The reported catches have remained high (500-1000 animals per year) and have perhaps even increased during this century (Teilmann and Dietz 1998). Slijper claimed that in the Netherlands, many people ate porpoise meat during the war years and that in Belgium and France, porpoise meat was sold regularly (Slijper 1962).

Hence porpoises are exploited directly for a variety of products, and indirectly as bycatch which forms the main subject matter of this thesis.

Conclusion

It can be seen from this brief review that although there are many biological parameters that are known, there are also equally many that are still unknown for the North Sea porpoise. Data from strandings and sightings have provided some insight. However, neither the exact stock structure nor the distribution or dispersal is well understood. Since some of these parameters are necessary to estimate the bycatch levels, it may be difficult to estimate the impact of bycatch on this population.

Chapter 3

Methodology to assess Bycatch

> *Now and then, it is not to be denied, the fishermen, with a repugnance for the interviewer which they share with the same in higher stations of life, find a pleasure in willfully misleading official inquisitors, but as one who mixes with them as much, as most unofficial landsmen, I do not hesitate to describe them as generally obliging and accurate when information is sought in the right way.*
>
> *Aflalo, 1904*

How can one estimate bycatch? Hall's (1996) approach to the bycatch problem was to break up bycatch into different components, such as by the spatial pattern of bycatch rates, by the temporal stratification, by the level of control (controllable or uncontrollable), by the frequency of occurrences (rare or common), by the degree of predictability (predictable or unpredictable), by the ecological origin of the bycatch (associated species or random encounters), by the level and type of impact, by legal or economic considerations.

In this thesis I use data from interviews, data from observer programmes and fisheries data for the specific objective of obtaining bycatch levels. Here, in this chapter I present a partial review of the existing types of methods to assess bycatch. Bycatch can be assessed directly by systematic surveys such as observer programmes, dockside monitoring, interviews or indirectly by observations of stranded animals or strandings (Donovan and Bjørge 1995).

I also use fisheries data to identify the spatial pattern and the high-risk or predictability of bycatch. Then, in order to determine whether bycatch is a problem in the North Sea, absolute porpoise abundance must be available for comparison. In addition, I briefly describe other survey designs, transect methods, relative indices of abundance, incidental sightings, volunteer programmes and ships of opportunity. Finally a synthesis of the best currently available techniques used to estimate bycatch levels is presented.

3.1 DIFFERENT METHODS TO ESTIMATE BYCATCH

3.1.1 OBSERVER PROGRAMMES

The most reliable method is an observer programme, incorporating a statistical sampling design to estimate bycatch by the whole fleet throughout the season (Donovan and Bjørge 1995). In general, only a sample of the fishing fleet can be observed, so techniques such as ratio estimators have to be used. Three factors must be considered when using observer data: 1) is the sample representative of the whole fleet with respect to season and area, 2) are all bycaught animals recorded, and 3) what is the drop out rate both at and under the water surface (See Equation 2 in Chapter 1). A further advantage of observer programmes is that other types of data not readily available can also be collected, such as the precise characteristics of a fishery and other bycaught species (Donovan and Bjørge, 1995). Donovan and Bjørge (*ibid)* emphasize that all sampling techniques require accurate total effort estimates in order to extrapolate the measured bycatch rate of observed trips to the total fleet. In the Gulf of Maine and Bay of Fundy, annual observer programmes have existed since 1990 (Donovan and Bjørge 1995, Bravington and Bisack 1996). Greenland also had an observer programme (Teilmann and Dietz 1995) as well as Sweden (Berggren 1994) and Denmark (Teilmann 1995).

In Alaska, an observer programme on large trawlers is directly funded by industry as a condition of fishing (Crowder and Murawski 1998). In the UK, an observer programme was initiated in 1996 to monitor the porpoise bycatch of the gillnet fleet. Although the results of observer programmes depend on the accuracy of being a representative sample size of the fleet, allocation of effort was determined on the basis of expedience (Northridge and Hammond 1999). This may not make the extrapolations representative of the whole fishery. More detail will be provided in Chapter 7. In a complex fishery, composed of different gear types and different target species, it is very difficult to sample representatively. Each main fishery must be observed at least once during the fishing season, in order to extrapolate afterwards. A team of six independent observers were used in the UK. The team may have been too small in 1996 to cover all types of fisheries adequately. However, the UK observer programme is continuing in order to include other gear types (Northridge *pers. comm.*).

Observer programmes can be an efficient method in order to obtain bycatch data, however, they are very expensive to implement. In cases where observer programmes are not possible, alternative solutions to examine bycatch need to be explored such as, placing observers onboard fishery patrol vessels, or observing from land based vantage points (Donovan and Bjørge 1995).

3.1.2 Dockside monitoring

Dockside monitoring or harbour inspection is another method used. This was done in the Bay of Biscay by Lens (1995) whereby fishermen were monitored as they landed their catches. It is however a method not commonly used since in order to be effective every small port has to be monitored. Systematic surveys of skippers or crews have been tried in a number of countries. Questionnaires were sent out to either all or a sample of fishermen in a region (Northridge 1995, 1996). This has the advantage of reaching a higher proportion of fishermen, but the response rates in such mail out surveys have usually been poor. Fontaine *et al.* (1994) obtained a response rate of 26%, and obtained minimum catch estimates with seasonal and regional differences. Bjørge *et al.* (1991) contacted all 580 fishermen licensed to fish for salmon with driftnets in order to make his estimates.

3.1.3 Examination of stranded animals

Another technique to document bycatch is to examine stranded porpoises. Physical evidence of entanglement in fishing gear is weighed according to a set protocol. In Denmark a data base of stranded and bycaught specimens which have been collected and analysed (Lockyer and Kinze 1999) provides the baseline for assessment purposes.

A set protocol (in the US) is used by personnel in regional networks to assess the carcasses of animals. Evidence of bycatch includes the impressions of net material in the epidermis, thin lacerations on appendages and mutilation including dismemberment and longitudinal cuts along the ventral abdomen into the body cavity (Cox *et al.* 1998). After initial examination, and measurement of standard morphometric data, the carcasses are examined in the laboratory. A similar programme exists in the UK (Jepson *pers. comm.*). The problem is that not all carcasses can be evaluated for evidence of entanglement due to advanced decomposition. Haley and Read 1993, *cited* in Cox *et al.* (1998) now have trained strandings network personnel. The process of transporting freezing and thawing carcasses may obscure subtle evidence of entanglement, so it is important for experienced observers to examine fresh carcasses. Effective handling of stranding data therefore depends heavily on a reliable network and trained personnel.

3.1.4 Bounties

Skora *et al.* (1988) reported in Donovan and Bjørge (1995) that bounties were paid to fishermen in Poland. In the 1920's, from tens to hundreds of bounty payments for porpoise heads were made each year. This also occurred in other Baltic countries, and although the historic record is incomplete, these payments track the development of incidental catch of porpoises.

Fishermen in the Gulf of St. Lawrence were paid $40 per carcass in a retrieval programme in 1989 (Fontaine *et al.* 1994). The payments were stopped before the fishing season was over, due to space limitations after 148 specimens were stored frozen.

3.1.5 Fishermen's interviews

I used interviews as part of the methodology. The information amassed through the lifetime of individual fishermen by observation is of a scale and quality not normally accessible to scientific surveys (Sarda and Maynou 1998). Obtaining such traditional ecological information and rendering it scientifically useful is one step in understanding the complex functioning of marine ecosystems and fisheries. Opportunistic dockside interviews have the advantage that they are relatively cheap and can be done quickly (Northridge 1995). Interviews can be made by telephone (Lien *et al.* 1994), by mail, or in person on the dockside. In this study I started with dockside interviews.

'Fishermen must be included to a greater degree in documenting, studying and solving the problem of porpoise entanglement. They should be consulted for their perceptions of the problem and how it can be solved' (Jefferson and Curry 1994). Interviews, when done properly can also serve as a network for any future collaboration with fishermen. Data from interviews can be verified by using a type of triangulation method. Lien *et al.* (1994) reported that the accuracy could be tested by phone interviews, logbooks, recall of port catches as well as payment for samples.

3.1.6 COOPERATIVE DATA GATHERING

Another method to estimate bycatch is to request the fishermen to collect bycatch data themselves. This would be analogous to the 'Sentinel Fishery' now operating off Newfoundland, where ex-cod fishermen are fishing the only legally permitted fish and tagging fish for scientists (Kurlansky 1998). Fishermen can collect data from their community for the scientists. This was also achieved in France by Collet (1995). Sequiera (1995) estimated bycatch in Portugal from reports generated by fishermen. The National Fisheries Conservation Center (US) recommended the usefulness of fisherman-gathered data (NFCC 1999).

3.1.7 MATHEMATICAL MODELS

Population modelling can also contribute to bycatch estimation. The problem is the lack of empirical data but the population's resistance or resilience can be estimated from varying the mortality levels. This will be handled in more detail in Chapter 4. In a recent paper, Caswell *et al.* (1998) developed an age structured model for harbour porpoises using known life history parameters obtained from a number of mammals such as the tapir. Then using Monte Carlo techniques, they estimated variations in model parameters to explicitly take into account uncertainty in estimates of population size and bycatch. Another model specifically designed for the North Sea porpoise was recently developed and will be explained in detail in Chapter 4.

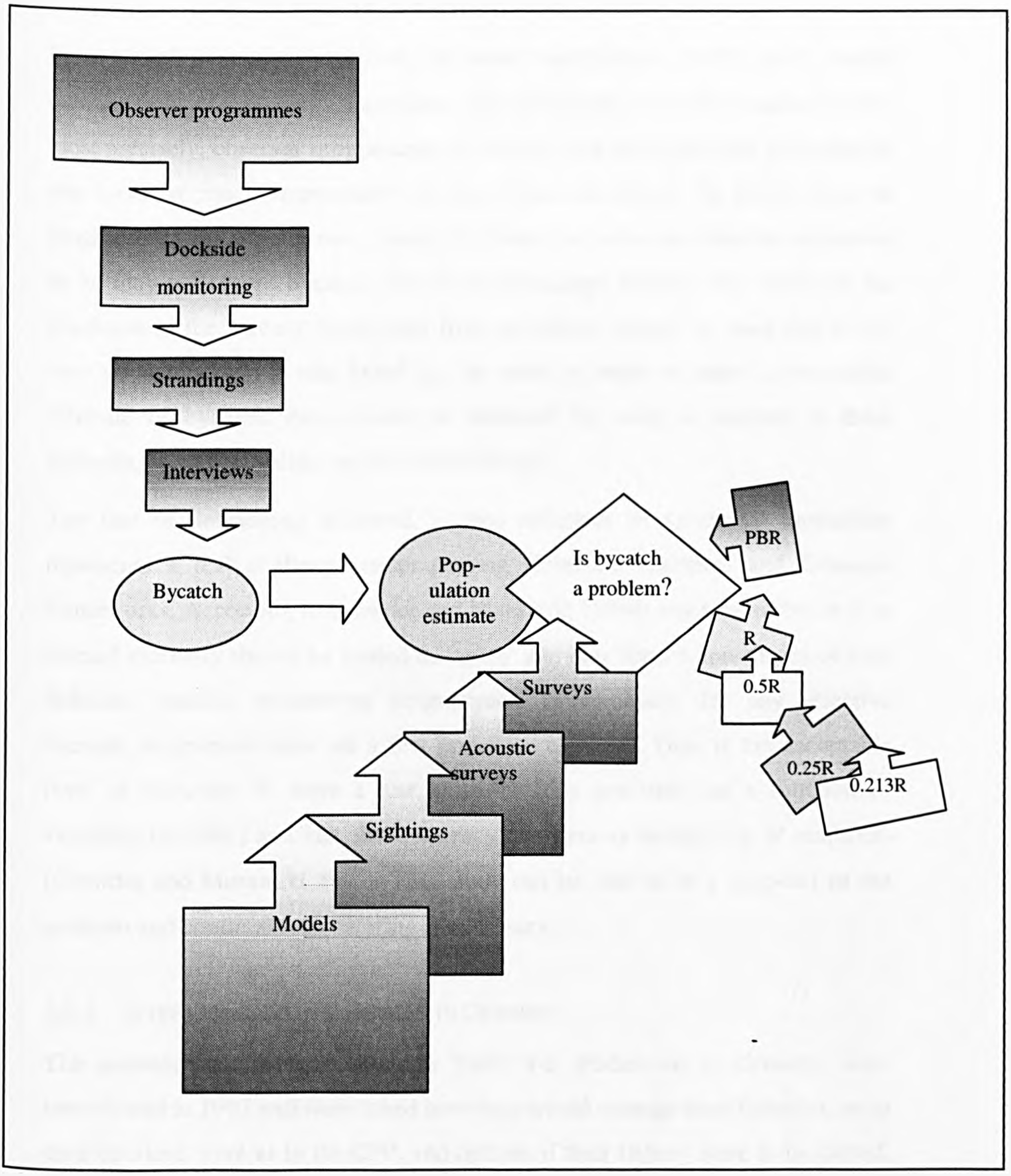

Figure 3-1. Methods to estimate bycatch (PBR is the Potential Biological Removals and R is the potential rate of increase)

3.2 Summary of methods used in this study

In order of increasing precision, Donovan and Bjørge (1995) have ranked examinations of strandings, interviews with fishermen, dockside monitoring and most precisely, observer programmes. However, data from observer programmes can have as much imprecision as data from strandings. In some observer programmes, the skipper may change his behaviour when an observer is present or he may not record bycatch. Data from strandings depend very much on the condition of the carcass. Some data from strandings cannot be used due to the very poor condition it was found in. In order to begin to make a reasonable estimate of bycatch, data should be obtained by using a number of these methods, as well as validating this methodology.

The fact of developing unbiased, precise estimates of incidental mortalities represents a real challenge encompassing technical, logistical and financial frameworks. According to Crowder and Murawski (1998) any type of bycatch or discard mortality should be treated as 'catch' and thus form a constituent of core fisheries statistics monitoring programmes. In summary, for any effective bycatch programme there are a few important elements. One, is the acceptable level of accuracy (is there a low bias). Next is precision (as a function of sampling intensity) and last, the frequency (continuous monitoring or snapshot) (Crowder and Murawski 1998). This study can be said to be a snapshot of the problem and continuous monitoring is necessary.

3.2.1 Interviews with fishermen in Grimsby

The questionnaire used is given in Table 3-1. Fishermen in Grimsby were interviewed in 1997 and were asked how they would manage their fisheries, what their opinions were as to the CFP, and options if their fishery were to be closed. No fisherman willingly catches porpoises in their nets. The capture of a porpoise is a nuisance and slows the fishing operation. Most fishermen are very aware of the bycatch problem. But fishing is their livelihood and with any 'hunting activity' there is always some 'waste'.

3.2.2 Interviews with fishermen in Denmark

Interviews were held with Danish gillnet skippers in August 1998. Each interview was held in person with a translator using the same questionnaire (Table 3-3). Some interviews were recorded but due to the opportunistic nature of the study, many interviews were only recorded on paper after translation (in Hvide Sande and Thorsminde). The interviews were based on the questionnaire but were essentially face to face and open-ended. Some interviews took 15 minutes but most averaged at least an hour. Many fishermen are aware of the problem and agreed that porpoise bycatch was a real problem, however, they did stress that many times they had no bycatch whatsoever. The peak times of bycatch were during the summer season from June, July and August.

3.2.3 Reliability

The reliability of the answers could be tested by check-back questions. A team composed of a biologist and translator asked questions in Danish and in English if the fisherman felt he was fluent enough to speak in English. Only a few of the Danish fishermen were unwilling to speak in English although they said that they understood. They were asked to estimate the total number of bycaught porpoises per year and then, on how many trips per year these porpoises were present, as well as the maximum porpoises that they had ever caught.

In situ interviews were conducted with the skipper, on their vessels, or at the dockside. The skippers were usually alone, or when interviewed, they would be asked the questions when they were alone. On two occasions, when the crew and other skippers were present, rather than positively reinforcing the answers, it was felt that the skippers were both nervous and reticent to answer in the company of the crew.

Interview methodology and triangulation

Most skippers were willing to discuss mismanagement in Brussels and this was my interview technique (adapted from Mikkelsen 1995). My technique was a mixture of semi-structured questions and open-ended discussion. I approached each skipper and extracted information about the CFP. Once the initial confidence and trust were established, then more controversial questions about bycatch were asked. The bycatch problem is a sensitive subject to discuss.

The UK interviews took place on the dockside, two inside the local pub and two at the skipper's home. All interviews in Denmark took place on the dock with one notable exception when the skipper invited the interview team to come to his home. This skipper did not wish to be seen being interviewed in front of his fellow skippers at the dockside but then at his home, he was one of the most enthusiastic and talkative persons. The team spent two hours with him. He spoke about the problems of bycatch as well as fisheries management, and invited the team to fish with him. He said he knew exactly when and where there were porpoises and how bycatch occurs. His estimate per year was also the highest estimate of all. However, the next day the same skipper claimed that his estimates were too high and to ignore whatever he had said earlier. He then was in contact per radio with his fellow skippers. In a small port everyone knows everyone else and so this became common knowledge. His estimate however was treated like the other estimates.

3.2.4 Validation methods for interviews

There are many ways to validate the interview results. The results from the semi-structured interviews I used could be verified with logbook results to estimate fishing location. One skipper showed me his exact fuel consumption and associated papers. Bycatch information, although required by EU law, is impossible to verify from the interviews alone. Follow up telephone calls for the next season as well as continuous observer programmes or dockside monitoring could be ways to check.

3.3 Methods to estimate porpoise abundance

3.3.1 Absolute abundance estimates

One of the most commonly used methods to estimate abundance is distance sampling, using line transects (Garner *et al.* 1999). In brief, the methodology involves the surveying or counting a set of lines from a suitable platform, either a ship or aeroplane, within a given survey area. The only abundance survey held in the North Sea was the SCANS (Small Cetaceans North Sea and Baltic) held in 1994 (Hammond *et al.* 1995).

The line transect method

The line transect method is originally derived from strip transects which is a common technique used for stationary objects, trees for example, whereby a series of strips of a given width are selected at random and all objects within the strip are counted. Density is then calculated as the total number of objects sighted divided by the area surveyed and total abundance is estimated as the product of density multiplied by the total area. A line transect survey is analogous to a strip transect except that not all objects within the strip transect are seen and the width of the strip is not known (Polacheck 1989). In general, density, D can be estimated from

$$D=n/2wL$$

Where n is the number of objects sighted within the distance w, of the trackline and L is the total length of the vessel's track line.

Visual surveys

In the case of harbour porpoises, porpoises are counted by observers at sea or on land. Line transect theory attempts to account for undetected animals. This assumption is based on the fact that the probability of detecting animals on the surface decreases with increasing distance from the observer. All animals directly on the trackline are assumed to be sighted. With this assumption, and the observed distribution of sighting distance, estimates can be made of the fraction of all animals at any distance from the vessel represented by those seen. The relationship between the probability of detecting an animal and its distance from an observer is called the 'detection function' or g(x).

According to Polacheck (1989), there are many problems of applying line transect theory to marine mammals. The actual distance to the animals must be known (not just estimated) and animals are continuously moving on and off the line. The other major problem is that animals beneath the surface cannot be seen. Therefore the probability of detecting an animal at a given distance is not constant but will vary with observers and weather (wave, or Beaufort sea state).

Since the detection function is central to the distance sampling concept, it must be ensured that all objects on the line are detected with certainty so that g(0)=1. This is not always the case with porpoises. Another assumption is that the objects do not move in response to the observer before being detected and that perpendicular distance data are accurate. However, porpoises are known to avoid ships (Gaskin 1977, Kraus *et al.* 1983, Polacheck and Thorpe 1990).

Additionally, porpoises are the more difficult cetaceans to study. They are small, difficult to see, occur singly or in small groups, and do not breach (Amundin and Amundin 1973 *cited* in Hughes 1998). In fact many porpoises change direction when a vessel approaches. In order to correct for the detection function, Palka (1995b) in the SCANS survey used two teams of observers of porpoises from a single ship, but from different platforms, which were visually and audibly separated. Animals detected by each platform were tracked for a number of sightings to enable animals detected by both teams to be identified for the analysis. Sightings recorded by both teams (duplicates) were then used to calculate an abundance estimate corrected for g(0).

In SCANS, the survey design was improved further by estimating g(0) and a correction factor for responsive movements of porpoise before they were detected (Hughes 1998). The exact statistical theory is available in Hammond *et al.* 1995. The two observer teams surveyed the water. The first team scanned with the naked eye and the second team searched ahead with binoculars.

Two aircraft also flew in tandem, one behind the other along the same track line. This allowed g(0) to be estimated from duplicates determined on a probabilistic basis (Donovan and Bjørge 1995). These methods provided an abundance estimate of porpoises in July 1994.

3.3.2 Relative abundance estimates

Many land-based surveys, use systematic watches from land or sea, or opportunistic vessels to estimates relative abundance for harbour porpoises.

These are good methods to estimate local trends over time and distribution rather than total numbers.

Tagging methods

Read and co-workers have successfully tagged a number of porpoises in the Bay of Fundy. This is possible because the herring weirs are large traps, which also catch porpoises, and they are trapped alive unlike in gillnets, where entanglement usually causes death. The programme is the result of local co-operation with fishermen since now fishermen will contact the scientists when there is a porpoise in the weir (Read 1999a). Read using small electronic tags that transmit data to orbiting satellites, was able to track the movements of porpoises. Sixteen porpoises have been tagged and studied for over six months and data is still being collected. This is mainly information on migration, dispersal and behaviour. At this early stage the data cannot be used for abundance estimates. Over time with increased tagging success, there may be further developments as more porpoises are tagged.

Other programmes

In the UK, the SWF (Sea Watch Foundation) and the JNCC Sea Birds at Sea Team (SAST), are both volunteer organizations which provide effort related data in terms of length of observer time or number of kilometres travelled.

The Sea Watch Foundation, established in 1992, now contains thirty-six regional groups throughout the UK. Regional coordinators are responsible for collecting all cetacean observations made by a network of volunteers. The data are recorded and separated by opportunistic sightings (not effort related) and systematic sightings (effort related).

The SAST was established with the Joint Nature Conservation Committee, JNCC in 1979 with the primary objective of mapping the offshore distribution of seabirds around the British Isles. This database is the largest comprehensive effort related sightings database. Many of the sightings made by SAST are made onboard platforms of opportunities, such as ferries and oilrig supply vessels. Sightings of cetaceans are collected during the survey used for bird populations, by scanning the line transect.

Another survey using dedicated line transect survey and distance sampling techniques and was made in the Atlantic Frontier area, west of Scotland in 1998. NASS-87 and NASS-89 were surveys restricted to the continental shelf and the focus was the porpoise and other small cetaceans. Both surveys were supported by Greenpeace and the Whale and Dolphin Conservation Society (WDCS). NASS-87 covered waters west of Britain, including the area west of the Hebrides and north west Shetland during June and July and NASS 89 covered Icelandic waters during August. Both studies violated the g(0) assumption and density per species could not be calculated. Due to the small sample sizes, caused by weather problems (17/33 days were used) absolute abundance could not be generated (Greenpeace 1998). Data from the survey however, could only be used as a relative abundance index in these waters.

3.3.3 SHIPBOARD SIGHTINGS

A number of studies have used incidental sightings or simple observations as the basis of study. For example Pierpoint *et al.* (1998) recorded observer effort using a simple index of 'presence' or 'absence' during dedicated observation periods in Wales. Data were collected to investigate porpoise ecology as well as to allow comparisons to be made between sites and over time. However, photographic evidence of re-sightings of a single well-marked animal as well as the results of radio tracking studies elsewhere (Gaskin *et al.* 1985) suggest that some animals may remain within one area or return to preferred areas at least in the short term. Evans (1997) reported that one well-marked animal was re-sighted at the same site in Shetland annually, from 1992-1994. Sightings data must be carefully interpreted and can only be used as a relative abundance index.

Shipboard sighting are sightings obtained from a ship. These ships may be chartered or contracted ships as well as ferries, which collect data voluntarily, and are called platforms of opportunity.

3.3.4 ACOUSTIC SURVEYS

Since harbour porpoises' vocalisation comprise a narrow band of ultrasonic pulses around 130 kHz, they can readily be detected in the field using a new development or hydro-phone (Chappell and Gordon 1994, Chappell *et al.* 1995). An automated harbour porpoise click detector was developed by IFAW (International Fund for Animal Welfare) in 1992, and is now undergoing further development. At present the detector can only provide presence and absence data (Chappell e*t al.* 1996). One advantage of acoustic surveys is that they can be conducted in all weather conditions, 24 hours a day from any vessel (Donovan and Bjørge 1995).

3.4 WHEN IS BYCATCH A PROBLEM?

Once the bycatch levels have been assessed, then dividing the total bycatch of about 250 animals for example, by a population size of about 5000 yields an incidental mortality rate of approximately 5% per year. Is this a problem? It would be a cause of concern only if it exceeded the potential rate of increase r or R. The potential rate of increase can be calculated using age-specific levels of natural mortality and reproductive rates. The problem is obtaining an estimate for any of these rates. Often an equation is used, such as Lotka's characteristic integral equation, and estimates are calculated for the whole population (Lotka 1939). Woodley and Read (1991) for example used Lotka's equation and empirical data from the Bay of Fundy and Gulf of Maine porpoises. A number of authors tried to estimate the level from demographic models of different species (Table 3-1) and the following estimates were made of the annual rate of increase for porpoises.

Estimated R	References
5%	Woodley and Read (1991)
4-10%	Palka (1994)
5-10%	Caswell *et al.* (1998)
9.5%	Barlow and Boveng (1991)
4%	Working group ASCOBANS (1999)

Table 3-1. Estimates of potential rate of increase R

Hence, the rate can be between 4 and 10%. Most authors stated that 10% was too high and that 4-5% was a reasonable estimate. ASCOBANS decided in 1999 that for harbour porpoises, and the purpose of bycatch calculations a rate of 4% was to be used (Read 1999b). If R is assumed to equal 4% then any incidental mortality cannot be greater than 2%. This is a conservative estimate and is now adopted by the ASCOBANS working group for the North Sea porpoise. Therefore, any incidental mortality should be maintained below the critical potential rate of increase. In 1991, the IWC (International Whaling Commission) recommended that the incidental mortality should not exceed half of the potential rate of increase (IWC 1991 *cited* in Caswell *et al.* 1998). In 1995, it was decided that a more cautious approach was necessary. Afterwards, in applying the MMPA, or the Marine Mammal Protection Act and adapting the Potential Biological Removal or PBR an even more cautious level to bycatch was adopted (see Table 3-2) that of 0.213 R (Caswell *et al.* 1998).

Scientific organisation	Date	Level of R
IWC	1991	0.5R
IWC	1995	0.25R
MMPA using PBR	1996	0.213R

Table 3-2. Different levels of PBR (Potential Biological Removal) used by management. R is the potential rate of increase, and MMPA is the US Marine Mammal Protection Act and IWC is the International Whaling Commission.

Conclusion

A number of methods can be used in order to obtain bycatch estimates. In this study, a combination of interview and observer methodology was used. The Grimsby observer data was evaluated in order to obtain an estimate for the bycatch for 1997 and 1998. Fishermen from the Danish fleet were also interviewed. Since 1992, Denmark has established annual observer programmes (Vinther 1999). In order to obtain the best results, a combination of methods should be used. The initial sampling strategy is also very important for the final extrapolation of bycatch rates for the whole fleet.

There is general agreement in advisory bodies that a bycatch of harbour porpoises which exceeds 2% of the population size is not sustainable (Bravington *et al.* 1997). The IWC estimated R at 4% and this is a conservative estimation. There is some evidence that bycatch rates in the North Sea currently exceed that value (Harwood 1999a).

However, the estimates of bycatch are incomplete in the North Sea. The problem with observer programmes is that the presence of the observer onboard can alter the fishing behaviour of a skipper (Read 199b). Also, observers cannot be placed on the small vessels where the mere presence of another person would encumber normal fishing operation. Accordingly, many small vessels are not observed and this could underestimate the results for the whole fleet (Bravington *et al.* 1997).

For future bycatch studies, more flexibility in methodology as well as in depth information would enhance the validity of the results. It has also been recommended that all gear be analysed and at least annual estimates of bycatch be made available (ASCOBANS 2000a).

Name : (optional)
Gear:
Date:
Place:

1.

How many years of fishing do you have?	

2.

What is the main species that you are fishing?	

3.

How long do you set your nets?	

4.

Do you agree with the CFP? How would you like to manage the fishery?	

5.

Do you have any bycatch? Seals? Dolphins? Porpoises? Birds?	

6.

If you catch porpoises, how **many** porpoises do you catch on a trip?	

7.

If you catch porpoises, on how many **trips** a year do you catch them?	

(8.)

Do you differentiate between dolphins and porpoises? Are these alive? Can you release them?	

(9.)

Are you fishing on wrecks? How do you separate ownership on the wrecks?	

(10.)

What else would you do if this fishery were to be closed?	

Table 3-3. Questionnaire for fishermen

Chapter 4

Virtual Porpoise Analysis

> *I am never content until I have constructed a mechanical model of the subject I am studying. If I succeed in making a model, I understand: otherwise I do not.*
>
> *Lord Kelvin*

In this chapter I analyse the effects of bycatch on a theoretical population by using a population model, PorpSim, specifically designed for porpoises in the North Sea. The results of this model, can be used as an exploratory tool of bycatch limits rather than being predictive (Nieder and McGlade 1999). I also discuss and compare other models that are used to estimate bycatch.

Fisheries scientists use a variety of models to estimate population size, including virtual population analysis (VPA), sequential population analysis (SPA), and cohort analysis (CA). The different models all have their strengths and weaknesses (McGlade 1989, Allen and McGlade 1986, 1987, McGlade and Shepherd 1992, Hilborn and Walters 1992, Clark 1990) depending on the parameters they aim to estimate and the techniques used to solve them. The data required for assessments are total landings, fishing effort, independent population biomass estimates from research surveys, specific weights, age specific lengths, fecundity parameters and larval survey data. These are the minimum data requirements in order to be able to estimate the total fish population abundance and then to predict yield.

Porpoises are much more difficult to assess compared to fish. This is primarily because of the paucity of data, lack of regular sampling or observer schemes. For example, the only survey for the North Sea was held in 1994 (Hammond *et al.* 1995). This means that population abundance in these areas must be validated against this one point, which is statistically impossible (J. Cushing, Dept. Mathematics, University of Arizona *pers. comm.*). Strandings data can provide opportunistic data but seldom provide enough for parameterisation. Sightings provide valuable presence/absence information. Some ageing data from teeth of stranded or bycaught animals are available but no regular age sampling programs exist. Bycatch is even more difficult to estimate.

4.1 RATIONALE FOR MODELLING PORPOISE POPULATIONS

It is important to understand what the main controlling feature of the population is even before estimating bycatch and to be able to predict a likely outcome in case of any change in the parameters. There are difficulties in studying marine mammal populations, such as the long life cycles, poor replicability, little and often inaccessible biological data, and extremely costly surveys. If science is a process for learning about nature, in which competing ideas about how the world works are measured against observations (Feynman 1985) then we are still in the very early part of the process about porpoise populations and any ideas as to how the population works can be acceptable since we know so little.

Despite this, the construction (see Lord Kelvin's quotation) of a model often forces the researchers to think about processes that were initially ignored. The formulation leads to the identification of parameters that must be measured and often helps crystallise thinking about processes (Hilborn and Mangel 1997). Models help us to understand which are the important parameters and processes. In any model, the parameters should then be tested or validated.

This is possible in the theoretical world of pure science, however, advice is often needed in the real world for managers in order to act to protect a species which may be threatened or endangered, such as the porpoise in the North Sea. Then the statistics such as population size, mortality rates, rates of increase, extinction rates are computed from data that are uncertain, sometimes extremely so (Caswell *et al.* 1998). In these cases, it may be the only method to apply.

Types of models

In building any biological model, life history parameters of the species is required. Some data sets are available for North Sea porpoises (fecundity, sexual maturity, reproductive rate, and maximum longevity).

The logistic equation is the most common model but the list also includes Potential Biological Removal (PBR), Rate of Increase (ROI) and Population Viability Analysis (PVA).

4.1.1 THE LOGISTIC MODEL

The basic mathematical equation used in the PorpSim model is the logistic growth equation. This was modelled after the Verhulst-Pearl equation, and it estimates population parameters based on a growth rate. From a low starting value, the population initially increases exponentially and then levels out to a constant carrying capacity or K. The increase of population size over time follows a sigmoid or S-shaped curve. The growth rate of the population is r (K/4) when the population reaches half the carrying capacity (Brown and Rothery 1993), where r is the per capita rate of increase and where the slope is greatest i.e. the point where the population growth rate is greatest. Most mammal populations comply with this model, and consequently it is likely to be a good empirical description of the porpoise population.

Resilience to bycatch

In the absence of bycatch, marine mammal populations naturally fluctuate about a natural capacity determined by the availability of food, suitable habitat and breeding area (Bravington *et al.* 1997). Adult and juvenile mortality is on average balanced by reproductive mortality rates, but if there are changes in food availability there may be imbalances as the carrying capacity fluctuates. When bycatch begins, total numbers are reduced while total resources stay the same, so per capita resources increase. This may lead to a density dependent response, such as earlier maturity, shorter birth intervals and higher juvenile survival. The current biological parameters of porpoises can therefore be seen as the result of adaptations to increased bycatch mortality. If the fecundity at age changes, it can be due to the response to the stress of increased mortality.

However, since both the environment and the natural resources that the porpoise feeds on in the North Sea are changing, the situation is very complex since then it becomes impossible to discern simple cause and effect.

4.1.2 POTENTIAL BIOLOGICAL REMOVAL (PBR)

> *Marine mammals should not be permitted to diminish beyond the point at which they cease to be a significant functioning element in the ecosystem of which they are a part and, consistent with this major objective, they should not be permitted to diminish below their optimum sustainable population.*
>
> *MMPA, 1994*

The PBR, introduced in Chapter 3, is a straightforward calculation using only three variables: the product of a minimum abundance estimate and two other estimates. The US has based its marine mammal management scheme on detecting a mortality limit. Any mortality above this limit would initiate management actions beyond basic monitoring (Wade 1998). It is understood that such a limit has to be unique and scaled to each population and therefore must be based on mortality relative to population size, not on an absolute level of mortality. For example, it is unlikely that the kill of a single dolphin would have any significance to a population estimated at 200,000. However, the kill of a single individual may be of importance to very small population such as the right whale (*Eubalaena glacialis*) where only 295 animals are currently estimated to be alive (Wade 1998).

The origin of this management scheme was based on the Marine Mammal Protection Act or MMPA. In 1994, the amendment to the MMPA authorised the state to provide protection of marine mammals and required a description and classification of the stock (Barlow *et al.* 1995).

The primary goal of the MMPA is to prevent any marine mammal stock from being reduced below its optimum sustainable population level, and to restore stocks that have been reduced below that level. A stock which has a level of human induced mortality that is likely to cause the stock to be reduced or kept below its optimum sustainable population is classified as 'strategic'.

A marine mammal stock is thus designated as 'strategic' if its levels of direct human-caused mortality (bycatch) exceed the potential biological removal (PBR) level. It is 'threatened' or 'endangered' if it is listed under the Endangered Species Act (1973) (Barlow *et al.* 1995). The consequences of being designated 'strategic' include the formation of a 'take reduction team'. The team, composed of fishermen, environmentalists, state and federal government representatives and scientists is required to develop methods, with an immediate goal of reducing the incidental mortality to levels less than PBR (Wade and Angliss 1997). Every year a stock assessment consisting of a description and classification is made per species. This includes a description of its geographic range, minimum population estimate, a maximum net productivity rate, a description of the population trend, and an estimate of bycatch and serious injury (Barlow *et al.* 1995).

The PBR can thus be described as another method to estimate total mortality. The PBR for instance, for the Gulf of Maine/Bay of Fundy porpoise population is 483. The bycatch or average mortality estimate is 1667 (CV = 0.09). Since bycatch mortalities exceed PBR, the population has recently been classified as a 'strategic stock' (Palka 1998).

Most of these parameters, such as the net productivity and the recovery factor, necessary for the calculations of the model, may be impossible to estimate accurately for porpoises, so informed guesses are usually employed (Wade 1998). The key aim is to be able to detect a decline in abundance caused by fishing mortality or human induced mortality in order to initiate a management response.

4.1.3 Rate of increase (ROI)

Since porpoises are subject to incidental mortality from entanglement in gillnets it is important to estimate whether or not this incidental mortality is a threat to the population as a whole. This depends on the magnitude relative to the potential rate of increase (i.e. the population growth rate at low densities). Incidental mortalities that exceed the potential rate of increase will, in the long run drive a population to extinction (Caswell *et al.* 1998).

The absolute upper limit for a sustainable per capita removal rate, is therefore equal to the maximum potential per capita or ROI, of a population usually expressed as an annual percentage. This can be estimated by studying life history parameters such as adult natural mortality rate, age at maturity, interbirth interval, juvenile survival etc. or by using certain parameters of other species with better studied parameters with similar life histories. If removal rates differ by sex or age, this may also affect a population's ability to withstand a particular removal rate although there is no conclusive evidence of this for the harbour porpoise.

4.1.4 Population Viability Analysis (PVA)

First developed more than 20 years ago, PVA has become 'conservation biology's greatest scientific achievement' (Shaffer 1999). The technique focuses on the fate of a population and what factors can determine or alter that fate. In its most common form, PVA combines a stochastic model of population dynamics with field data on a species and its habitat, from birth and death rates to the frequency of natural disasters, to predict how long a population will persist under given circumstances. Examples of how PVA has been successful include helping to identify measures for boosting grizzly bear populations in Yellowstone National Park (Shaffer 1999). However, PVA is too simplistic, overly demanding of data, error prone, and hard to validate, and the model ignores the genetics problems of small populations (Shaffer 1999). Shaffer examined the PVA and derived the minimum viable population, which he defined as a smallest possible bear population with a 95% probability of surviving 100 years, and determined that the most important factor influencing how long a bear population would survive is the death rate of the adult females. If this is the case with the porpoise population, then adult female porpoises should be protected especially when they are with their young near the Danish coast in the summer.

4.2 THE PROGRAM PORPSIM

I analyse a model which was written by R. Nieder to investigate the effect of bycatches and different dispersal rates on porpoise substocks in the North Sea[1]. It is used here with her permission in order to explore the behaviour of the population on different bycatch levels.

Basic Dynamics

The program runs the following model:

$$N_s^{t+1} = N_s^t + rN_s^t\left(1 - N_s^t / K_s\right) - M_s^t - C_s^t \qquad \textit{Equation 1}$$

where

N_s^t is the abundance for substock *s* at time *t*,

r is the per capita growth rate,

K_s is the carrying capacity of substock *s*,

M_s^t is the overall loss or gain of individuals in substock *s* at time *t* as a result of dispersal and

C_s^t is the bycatch from substock *s* at time *t*.

This is the discrete time logistic model, with the addition of migration and bycatch mortality.

4.2.1 DISPERSAL AND MIGRATION

The term 'dispersal' is defined as the movement of an animal from its natal area to a new area where it lives and reproduces. Dispersal is important in the persistence of populations and species. Environments or habitats change over time, and if an animal or species does not disperse, it has no ability to colonize new area. Dispersal also functions to prevent inbreeding and provides new genetic material for other subpopulations[2]. Dispersal is important but it is also one of the more difficult

[1] See Annex 1 for detailed explanation

[2] Daniel Edge, Department of Fisheries and Wildlife, Oregon State University at http://www.orst.edu

parameters to study. Dispersal usually occurs about the time an animal becomes an adult and it is often sex biased. Male porpoises for example disperse more than females.

There are four models of increasing complexity for calculating dispersal rates between the substocks. The first two models are those used by Taylor (1995); the second pair were developed for this program. Dispersal patterns matter and in any management context it is very important to identify these patterns.

Since little is known about the actual patterns, theoretical mechanisms are included to determine the potential importance. Migration (M) is arrived at by $M_s^t = D_s^t N_s^t$.

Model 1

This is the most basic model. It assumes that each individual has a fixed probability of dispersing (D). If D=0.01 then any individual has a 1% chance of dispersing per unit time (Taylor 1995).

Model 2

This model assumes that the probability of dispersal depends upon the density of the 'home' population (Equation 2).

$$D_s^t = D\frac{N_s^t}{K_s}$$ *Equation 2*

where

D_s^t is the dispersal rate for substock s
D is the maximum dispersal rate
N_s^t is the abundance for substock s at time t
K_s is the carrying capacity for substock s

The maximum dispersal rate (D) is achieved as the substock approaches K (Taylor 1995).

Model 3

This is a modification of the third model as used by Taylor (1995) and considers the density of the 'target' population in addition to the density of the 'home' population (Equation 3).

$$D^t_{s,j} = DN^t_s \frac{N^t_s}{K_s}\left(1-\frac{N^t_j}{K_j}\right) \qquad \textit{Equation 3}$$

where

$D^t_{s,j}$ is the dispersal rate from substock s to substock j at time t,
N^t_j is the abundance for substock j at time t
K_j is the carrying capacity for substock j
and the other parameters are the same as described previously.

Model 4

This model takes into account the differences in carrying capacity that might occur between substocks (Equation 4).

$$D^t_{s,j} = DN\left(\frac{2K_j}{K_j + K_s}\right) \qquad \textit{Equation 4}$$

where all the parameters are as hitherto described.

Models 3 and 4 generate a matrix of dispersal rates that can be represented as

$$\begin{array}{cccccc} & & & \text{From} & & \\ & \text{substock} & 0 & 1 & \cdots & n \\ & 0 & - & D^t_{0,1} & \cdots & D^t_{0,n} \\ \textit{To} & 1 & D^t_{1,0} & - & \cdots & D_{1,n} \\ & \vdots & \vdots & \vdots & \ddots & \vdots \\ & n & D^t_{0,n} & D^t_{1,n} & \cdots & - \end{array} \qquad \textit{Equation 5}$$

The application of dispersal rates is more complicated in this multi-substock scenario than used by Taylor (1995). This is mostly because the substocks have very different carrying capacities. For this reason, the first two dispersal models, which do not take into account the density of the target substock, result in the smallest substock increasing in size beyond the carrying capacity (Dispersal 1 and 2 in this program). Dispersal 3 takes into account the density of the target population - as it reaches carrying capacity, the actual dispersal rate from the home substock to the target substock approaches zero. This was adopted in preference to dispersal 3 described by Taylor (1995) because of the differences in substock carrying capacities; her third model which accounts for the density of the target population is:

$$D1 = D\frac{N1}{K1} \qquad \textit{Equation 6}$$

describing 2 substocks,

where

D1 is the dispersal rate of substock 1
D is the maximum dispersal rate
N1 is the abundance of substock 1
K1 is the carrying capacity for substock 1 and

$$D1' = D1\left(Y - \frac{Y-1}{K2}N2\right) \qquad \textit{Equation 7}$$

where

D1' is the maximum dispersal rate of substock 1 (see Equation 6)
D1 is the dispersal rate when target substock is at K
Y is the multiplier of the dispersal rate when the target population is at zero (set to 2)

4.2.2 Calculations from PBR

The bycatch can be determined from calculating the potential biological removal (PBR) for the sum of all the substocks - $\sum_s N'_s$ and then allocating portions of it to the various substocks as a parameter in the parameter file, or allowing the allocation to be calculated according to the relative substock sizes. The PBR is calculated as follows in Equation 8.

$$PBR = N_{\min} r_{mnpl} F_r \qquad \textit{Equation 8}$$

where

$N_{\min}$ is the population estimate that is likely exceeded by the true population size,

r_{mnpl} is the growth rate at maximum net productivity (taken to be r/2 (r from the logistic equation)) also called R_{max}

F_r is a recovery factor.

$N_{\min}$ is initially calculated from the substock size provided in the parameters file and subsequently from the result of the logistic equation. These sources are assumed to provide a value for N_{mean}:

$$N_{\min} = mN_{mean}$$
$$m = e^{z\sqrt{\ln(1+CV^2)}} \qquad \textit{Equation 9}$$

where z = desired percentile from the Z-distribution and CV is the coefficient of variation of abundance estimates.

Results for PBR for the North Sea

The calculations for the North Sea PBR are as follows. I assume that N equals 341,366 animals, for all surveyed blocks in the North Sea (Hammond *et al.* 1995). R_{max} is 0.04 or the value for cetaceans based on theoretical modelling showing that cetacean populations do not grow at rates greater than 4% given the constraints of their reproductive life history (Barlow *et al.* 1995, Taylor *et al.* 2000). The recovery factor is 0.5, assuming the same conditions of recovery as in the US, which accounts for endangered, depleted, threatened, or stocks of unknown status. Then, PBR for the North Sea porpoise is 3414. Any mortality above this level will be too high. Estimates of mortality of incidental capture or bycatch in 1999 are at least 6785 porpoises off Denmark (Vinther 1999). Since these values exceed the PBR, the porpoise stock should be classified as 'threatened' or 'strategic' and protected.

R_{max}=.02	F	PBR	R_{max}=.04	F	PBR	R_{max}=.06	F	PBR	R_{max}=.08	F	PBR
0.01	0.1	341	0.02	0.1	683	0.03	0.1	1024	0.04	0.1	1365
0.01	0.2	683	0.02	0.2	1365	0.03	0.2	2048	0.04	0.2	2731
0.01	0.3	1024	0.02	0.3	2048	0.03	0.3	3072	0.04	0.3	4096
0.01	0.4	1365	0.02	0.4	2731	0.03	0.4	4096	0.04	0.4	5462
0.01	0.5	1707	0.02	0.5	3414	0.03	0.5	5120	0.04	0.5	6827
0.01	0.6	2048	0.02	0.6	4096	0.03	0.6	6145	0.04	0.6	8193
0.01	0.7	2390	0.02	0.7	4779	0.03	0.7	7169	0.04	0.7	9558
0.01	0.8	2731	0.02	0.8	5462	0.03	0.8	8193	0.04	0.8	10924
0.01	0.9	3072	0.02	0.9	6145	0.03	0.9	9217	0.04	0.9	12289
0.01	1	3414	0.02	1	6827	0.03	1	10241	0.04	1	13655

Table 4-1. Results of calculations of PBR using different R_{max} *(0.02,0.04,0.06,0.08) and recovery factors F (0.1-1.0) at population abundance of N=341,366 (CV=0.14)*

The PBR of 3414 however, is the value if the recovery factor F, is 0.5. The possible range of values is from 683 to 6827 (Table 4-1). Since R_{max} is an estimated value, PBR can range from 1707 to a high of 6827. Although this calculation is simple and direct, the table above shows the wide range of possible solutions.

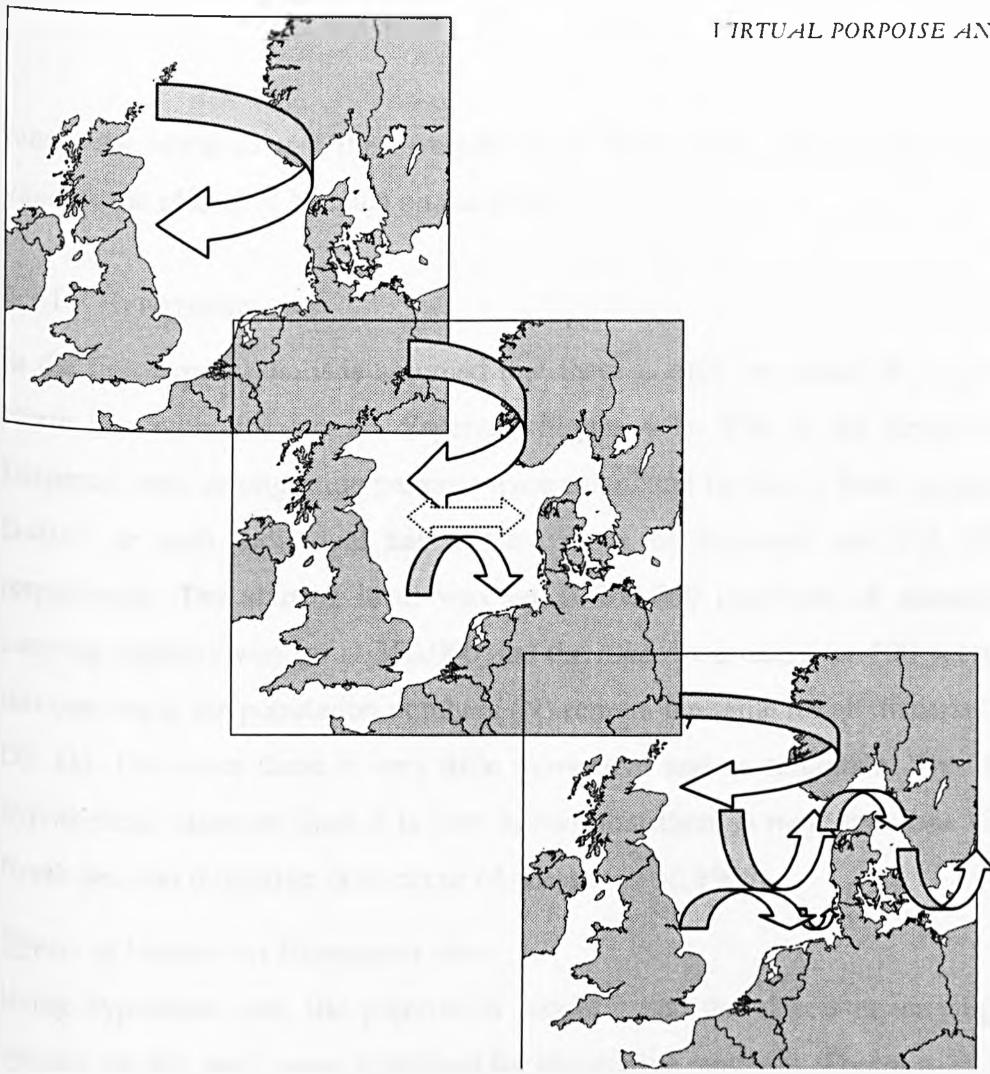

Figure 4-1. Three hypotheses for porpoise population structure in the North Sea used in the model PorpSim

4.3 RESULTS FROM PORPSIM

A number of runs were made to test the sensitivities of the model. The substocks, their size and carrying capacity were set as a basic starting point. Then, applying three hypotheses of the different stocks, as shown in Figure 4-1, the analysis was made. In each case, dispersal rates were examined, then population numbers were calculated using equation 1 and finally bycatch effects were examined. At the most simple level, the catch and dispersal rate were fixed and the model was run over a certain number of years (100 years) so that the population trend could be examined over time. Finally bycatch effects (C=2000, 3600, 5000 and 7000 animals per year) were examined for each hypothesis. Then, the distribution of bycatch was also varied and a number of runs were made to test these results. In a final series, survey data was used to validate the effects of bycatch on the model.

4.3.1 HYPOTHESIS ONE

In the first hypothesis, it is assumed that there is only one stock of porpoises in the North Sea with little to no dispersal (Figure 4-1). This is the simplest scenario. Dispersal rates or migration patterns were calculated for D1 or fixed dispersal, where D=0.01 or each individual has a 1% chance of dispersal, and D2, D3 and D4 respectively. The starting level was set at 269,000 (numbers of animals) and the carrying capacity was set at 350,000 and the model was run over 100 years. Thus for this one stock, the population numbers (N) remain the same for all dispersal rates (D1, D2, D3, D4) since there is very little movement and no migration. This is a purely hypothetical situation since it is now known that there is more than one stock in the North Sea and migration does occur (Andersen *et al.* 1999).

Effects of bycatch on Hypothesis One

Using hypothesis one, the population numbers and the effects of varying levels of bycatch on this stock were examined for illustrative purposes (Figure 4-2). Only after bycatch 3600 animals per year, does this population show signs of decline (Table 4-1) and at bycatch 7000 the population becomes extinct after 67 years. These calculations were made using the D1 rate. The other rates produce the same results.

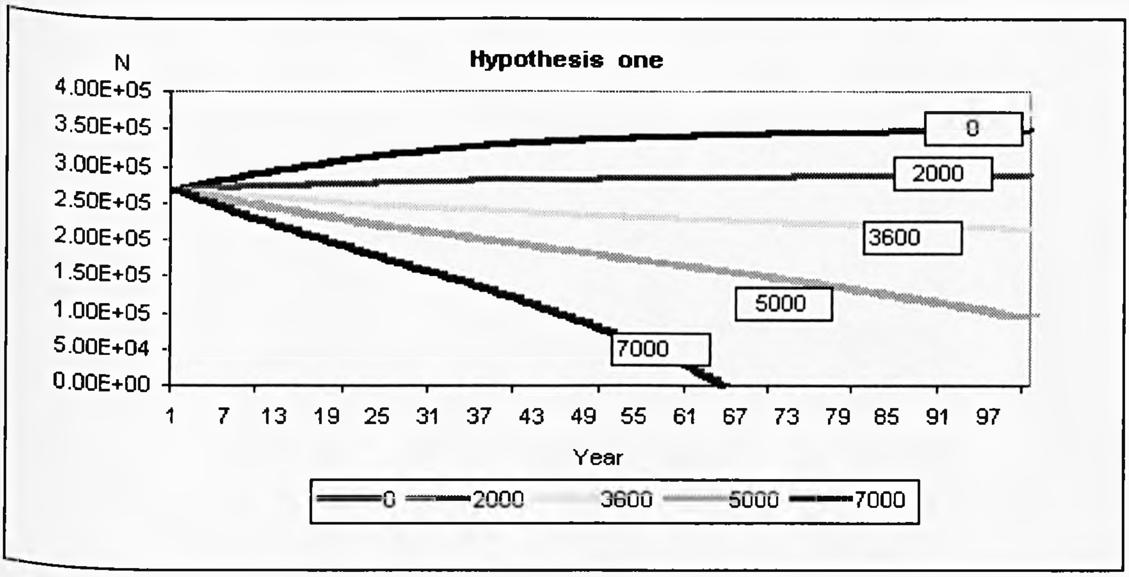

Figure 4-2. Hypothesis one and different bycatch levels: 0, 2000, 3600, 5000 and 7000 at dispersal 1

4.3.2 Hypothesis two

In hypothesis two I assume that there are at least one large northern and a smaller southern stock with a buffer zone in between. Again, the starting point was set at 203,000 animals (one large stock) and a smaller stock at 66,000 (the second stock). The carrying capacity was set at 350,000 and 113,000 respectively. The model was run over 100 years with different dispersal rates. Dispersals 3 and 4 (models 3 and 4) are very similar (Figure 4-3c,d). At N/K, an abundance index, it can be seen that for both large and small populations, at D3 and D4, the population levels are at 0.5 and equilibrate to 1.0 after 100 years. Total population numbers (N) were then calculated using these dispersal rates and then effects of varying bycatch were examined.

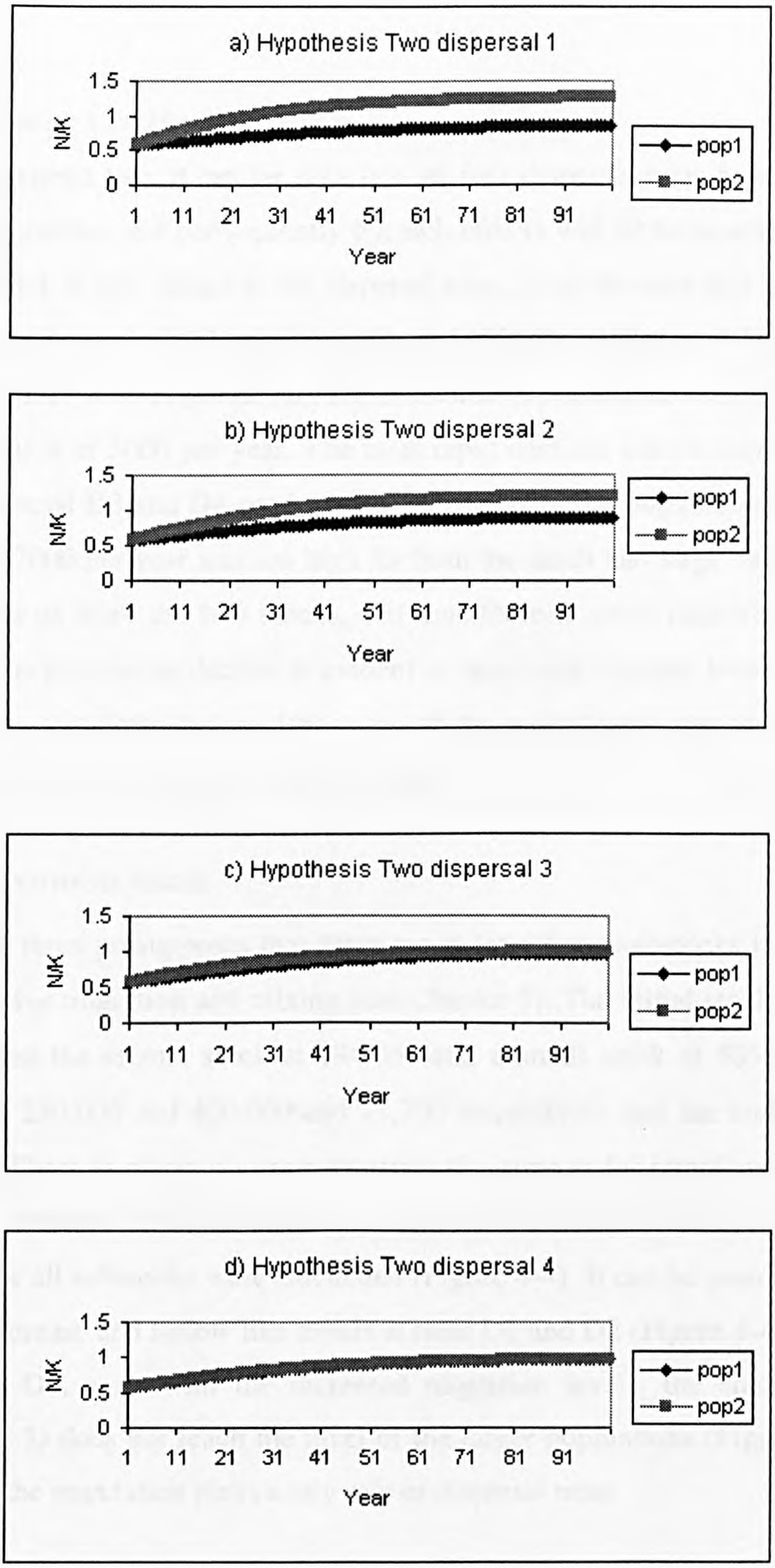

Figure 4-3. Hypothesis two with dispersal rates from a) D1, b) D2, c) D3 and d) D4

Effects of bycatch on Hypothesis Two

Using hypothesis two, it can be seen that all four dispersal rates have similar effects on the two stocks, and consequently bycatch effects will be comparable (Table 4-2). When bycatch is now added to the dispersal rates, it can be seen that both stocks start to decline at bycatch 3600, more rapidly at 5000 and suddenly at 7000 (after a few years) with D1. With dispersal rate D2, a decline in population numbers is noted only after a bycatch of 5000 per year. The most rapid declines can be seen in the smallest stock. Dispersal D3 and D4 produce similar results in the population numbers, and a bycatch of 7000 per year was too high for both the small and large stock. Since under this hypothesis there are two stocks, and thus there is some migration added to the numbers, the population decline is evident at increasing bycatch levels but extinction could not be predicted before 100 years. If the model were run over 250 years or longer, predictions of decline could be made.

4.3.3 Hypothesis three

Hypothesis three presupposes that there are at least three substocks in the North Sea with extensive migration and mixing (see Chapter 2). The initial stock size was set at 110,434 then the second stock at 194,064 and a small stock at 5858 with carrying capacity of 230,000 and 400,000 and 11,700 respectively and the model was run for 100 years. These numbers are approximately the same as for hypotheses one and two. Then, the different dispersal rates were determined from D1 to D4 and population numbers for all substocks were calculated (Figure 4-4). It can be seen that population numbers increase and follow like trends at rates D1 and D2 (Figure 4-4a, b). However at D3 and D4, even with the increased migration levels, the smaller population (population 3) does not reach the level of the larger populations (Figure 4-4c). Thus, the size of the population plays a key role in dispersal rates.

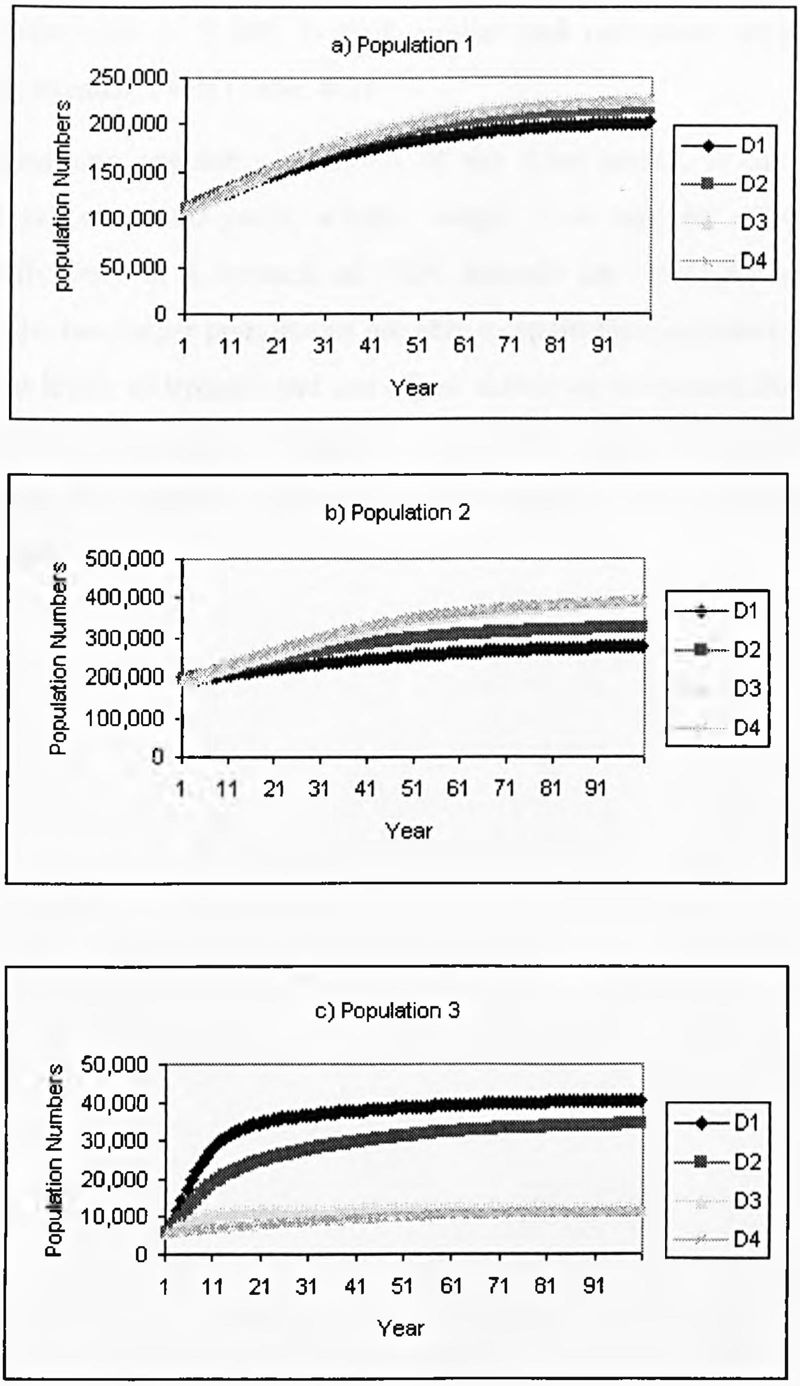

Figure 4-4. Hypothesis three with a) population 1, b) population 2, and c) population 3 and all dispersal rates (D1 to D4) with no bycatch

Effect of bycatch on populations using Hypothesis Three

Using hypothesis three and applying the same bycatch levels, the results from all stocks (population 1, 2 and 3) look similar and extinction happens earlier with increasing bycatch levels (Table 4-2).

When examining population numbers of the three stocks, it can be seen that at dispersal D1 over 100 years, a large single stock will be affected and decline dramatically only at a bycatch of 7000 animals per year. As levels of bycatch increase, the two larger populations are able to attain the maximum carrying capacity at different levels of bycatch and can adjust slowly up to bycatch 5000. Only then do declines occur. Similarly, at dispersal D2, the three populations slowly adjust with increasing bycatch levels (Figure 4-5) but decline most rapidly at bycatch 7000 (Figure 4-5d).

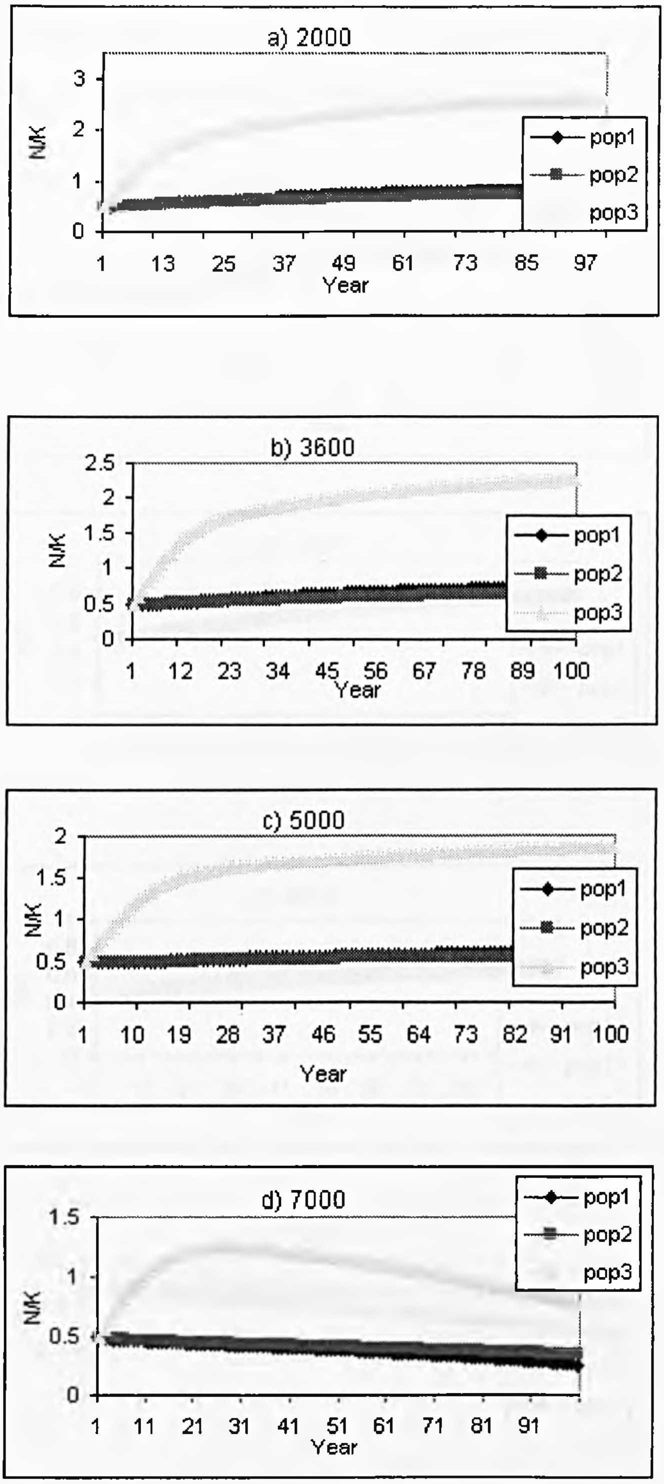

Figure 4-5. Dispersal 2 with bycatch levels of a) 2000, b) 3600, c) 5000 and d) 7000 and three populations (pop1-3)

At dispersal D3 (Figure 4-6) the three populations slowly decline with increasing bycatch. All populations decline at 7000 (Figure 4-6d).

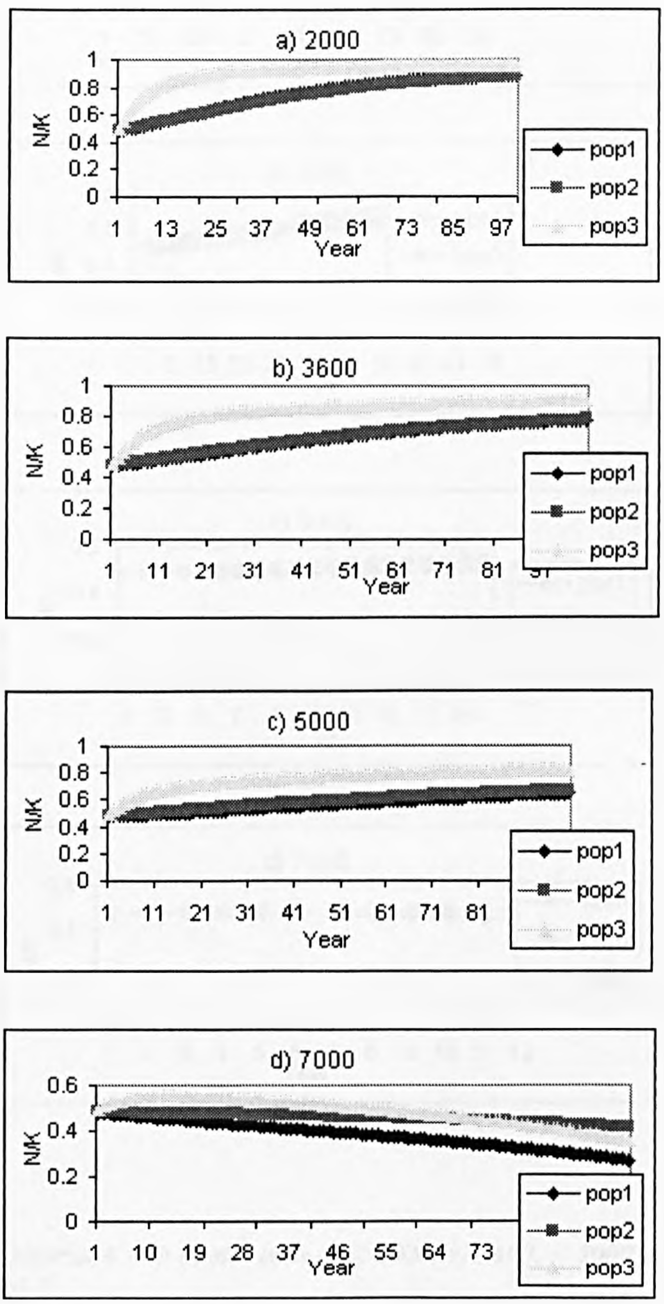

Figure 4-6. Dispersal 3 with bycatch levels of a) 2000, b) 3600, c) 5000 and d) 7000 and three populations (pop1-3)

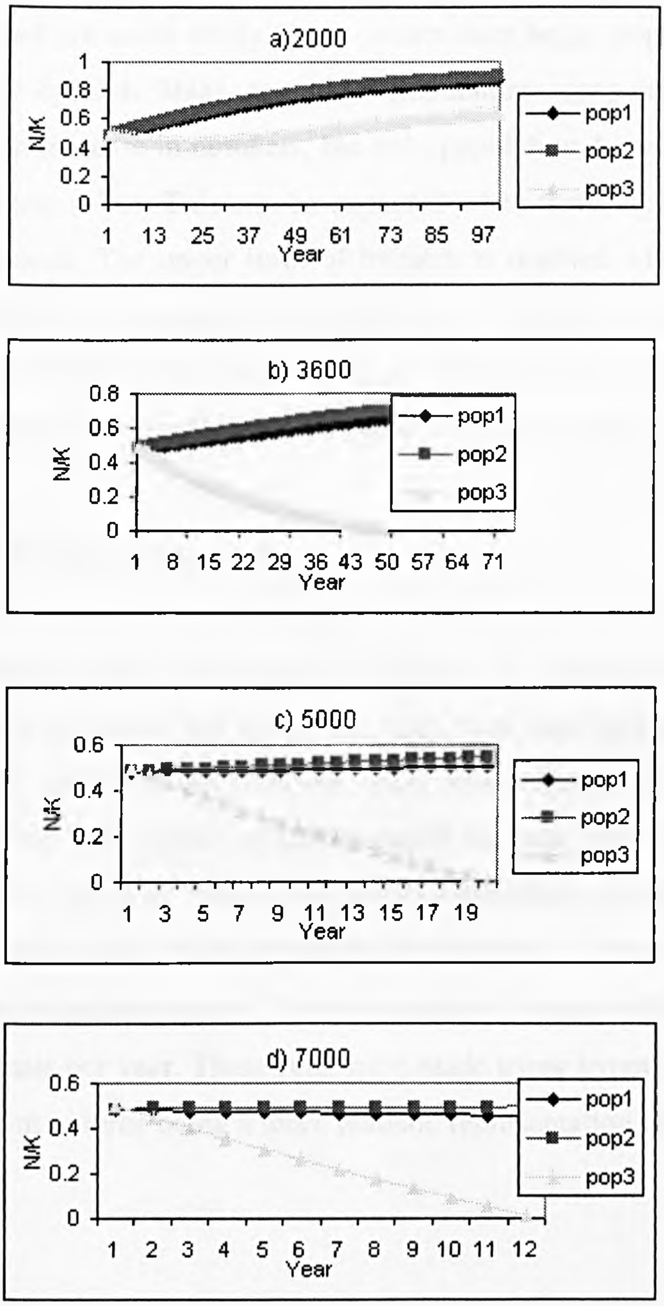

Figure 4-7. Dispersal 4 with bycatch levels of a) 2000, b) 3600, c) 5000 and d) 7000 and three populations (pop1-3)

At D4 (Figure 4-7) the larger populations receive migratory animals into their population and can withstand the bycatch. However, the net migration out of the smaller population, population 3 and the increased mortality of bycatch cause a decline. Small populations which have negative net migration are very vulnerable to bycatch and are more likely to go extinct than larger populations (Gilpin and Soule 1986). At bycatch 3600, the large populations (population 1 and population 2) continue to increase in numbers, but only population 3 crashes dramatically before 43 years (Figure 4-7b). This can be expected when there are high bycatches on a small local substock. The upper limit of bycatch is reached when bycatch is increased to 5000. The large population 1 and population 2 are also declining but at a slower rate. Population 3 declines in year 12 (Figure 4-7d). It can be seen at bycatch of 7000, that this is over the threshold limit. Population 3, at any dispersal rate, goes extinct very rapidly.

Equal distribution of bycatch

The above runs were made using an arbitrary level of distribution of bycatch over each substock at 40%, 50% and 10% (Table 4-2). However, in order to investigate the effects of distribution per stock, the same runs were made but equal percentages of 33%, 33% and 34% were chosen. This means that the bycatch level of 3600 for example was split equally as 1200 animals per year over populations 1, 2 and 3. The following result was found. All three populations irrespective of dispersal rate, declined immediately from the increased mortality at bycatch starting at 2000 (Table 4-2). The exception was at D3 where negative bycatch effects were noted only after 3600 animals per year. These runs were made using hypothesis three, since the above results point to three being a more realistic representation of the North Sea.

	Dispersal						
Bycatch (C per year)			0	2000	3600	5000	7000
Hypothesis 1	D1	Pop1	+	+	-	-	-
	D2	Pop1	+	+	-	-	-
	D3	Pop1	+	+	-	-	-
	D4	Pop1	+	+	-	-	-
Hypothesis 2	D1	Pop1	+	+	-	-	-
		Pop2	+	+	+	-	-
	D2	Pop1	+	+	+	-	-
		Pop2	+	+	+	-	-
	D3	Pop1	+	+	+	-	-
		Pop2	+	+	+	-	-
	D4	Pop1	+	+	+	-	-
		Pop2	+	+	+	-	-
Hypothesis 3	D1	Pop1	+	+	-	-	-
		Pop2	+	+	-	-	-
		Pop3	+	-	-	-	-
	D2	Pop1	+	+	-	-	-
		Pop2	+	-	-	-	-
		Pop3	+	-	-	-	-
	D3	Pop1	+	+	-	-	-
		Pop2	+	-	-	-	-
		Pop3	+	-	-	-	-
	D4	Pop1	+	+	-	-	-
		Pop2	+	-	-	-	-
		Pop3	+	-	-	-	-
Equal bycatch	D1	Pop1	+	-	-	-	-
		Pop2	+	-	-	-	-
		Pop3	+	-	-	-	-
	D2	Pop1	+	-	-	-	-
		Pop2	+	-	-	-	-
		Pop3	+	-	-	-	-
	D3	Pop1	+	+	+	-	-
		Pop2	+	-	-	-	-
		Pop3	+	-	-	-	-
	D4	Pop1	+	-	-	-	-
		Pop2	+	-	-	-	-
		Pop3	+	-	-	-	-
Empirical data	D1	Pop1	+	+	+	+	+
		Pop2	+	+	+	+	-
		Pop3	+	+	-	-	-
	D2	Pop1	+	+	+	+	+
		Pop2	+	+	+	+	-
		Pop3	+	+	-	-	-
	D3	Pop1	+	+	+	+	+
		Pop2	+	+	+	+	-
		Pop3	+	+	-	-	-
	D4	Pop1	+	+	+	+	+
		Pop2	+	+	+	+	-
		Pop3	+	+	-	-	-

Table 4-2. Summary of results obtained from PorpSim (where + denotes increase and – denotes a decrease in population numbers) and pop1, pop2 and pop3 denote population stock 1, 2 and 3 respectively. These results are obtained from using different hypotheses (1-3), and dispersal rates (D1-D4)

The distribution of bycatch over a substock is therefore an important factor. The smallest substock declines rapidly whether at 10 or 33% distribution of any bycatch level (Table 4-2).

Survey data and effects of bycatch

In a final set of simulations, empirical data was used to estimate the effects of bycatch. Rather than starting the model at a theoretical number of 269,000 animals as in the previous runs, the starting point was set at 130,956 for the northern North Sea stock, 16,939 for the central UK stock and 26,725 animals for the Danish substock. These were population estimates obtained from the SCANS survey by summing survey blocks C, F, G, L, H and Y (Hammond *et al.* 1995). Bycatch levels were set at 0, 2000, 3600, 5000 and 7000. The division of bycatch was set at 10, 20 and 70% for the Northern, UK and Danish stock since it is known that most of the North Sea bycatch occurs in Danish waters (Vinther 1999). The model was run using the four different dispersal rates under Hypothesis 3. The carrying capacity was set at 262,000 35,000 and 54,000 respectively. At dispersal D1 (fixed) the three substocks gradually increased and behaved according to the logistic assumptions. At D2, a similar situation was seen, only D3 and D4 were slightly different. If bycatch is now added to the population, the following is noted. Under dispersal D1, even at 2000 animals per year the Danish population is not robust and the numbers are lower (Figure 4-8b). With the additional mortality of 3600, the porpoises of the Danish population crashed at 31 years, (Figure 4-8c) at 5000 it declined after 15 years and with 7000 annually, the population goes extinct after 9 years (Figure 4-8e). Dispersal 1 is the most conservative yet D2 shows a similar pattern whereby the population in Denmark begins to decline with bycatch 2000, at bycatch 3600 after 19 years, at 5000 after 11 years and at 7000 after 7 years (Figure 4-9). Similar results were obtained using D3 and D4 where the populations declined rapidly.

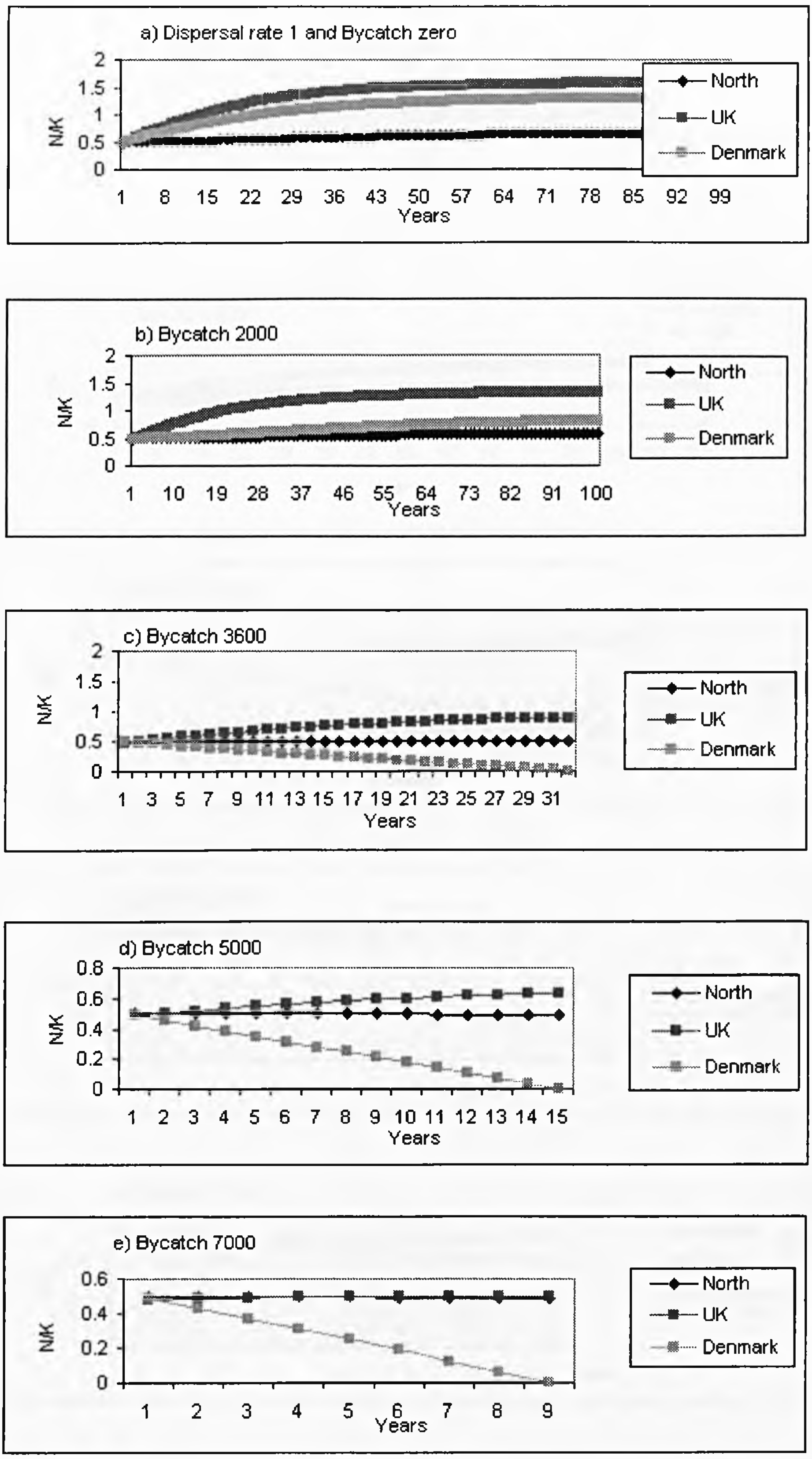

Figure 4-8. Dispersal 1 using survey data and bycatch levels of a) zero b) 2000 c) 3600 d) 5000 and e) 7000 and three populations

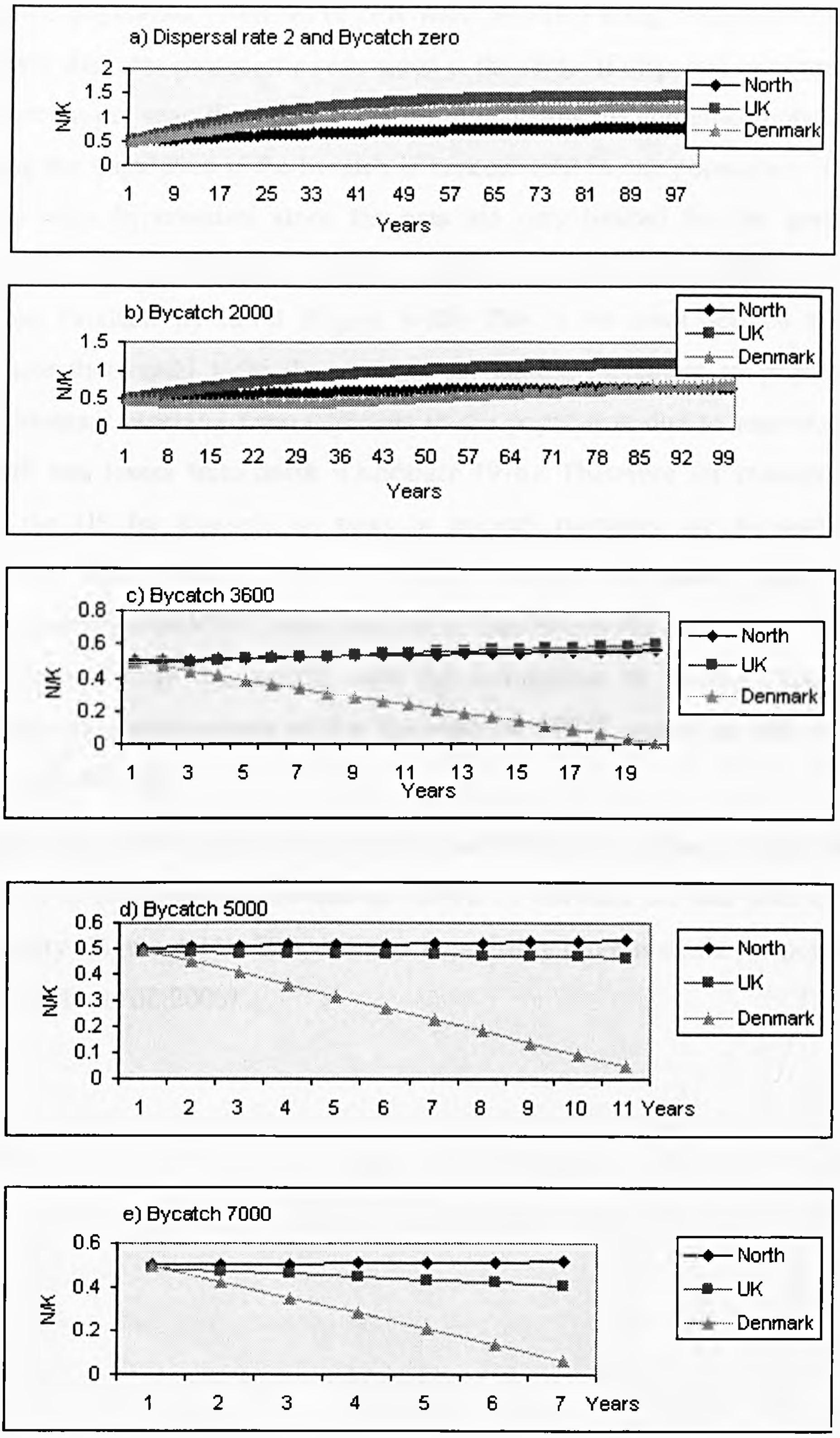

Figure 4-9. Dispersal 2 using survey data and bycatch levels of a) zero b) 2000 c) 3600 d) 5000 and e) 7000 and three populations

In PorpSim, the population estimates of N/K were provided using different dispersal rates. Whatever the rates chosen, the conclusion is the same: if dispersal rates are less than a few percent per year, then there is danger of depleting the combined population or eliminating the population if the bycatch is concentrated in one population. These estimates are very hypothetical since the data are very limited for the porpoise population. Using this biological model is similar to estimating MNPL or the Maximum Net Productivity Level (Figure 4-10). This is the level defined as that population size that could yield the greatest net annual increment in population numbers or biomass resulting from additions to the population due to reproduction and/or growth less losses from death (Gehringer 1976). Therefore for management purposes in the US for example no takes or bycatch mortality are allowed if a population falls below MNPL. The problem is always estimating where the population is in relation to MNPL since there is no data on growth rate, N and K. The theory was derived from the logistic with the assumption of density dependent growth, and constant environment so that the resultant MNPL occurs at 50% of the carrying capacity or 0.5K.

On the contrary, the PBR model can incorporate uncertainty by varying the precision (from CV =0.2 to 0.8) and still provide an MNPL of between 0.5 and 0.85 of the carrying capacity (Figure 4-11). This estimate is probably more realistic for porpoise populations (Taylor *et al.* 2000).

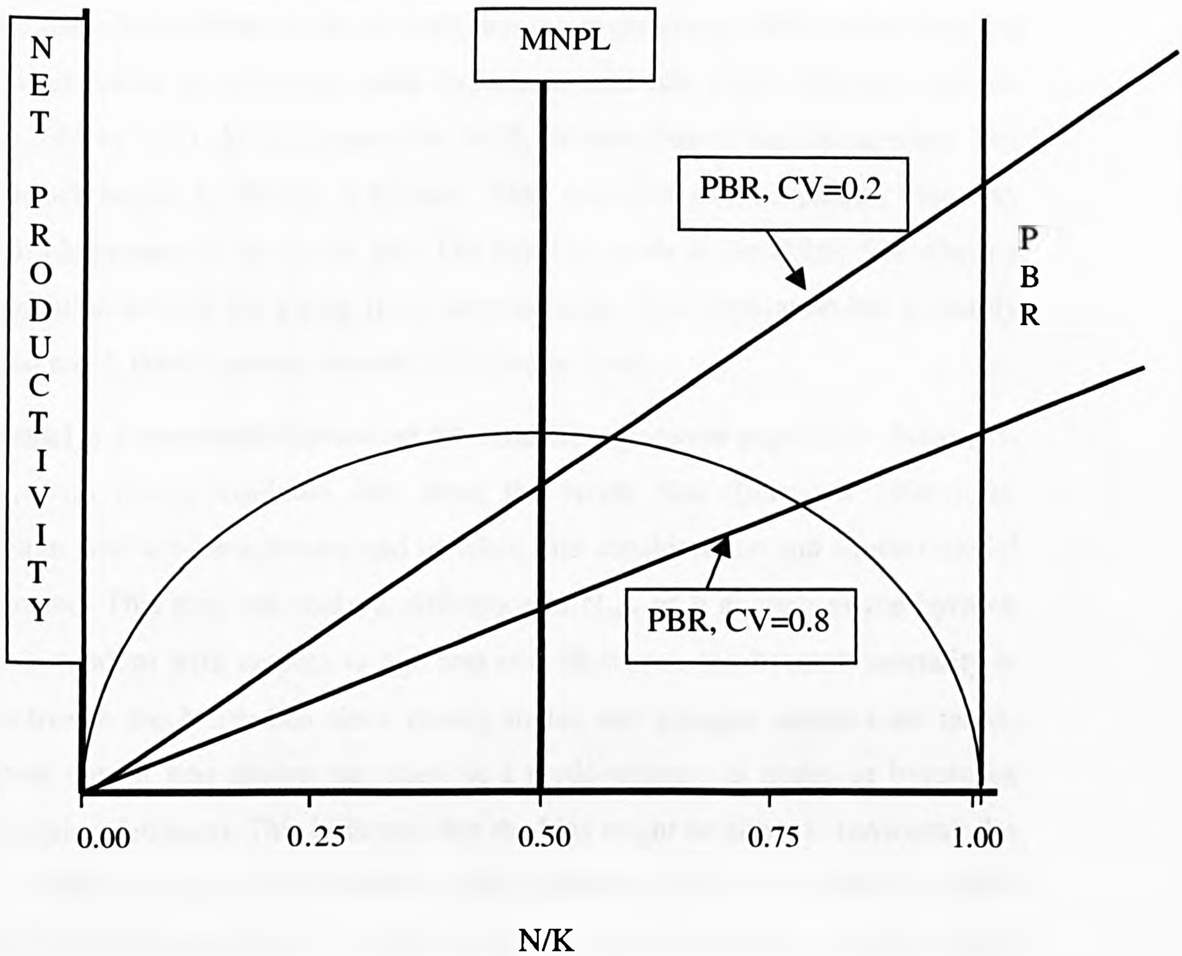

Figure 4-10. Relationship of net productivity and Potential Biological Removal (PBR) for different levels of abundance / carrying capacity (N/K) with the same scale (adapted and redrawn from Taylor et al. *2000)*

4.4 LIMITATIONS OF PORPSIM AND PROPOSED IMPROVEMENTS

1. Results from these runs show that dispersal rates matter, when based on basic population dynamics. There is however, little quantitative data available on dispersal, migration or mixing of porpoises in the North Sea to estimate these rates and determine a threshold rate for population extinction. Dispersal rates are important in order to calculate the effect of migration and mixing since there are a number of stocks (Walton 1999). The rates can be obtained by tagging, genetic studies, photographic studies, satellite tracking etc. and there are current studies underway,

but the data to estimate these rates are not yet available. Read (1999b) recommended that more research be undertaken to estimate such rates across the North Sea.

2. Despite these limitations, it can be seen that the populations when using PorpSim are not at all robust at whatever stock hypothesis and can only withstand bycatch levels of 2000 to 3600. At bycatches over 3600, the populations cannot increase. The small substock begins to decline at bycatch 2000, and does not recuperate. This may be what has happened in the North Sea. The bycatch levels in the Baltic Sea where a small population existed for a long time were too high. This population has probably declined so much that it cannot recover to its former level.

3. This model is a reasonable framework for modelling porpoise population dynamics. However, with newly available data from the North Sea (Harwood 1999a) for example, age- and sex- structures could be taken into consideration and another model be constructed. This may not make a difference in N_{min} or F as long as the bycatch mortality is random with respect to age and sex. However, the bycatch mortality is very selective in the North Sea since mostly males and younger animals are taken. From recent data it was shown that there is a predominance of males in bycatches (1.2:1.0) (males: females). This indicates that the bias might be either behavioural: the males are wider ranging and the females more restricted, perhaps to shallow coastal waters and they may even feed in a different area/depth than females. Walton (1997) suggested that a disproportionate ratio in sexes usually indicates some kind of segregation and might reflect the general hypothesis that males are more mobile and wider ranging than females (Lockyer and Kinze 1999).

4. The model does not include the Allee effect (Allee 1931). This effect is the result in a population due to changes in fecundity at low densities. There is no long time series of fecundity available for any porpoise population (Read 1999b) but there are known differences in time in fecundity among North Sea populations demonstrating that fecundity is a potential source of variation in r. More basic research is needed.

5. The model is conceptually and computationally straightforward but it depends heavily on r. Since there are no empirical data for r nor K and only one estimate for N, this limits its usefulness. One of the biggest difficulties is obtaining K and N and this could cause bias in either downward or upward direction of the dispersal rates. Since

there was only one estimate for N all the values used in the runs were hypothetical.

6. The structure of the model, based on the logistic, is probably a sufficient basic model to use. However, the addition of unknown dispersal rates (and bycatch) when N, r, and K are unknown may weaken the model considerably.

7. The survey data have shown that the populations from the model are not resilient under any dispersal patterns calculated when bycatch is added. In order to investigate the basic structure of the model, growth rate was adjusted from the 0.04 to 0.4. This change, caused the three populations to alter and equilibrate under the real 7000 bycatch conditions. Biologically this is not possible. It can therefore be concluded that in this version PorpSim has some structural problems.

8. At a recent meeting of IWC and ASCOBANS, a similar model was tested, using the logistic for porpoise management options (Read 1999b). However, the model did not use dispersal patterns, but was based entirely on the logistic equation. This may be a more useful option to explore.

9. PBR for the North Sea is calculated to be 3414 individuals. If bycatch estimates are correct, at 6785 for 1999, then the levels are higher than PBR and the porpoise populations must be protected. PBR is also a more direct measure and may be a viable management tool.

10. PorpSim is also deterministic rather than stochastic. Simulations using stochasticity should be possible and interesting in order to examine the effects of environmental changes or catastrophic events on the population(s). Another possibility would be to develop a stage-structured model consisting of dependent calves, immature animals and adults.

11. The ultimate model would be one that incorporates uncertainty into the assessment of risk, so that any delays of action can be reduced or eliminated. In any population model it would be preferable to use demographic (between individual) and environment (between year) stochasticity (Taylor *et al.* 2000). Uncertainty can be estimated by running a model for different combinations of survival and reproductive rates. Models should also be constructed with multi-year data and cross-validation methods (Forney 2000). The model used here has validation data only for one year.

Conclusion

Good management models and good models for understanding biology differ in basic philosophy. Management models, such as PBR, must aid management decisions despite large amounts of uncertainty about the managed populations. Such models must be based on parameters that can be estimated readily, must explicitly account for uncertainty and should be simple to understand and implement. In contrast, biological models are designed to elucidate the workings of biology and should not be constrained by management concerns (Taylor *et al.* 2000).

Models such as the PBR are simple to use and have been used in the US in favour of the logistic model. Here, I have calculated the PBR for the porpoise stocks. It would be advantageous to use this simple model to manage the porpoise stock(s) in the North Sea rather than PorpSim. PorpSim on the other hand, is a biological model, demanding data that are not yet available.

The construction of a model is a requirement in understanding a biological problem. The results demonstrate that population structure and determination of migration rates have considerable influence on porpoise population dynamics under bycatch mortality. Clearly, understanding these issues and the collection of appropriate data is a priority if quantitative assessments and prediction are to be achieved.

Chapter 5

Fleeting and Fishing: The gillnet fleets of Grimsby, UK and Hvide Sande, Denmark and their influence on Porpoises

> *I must now pass on to the damage done by a creature far more voracious than the porpoise or shark: I mean the fisherman, and especially the small fisherman…in virtue of the law of the least resistance, the small fisherman works again and again upon the same coastwise shoals, until the day when their exhaustion no longer enables him to draw a living from them.*
>
> *Hernbel, 1912*

The study fleets were based in Grimsby, UK and along the North Sea coast of Denmark. The bottom-set gillnet fleets from both areas are known to experience high by-catches when fishing in the southern North Sea and off the coast of Denmark. The area off Denmark is particularly important as it is one of the most densely populated in the North Sea (Hammond *et al.* 1995) and this is where high by-catch levels especially during the summer months have been reported. This chapter comprises the results of my own analysis of interviews in the UK as well Denmark.

The Grimsby wrecknet fishery

Grimsby is a small port situated on the Humber River, approximately 9.5 kilometres from the North Sea. It used to be world famous as a deep sea trawling port (Turnstall 1962). But today only a small fleet of gillnetters operate here. Fixed or anchored nets have been used as a means of catching fish for centuries and a wide variety of traditional nets have developed to suit local conditions. Although some of these nets are still used they declined considerably in popularity following the development of efficient trawls and the widespread use of petrol or diesel engine boats. The introduction of synthetic netting materials and the relatively great increase in marine fuel prices in recent years has led to a revival in the use of fixed nets (Milner 1985).

The development of small precision sonar equipment capable of indicating the position, shape and orientation of the seabed obstructions has led to a rapid expansion of a fishery using gill nets laid around and on top of wrecks in the North Sea (Milner 1985).

Gillnetting

Gill net fishing is one of the most traditional and ancient methods of fishing. There are two types, drift and set gillnetting. Drift gillnetting is gillnetting with the tide, where the net is set loose as the tide drifts. The set gill nets are set with the bottom part attached to the sea bottom and only the top part (head line) attached to a float (Cushing 1988). A detailed description of bottom set gillnets used in the UK is now presented using the form of IWC Guidelines. These data were verified by a gillnet maker in Grimsby in 1997 (Table 5-1).

1. Target species	Cod and plaice
2. Country or region	Method adapted from Danish gillnetters
3. Mesh size (stretched)	85 mm square diamond to 170mm
4. Twine webbing material	Nylon
5. Twine construction	Multifilament, monofilament
6. Twine size	6
7. Height of net	4m
8. Length of net	70m
9. Hanging ratio	Roughly 35%
10. Framelines	Upper=floatline with 24 floats on 1 net, Lower =leadline #4 leaded ropeSide=sideline 10 mm polypropylene split film
11. Flotation	24 float on one net, 115 gm buoyancy
12. Weight on the leadline	9kg per net
13. Total length of the string (or fleet) of net	3 nets or 3x70m for wreck fishing
14. Time of fishing	Overnight (depends on tide
15. Duration of soak	12-24 hrs depending on season
16. Areas	Outside Grimsby near wrecks
17. Depth	Depends on tide
18. Approx. price	£78 in 1997
19. Vessel length	Average vessel length for the fleet is 19m

Table 5-1. Guidelines for the correct description of a gillnet used in the North Sea (format according to the International Whaling Commission, IWC 1994)

The gillnet consists of a single sheet of thin multifilament or occasionally monofilament nylon: it is 19 meshes deep, about 1000 meshes long and is attached to a 53m long headrope consisting of two 6mm braided nylon topes with floats at 1m intervals. The bottom of the net is attached to a single foot rope which is less robust than the headline. If the net snags, when strain is put on the net during hauling, the footrope will part allowing the rest of the net to be retrieved. For the same reason galvanised steel rings 22cm in diameter are used instead of a leadline to weight the net: the rings are whipped on at approximately 1m intervals using a natural fibre twine which will allow the net to be pulled free if a ring becomes trapped. It has the additional advantage that if the net is abandoned the twine will rot in time, allowing the net to drift clear of the wreck. Another adaptation to wreck fishing is to leave each end of the panel of net bare with no strengthening selvage so that the net can be torn free if caught on the wreck (Milner 1985). In cod fishing the majority of multifilament wreck gill nets have a stretched mesh size of 190mm but in some cases 180mm nets will also be used. Monofilament wreck nets tend to be slightly smaller with a stretched mesh size of 160mm. The position of the wreck is known from charts or from previous trips and is relocated approximately using echolocation. At the same time sonar is used to search the seabed until the wreck is found. Usually a skipper will make several runs over a wreck which is new to him to see how it is lying on the sea bed before deciding to shoot his nets and will aim to lay the set or group or 'fleet' of nets with the middle net stretched across the wreck (Milner 1985).

The nets are fished in fleets of three or five nets and up to four fleets may be placed over and around a single wreck. They are left for two tide changes or for up to 18 hours at the longest and as many as six to nine wrecks may be worked at the same time. Most of the boats larger than 15m will carry 150 - 300 nets and will work less than half of these at any one time. Hydraulically driven net haulers are used to retrieve the nets and as many fish as possible are cleared as the nets come aboard. If the catch is large, the net is set aside and cleared later. On a productive wreck, the nets may be shot again as soon as they have all been cleared. Repeated fishing on the same wreck will result in reduced catches unless the wreck is left for a period to recover (Milner 1985).

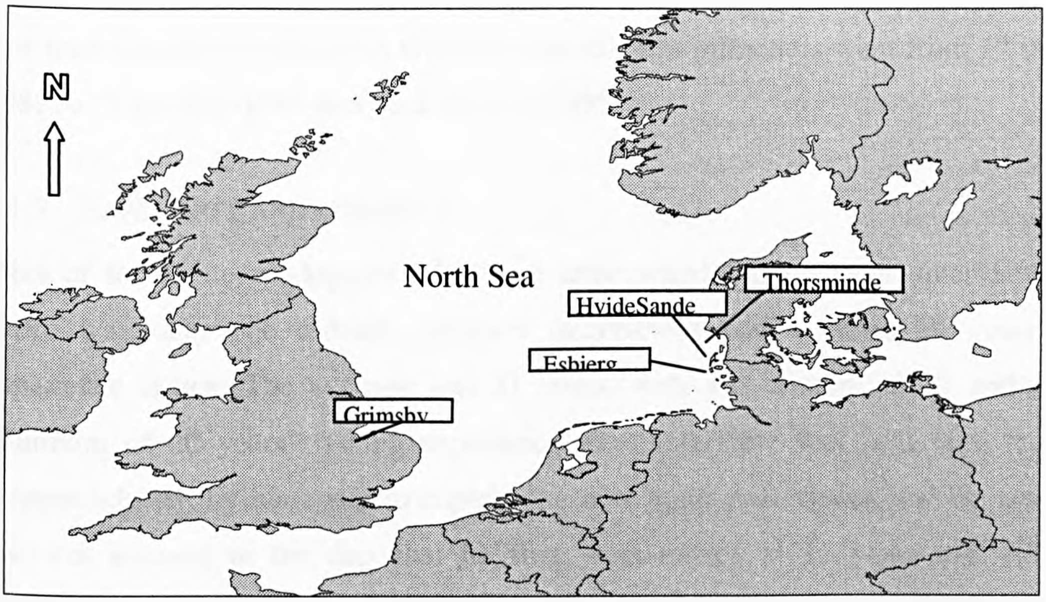

Figure 5-1. Location of study sites: Grimsby, UK and Esbjerg, Hvide Sande and Thorsminde, Denmark

5.1 UK Study Fleet analysis

In this section the structure and operations of the UK fleet are described. *In situ* interviews were held with most skippers in the fleet.

5.1.1 Social and operational structure of the UK fleet

Over the past two decades, 50 vessels have been classified as gillnetters with the code 56 by CEFAS. Today, the fleet is comprised of 17 active vessels, 10 of which fish full-time. Although these vessels are classified as gillnetters, they may change to anchor seining, long-lining or other types of fishing for certain months of the year. Some vessels even change to another type of fishing for a year and return to gillnetting afterwards. According to local fishermen, the fleet in Grimsby is declining in numbers, a trend which can also be seen in the official statistics.

From the 50 vessels listed in the database, 27 were selected for the detailed fleet analysis. Those vessels which only tried gillnetting for one or two years were excluded to ensure that the analysis was based on active fishing vessels only. All vessels were given a number and the only identifying characteristic provided was the total length class in meters.

The total number of vessels in Grimsby classified as gillnetters went from 17 in 1986 to 27 in 1991-1995 and back to 17 in 1997.

5.1.2 Experience and ethnicity

Most of the Grimsby skippers who were approached, agreed to an interview. There was only one refusal. Skippers interviewed had at least 20 years' experience at sea. The average was 31 years, with a maximum of 45 and a minimum of 20 years' fishing experience. One interview was held with the skipper selected by his agent to captain the new multi-gear vessel, and he was also not unusual in the fact that he first went to sea at 15 years old. All interviewees were highly experienced and knowledgeable about fisheries in general. Three out of the 14 skippers were born in Denmark; one came over to Grimsby when he was 17 years old, and the other two at an earlier age; only two out of the 14 fishermen interviewed did not have a father or close relative working in the fishing industry. These social connections created the unique and close networks that were found within the fleet and helped to explain why there were seldom written contracts between the various parties.

5.1.3 Number of fishermen

On a small vessel (length 15-20m) there was usually a skipper and three crew members; on larger vessels there were usually 4 or 5 crew members when gillnetting and 7 when long-lining. On average, there were about four fishermen associated with a single vessel, however some crew were part-time and the total number onboard could change between trips. Gillnet skippers were all responsible for at least 5 people. Anchor seining required a total crew of four. With 17 vessels classified as gillnetters in 1997, approximately 70 fishermen were fishing out of Grimsby in the study fleet.

5.1.4 Fishing practices

The most common fishing practice in the fleet was bottom-set gillnetting, as described in the section above (i.e. the net is set at the bottom of the seabed and then the upper part floats with the tide).Gillnetting is a very selective way of fishing in that only larger and older fish are caught.

Since the early sixties, Danish gillnetting, wrecking or wreck-netting, has evolved. This method uses known shipwrecks and relies on the fact that they act as natural attractors or habitats for cod; three nets are either set in parallel across the wreck, or two in parallel with a third one across them. It is probably a method which originated in Denmark and which the Grimsby fishermen adopted from the Danes who settled in Grimsby. It is a very 'net' intensive method since the possibility of losing or catching a net on the wreck is very high. Half of the skippers said they left their nets in for approximately 12 hours. Another skipper differentiated winter times (nets could be left for 18 hours) from summer (only four hours). Another practice used in the fleet was anchor seining, with a soak time of only 2.5 to 3 hours.

5.1.5 Operational and commercial arrangements

According to the data collected in the interviews, fishing trips lasted for up to a week, but could range from a few days to two weeks. Usually the length depended on the going market prices of cod. The agent arranged for the best price while the skipper was still at sea. If there were better prices to be obtained in the Netherlands, the vessel would land there and extend the trip for a day or so.

Most often, Grimsby gillnetters would land at the Grimsby market. However, the Anglo-Dutch fleet (Danbrits) which has its administrative offices in Grimsby, operates mainly out of Holland, with a mixture of Dutch and British owner-skippers.

In the fisheries examined, there were no contracts or no written agreements between the skippers and their crew, or between the skippers and their agents. The agents however, had written contracts with service industries (Furuno sounders, echo sounders, computer services etc.). (In some of the larger companies in Grimsby written contracts did exist i. e. a mere handshake was not enough). Where an agent or broker was involved, the commission levied to cover the costs of transacting trade was typically 3% taken from the price of all fish sold. Information on revenues was not explicitly sought in this part of the study, as the focus was on obtaining better estimates of bycatch and views on reforms to governance. However, given the level of landings and market price of cod as the main species (£1.28 per kg; source CEFAS Lowestoft and Table 5-2) many of the vessels would have had revenues between £100-150k (base year 1997).

Year	Price £ /Kg		
1983	0.64505		
1984	0.70884	1991	1.45746
1985	0.82352	1992	1.44871
1986	0.99902	1993	1.37407
1987	1.04538	1994	1.22205
1988	1.02409	1995	1.20354
1989	1.11289	1996	1.18976
1990	1.41882	1997	1.28684

Table 5-2. Price of cod in £ per kilo for UK gillnetters from 1983 to 1997 (source: CEFAS)

5.2 Danish Fleet analysis

The analysis of the Danish fleet was based on field trips to the coastal ports of Esberg, or Esbjerg, Hvide Sande and Thorsminde, where the target species included plaice, sole, turbot and cod. The area is one of the most densely populated in terms of numbers of porpoises per km^2 (Hammond *et al.* 1995) and the area is also important as a breeding and nursing area (Figure 5-1).

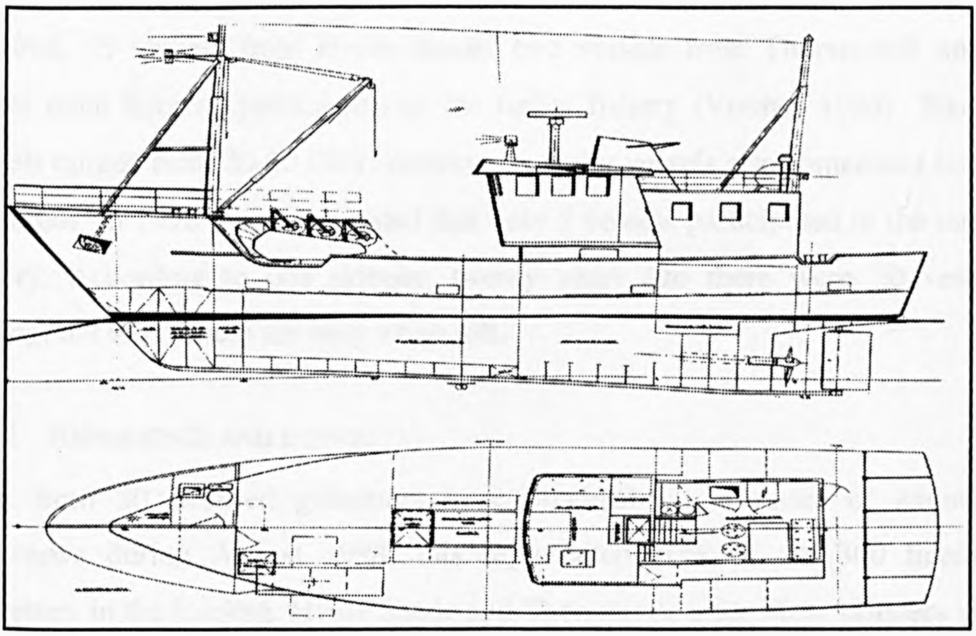

Figure 5-2. Drawing of a typical gill net vessel from Denmark (source: Flintegard 1986)

5.2.1 Social and operational structure of the Danish fleet

Fleet size and classification

There were a total of 114 licensed fishing vessels in Esbjerg, a small percentage (less than 5 percent) were of gillnetters. There were 339 licensed vessels in Hvide Sande, most of which were gillnetters, and there were 126 registered vessels in Thorsminde, another small port further north along the Jutland coast (Year Book of Danish Fishery Statistics 1996). Esbjerg, also known as the 'Sandeel town of Denmark' had the larger vessels, 20-70m length. Hvide Sande, also known locally as the 'Cod town of Denmark', had vessels mainly between 20 to 25m. It was in Thorsminde that the vessels were relatively small (<20 m) and had a wooden hull (Figure 5- 2). The smaller boats were usually one-man boats, and the larger ones (> 17m) had 3-4 crew on board (Flintegard 1986). The smaller vessels (<20m) were usually the older vessels as well (Table 5-3).

Length	Average age (years) of vessel
<12m	28.8
12-16m	35.3
16-24m	29.2
24-30m	21.7
>30m	22.1

Table 5-3. Length and average age of vessel in Denmark (source: Vedsmand et al. 1996)

In 1993, 15 vessels from Hvide Sande, two vessels from Thorsminde and 1 vessel from Esbjerg participated in the turbot fishery (Vinther 1994). The 18 vessels ranged from 20-60 GRT. However, smaller vessels also sometimes fished for turbot. In 1998 it was estimated that only 5 vessels participated in the turbot fishery. According to one skipper, twenty years ago there were 20 vessels fishing, but today there are only a few left.

5.2.2 Experience and ethnicity

Data from 30 licensed gillnetters were obtained via a series of extended interviews during August 1998; this represented 10% of the 300 licensed gillnetters in the Esbjerg, Hvide Sande and Thorsminde area. Most skippers who were approached for an interview agreed. Only five refused. The average number of years fishing per fisherman was 26 years. The maximum was 45 years and the minimum was 8 years of experience in the industry. Most skippers (59%)

had 21 to 40 years of experience and 37% had at least 20 years' experience. Some of the skippers knew or were related to skippers interviewed in the UK component of the study.

5.2.3 Number of fishermen

There are 6000 fishermen employed in Denmark (OECD 1997) and 13 820 in the related industry (Nielsen and Vedsmand 1999) and approximately 1800 involved in the gillnetting industry in Esbjerg, Hvide Sande and Thorsminde.

5.2.4 Fishing practices

The gillnet fishery is concentrated along the western coast of Denmark. Throughout the year the fishermen targeted plaice, sole, turbot and cod. In the spring and summer the fishermen targeted sole and turbot. The preferred fish was cod since it brought the highest price. However, when a fisherman could not go for cod (i.e. quota used up or season) then the next choice was plaice. The last choice was sole and some smaller inshore fishermen had specialised in the sole and plaice fishery. Most gillnetters targeted cod and the peak season was from October to December. Cod in the North Sea spawn from January to February and during this time they were targetted as the fish were concentrated and hence easy to catch.

5.2.5 Operational and commercial arrangements

The fish is landed at Hvide Sande or Thorsminde after 3-4 days at sea for the larger vessels and daily for the smaller ones. The fish is sold fresh at the auction for the domestic market as well as other European countries. Refrigerated or frozen fish is exported to France, Belgium, Italy, Spain, and Germany. Ex-vessel prices for cod in year 1998 were very good and ranged from 10 to 20DK/kg. However, prices for turbot in 1993 were estimated at 50.70DK/kg. In that year cod prices averaged at 12.24DK/kg. (Vedsmand *et al.*1996). It can thus be seen that the high price of turbot is worth the individual fisherman's effort.

5.3 Differences and similarities in the two communities

5.3.1 Fisheries management in Denmark

Fishing has always been an important industry in a maritime nation such as Denmark. Denmark, surrounded by four seas, the Baltic, the Kattegat, the Skagerak and the North Sea has the longest stretch of coast in Europe (7300 km) in relation to the size of its territory (Worm 1997).

Danish fishermen have a long tradition for exploiting the sea and they used hooks, gill and fyke nets, beach seine, eel weirs, pound nets among others (Hansen 1997). This type of fishing took place directly from the beach using rowing boast and small sailing boats. Fishing then progressed from sea-going boats with drift nets and long lines. Fishing along the coast was often mixed with other activities, which also included farming, animal husbandry, forestry, hunting and commerce. Fishing, as a main occupation is a relatively late feature in the history of Nordic fishing, and thus is a decisive factor in the development of the fishing industry. By contrast, England and the Netherlands have been fishing, not only in the North Sea, but also in distant waters, since 1400. Deep sea fishing by these nations was controlled by shipping companies that owned fleets of vessels, which were sent to the deep sea fishing grounds and to the Grand Banks (Hansen 1997).

Nordic sea fishing developed in a different way, because it was based on smaller vessels owned by fishermen themselves (Hansen 1997). This has the advantage of a more flexible and less capital intensive industry utilising modern technology at the same time. Larger vessels require large concentrations of fish to make fishing profitable, while smaller boats can exploit less dense concentrations of fish. In this way, fishermen use the local waters in which they can switch from one species to another, and land the catch daily. This is an important difference, the fact that it was not a question of 'shipping company fishing', in which one or more investors would buy a vessel and the associated work force. Instead, the majority of Nordic fishing today is organised into co-operatives, in which fishermen themselves do the fishing, arrange loans, investments, and still own the boats (Hansen 1997).

The fisheries in Denmark, as well as the UK fisheries, are regulated by the Common Fisheries Policy (CFP) that allocates quota to each member state of the European Union (Nielsen and Vedsmand 1997). The measures include Total Allowable Catch or TAC's, licenses, periodic catch limits, vessel lengths and HP limits, and new experimental measures of days at sea and individual vessel quotas (OECD 1997). The Danish fleet is comprised of about 3149 vessels, dominated by static gear such as gill netters (Figure 5-2). The rest are demersal trawlers and Danish seiners. The decommissioning scheme adopted by the European Union in 1986 reduced the fleet from 137,000 GRT to 94,000 GRT by 1995 (OECD 1997).

5.3.2 Fishermen's organisations

The Danish fishermen's organisations are separated into three groups: the fishermen's organisation, the trade union and the Producers Organisation (or PO's). The fishermen's organisation are the Sea Fishermen's Organisation (SFA) and the Danish Fishermen Association (DFA). Almost 90% of all fishermen are represented. There is no major difference between the SFA and the DFA. However, the majority of small vessel fishermen are represented in the DFA, whereas the SFA are mainly represented by larger vessels. Both skippers and owners and crew are organised in one of the above organisations and thus represent the interests of both sides. A characteristic of the Danish fleet is the fact that skippers usually own their own vessels. Company owned vessels do not play an important role, except in the purse seine fishery (Vedsmand *et al.* 1996).

5.3.3 Unique aspects of the Danish system of management

Denmark is one of the first countries to really implement co-management and devolved fishing governance (Nielsen and Vedsmand 1997). Co-management can be defined as a dynamic partnership whereby responsibility for resource management is shared between the government and user groups (Nielsen and Vedsmand 1999). To describe it generally one can say there are five types:

instructive, consultative, co-operative, advisory and informative. Co-management is like a set of institutional and organisational arrangements (such as rights and rules) which define the co-operation between the administration and user groups. These arrangements are influenced by the existing property rights structure, and by the extent to which the user groups are involved in the decision making process. These existing management institutions (state, regional or local bodies and/or private sectoral organisations) are active enough and concerned about bycatch to have sent a representative with a petition to the ASCOBANS meeting in Aberdeen, 1999. This is an example of an active formalised system of consultation and consensus building (Kooiman *et al.* 1999).

Conclusion

The two fishing communities examined here have a number of similarities. The two communities are insular, as fishing communities and the number of active fishermen is small in comparison to the total population of the country. The major difference is the fact that most Danish fishermen are individual boat owners whereas UK fisherman are part owners. This makes the UK fishermen closely dependent on shipping company owners.

In 1994, the UK fleet comprised 11,100 vessels of which 70% were under 10m (University of Hull 1994a, 1994b). The principle fishing ground is still the North Sea (accounting for 51% of the landings) but the UK fleet is ageing, and most vessels are over 20 years old. Despite a relatively low per capita consumption in comparison to the rest of the EU, the UK represents a significant consumer market for fish whereby 60% of UK consumption is provided by imports. Moreover, measured in employment, the UK processing sector with 21,000 workers is the largest in the EU (University of Hull 1995a, 1995b).

If the socio-economic aspects were to be examined in a general way, then two striking characteristics appear. If the employment sector is examined, for services, industry and agriculture for instance, it is evident that the same percentages are seen in Humberside (Hull and Grimsby) as in Denmark. This means that the two socio-economic profiles, although the comparison is not perfect, are similar. The agricultural or rural sector of each community employs a low percentage of people, but it is the services that employ 65-70 percent and industry which make up 32 percent of the total employment (Figure 5-3).

From this brief background on the case studies, it is evident that although the gillnet fisheries in the North Sea are small in number they are very important locally. The gillnet fleets from Grimsby and Denmark have common origins, and exploit the same groundfish fisheries for cod, flatfish and turbot. These set gillnets, set across wrecks, are also one of the main causes for bycatch of porpoises. The Grimsby gillnet fleet today has only a dozen active vessels left but the gillnet fleet in Denmark is composed of over 300 vessels.

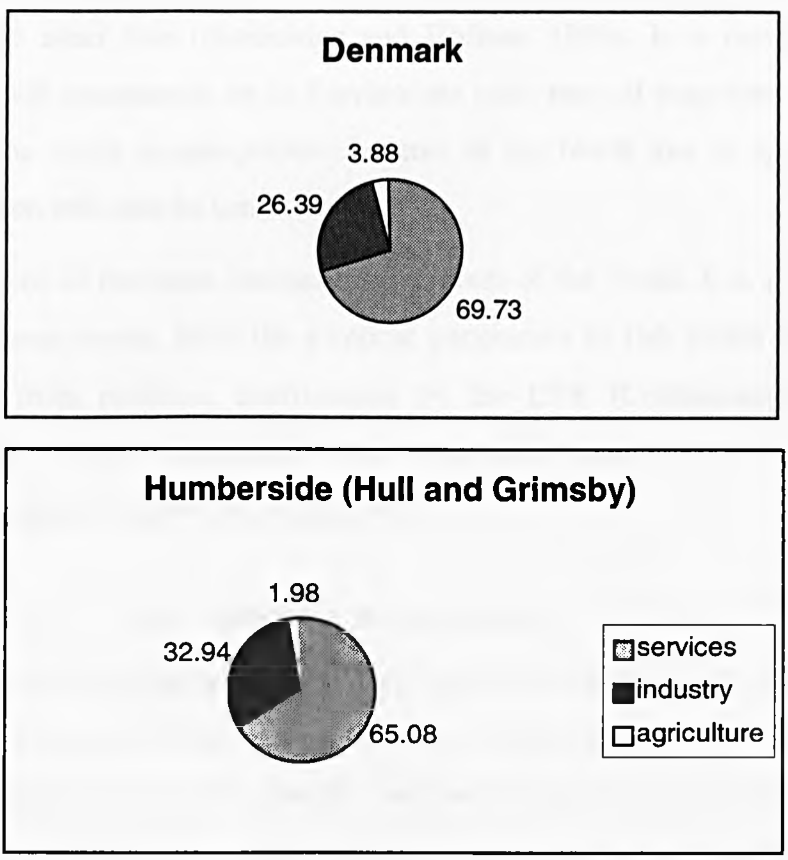

Figure 5-3. Socio-economic profiles of Humberside and Denmark: the percent employment in the different sectors, services, agriculture and industry during 1995 (source: EU DG XVI)

Chapter 6

Biophysical Features of the North Sea in association with Porpoise distribution

Porpoise school flying in the evening red sky along oceanic front.

Michitaka Uda, 1977

There are two types of interactions of marine mammals and fisheries. There is the technological one where marine mammals or porpoises interact with fishing gear such as gill nets as described in the previous chapter, and then there is the biological interaction where porpoises compete for the natural resources such as the herring, mackerel, cod and other fish (Northridge and Hofman 1999). It is the biological interaction that I will concentrate on as I review the main prey of porpoises and their concentrations. The major oceanographic features of the North Sea as it relates to porpoise distribution will also be summarised.

The North Sea is one of the most intensely fished areas of the world. It is also one of the most studied ecosystems, from the physical parameters to fish yields (Beverton and Holt 1957), from plankton distributions by the CPR (Continuous Plankton Recorder) to total primary production, from ecosystem models (Steele 1974) to individual based models or IBMs (McGlade 1999).

6.1 General background

The North Sea, situated on the continental shelf of northwest Europe, is open to the Atlantic Ocean in the north, to the English Channel in the south and to the Baltic Sea in the east. The climate of the North Sea is dominated largely by the Atlantic Ocean and is therefore characterised by a large variety of wind directions and speed, a high rate of cloudiness and relatively high precipitation (Stanners and Bourdeau 1995). One of the main influences is the inflow of oceanic water from the Atlantic Ocean and the large-scale westerly air circulation, which frequently contains low-pressure systems.

The North Sea covers 750 000 km^2 with a volume of 94 000 km^3. The greater part of the basin is shallow (30-200m). The depths of the Channel gradually deepen from 30m in the Strait of Dover to about 100m in the western part. Then the depth increases towards the Atlantic Ocean to about 200m at the edge of the continental shelf. The Norwegian trench reaches a maximum depth of 700m (See Figure 6-1 for the 200m contours). In the shallow North Sea, the entire water body derives from North Atlantic water and freshwater runoff in different admixtures (Stanners and Bourdeau 1995). Most of the North Sea water flows through the Skagerrak before leaving through the Norwegian Coastal current. The flow from the English Channel is from west to east, feeding a salty core of Atlantic water through the Strait of Dover (Stanners and Bourdeau 1995).

Most areas are well mixed in winter. In late spring, a thermocline is established over large areas; this separates the lower from the upper layer and a self stabilising stratification develops (50m in the northern North Sea, 20m in the western English Channel). The deeper parts (Norwegian Trench and Kattegat) are permanently stratified. A coastal strip along the southern part of the North Sea, stretching from northern France to the German Bight, remains vertically mixed during the whole year (Stanners and Bourdeau 1995). Tidal currents are the most energetic features in the North Sea, stirring the entire water column in most of the southern North Sea, and the English Channel. Tidal energy from the Atlantic Ocean also forces a persistent current with an anti-clockwise circulation. Tidal heights are greatly amplified in the bays of the French coast of the Channel. The residence time can vary greatly between areas and layers in the North Sea. In the Skaggerak, the residence time is much longer for the deeper water (one to three years) than for the near surface water (one month) and times for up to 3.9 years are observed along the British coasts (Stanners and Bourdeau 1995).

6.2 Detailed description of the Physical environment

The North Sea is surrounded by the most heavily industrialised European countries through which several major rivers flow, the largest of which are the Rhine and the Elbe. The freshwater outflow discharges from estuaries into coastal waters slowly mix into the North Sea. These areas near the coast have increased loads of phosphorous, nitrate and heavy metals (North Sea Task Force 1993).

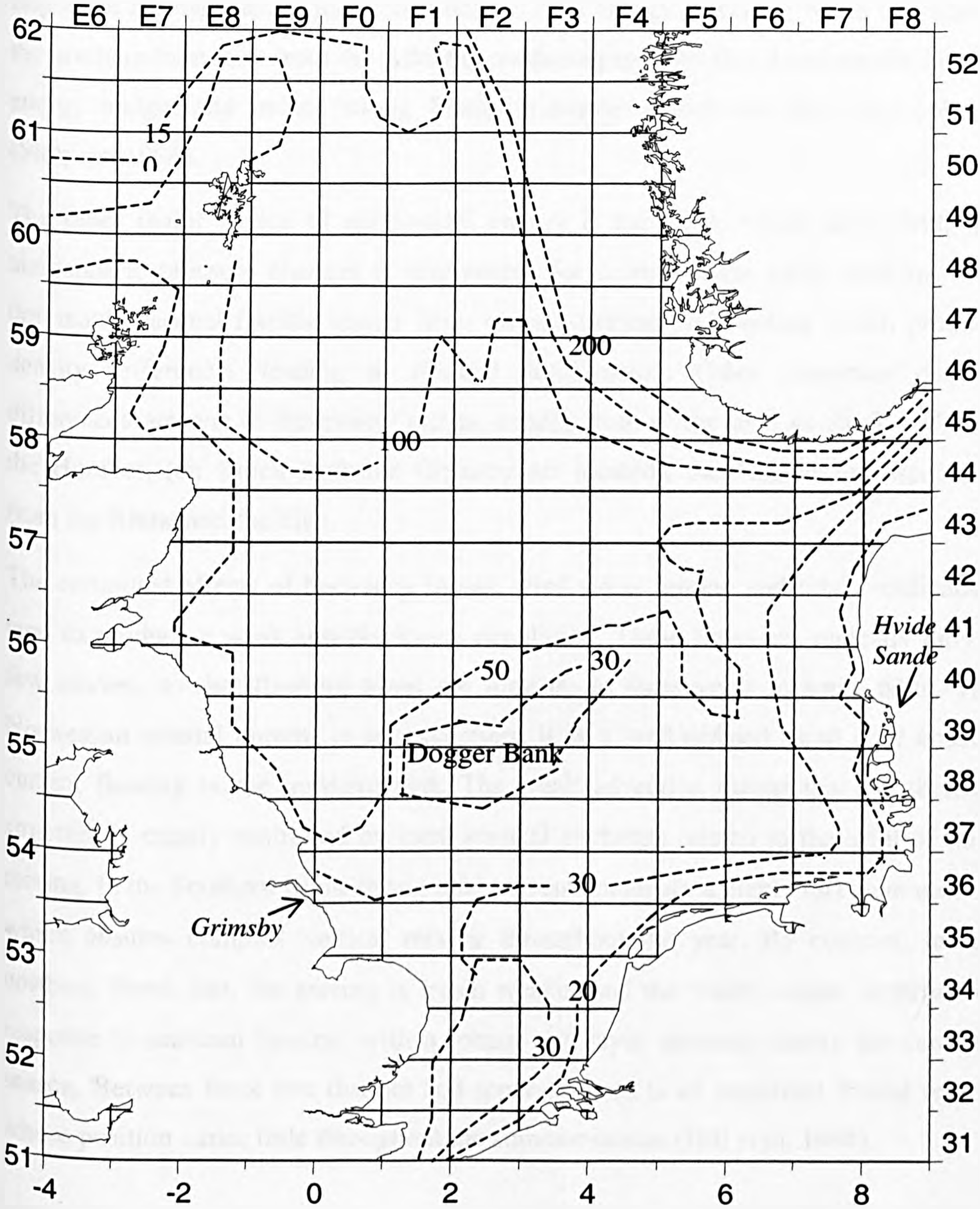

Figure 6-1. Location of the study areas indicating the Dogger Bank, the ICES rectangles and selected depth contours in meters

Energetics

The energetics of the North Sea are forced by several different mechanisms. The most important are the tides as mentioned before: tidal energy enters the North Sea across the northern boundary from the Atlantic, producing motions that dominate the kinetic energy budget and induce strong frictional stresses which stir the water column (Simpson 1994).

The other major source of mechanical energy is the wind, which along with the atmospheric pressure changes is responsible for driving storm surge motions. The dominant seasonal forcing comes from surface heating and cooling which produce density differences leading to thermal stratification. Other important density differences are due to freshwater inputs, mainly from rivers such as the Tyne/Tees, the Humber, (on which Hull and Grimsby are located), the Thames but especially from the Rhine and the Elbe.

The combined effects of buoyancy inputs, wind stress forcing and tidal rectification tend to produce a weak anti-clockwise circulation. These flows are typically only a few cm/sec. so that flushing times are long up to three years in some parts. The Norwegian coastal current is an exception: it is a well-defined rapid cold coastal current flowing in the northern part. The weak advection means that the thermal structure is mainly controlled by local vertical exchange related to the level of tidal mixing. In the Southern Bight strong tidal currents maintain a highly turbulent motion which ensures complex vertical mixing throughout the year. By contrast, in the northern North Sea, the stirring is much weaker and the water column stratifies in response to seasonal heating, with a robust two layer structure during the summer season. Between these two distinct and separate areas is an important frontal region whose position varies little throughout the summer season (Hill *et al.* 1994).

6.2.1 FRONTOGENESIS

Fronts are a very noticeable feature in the North Sea. From satellite infra red images, it can be seen that fronts are seldom fixed entities and occasionally show eddies and instabilities (P. Miller, Plymouth Marine laboratory *pers. comm.*). Meanders of 10 km are present at fronts, apparently as a result of instability as the fronts leaves the coast (Hill *et al.* 1994). Why does this occur? And what are their implications? As Longhurst (1998) described:

'When the semidiurnal tide encounters shoaling water, as over the continental slope, the amplitude of the tidal wave and its horizontal velocity progressively increases. At some depth, usually shoaler than the continental edge, vertical turbulence produced by friction between the tidal stream and sea bed is sufficiently enhanced (when added to turbulence produced by wind stress at the sea surface) as to overturn seasonal thermal stratification of the water column, giving trice to the tidally mixed regions of the shelf'. Simpson compared the frictional effects of the tidal streams to hurricane force winds blowing regularly twice a day (Simpson 1994). No wonder that that stratification is so regularly broken down on continental shelves (Longhurst 1998). The tidally mixed and stratified regions of the shelf are separated by a frontal region that migrates semi diurnally and also seasonally because, of course, the area of vertically mixed water over the shelf is larger in winter because of increased wind mixing.

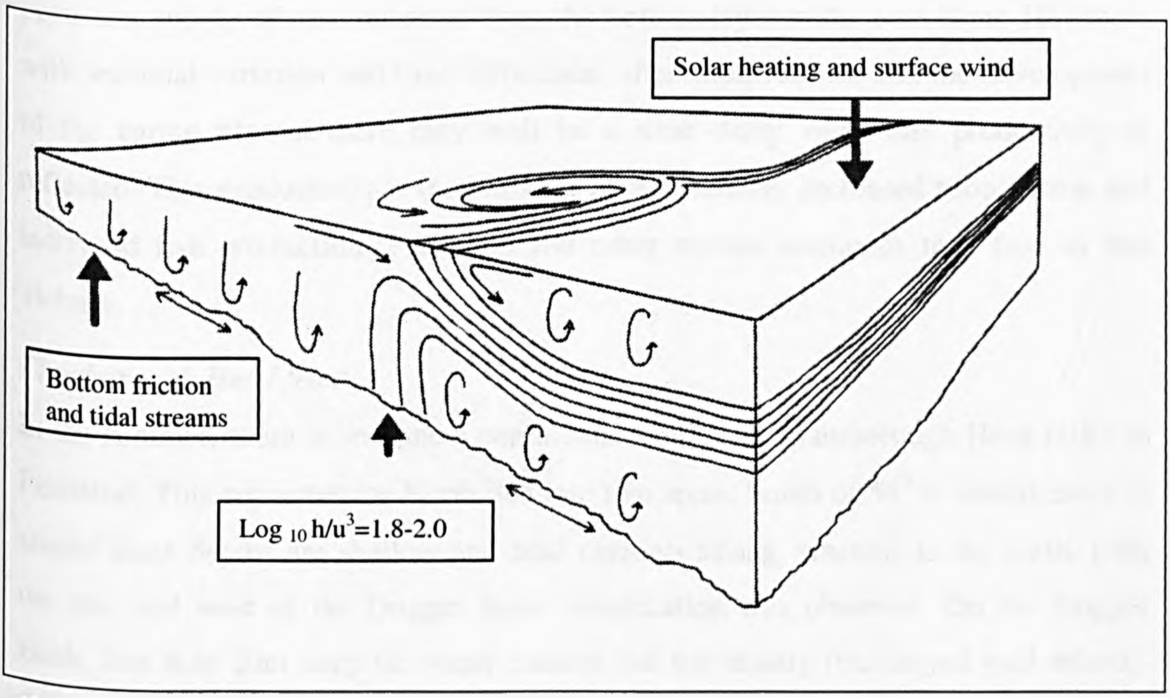

Figure 6-2. Schema of the formation of a front where h is water depth and u is tidal current strength (adapted from Longhurst 1998)

Main frontal equation

The summer thermal stratification can be predicted by the following equation:

$$h/u^3$$

where h is the water depth and u the tidal current strength (Charnock *et al.* 1994). There are other and more complex formulations, but the equation can be used to locate the transition between mixing and stratification. For most shelf areas the critical value of this parameter is between 1.8 and 2.0. Stated more simply, a tidal stream of 1m per sec in 100m of water falls between this range and therefore mixes. Along the length of these fronts important dynamical and biological processes take place.

Biological implications of fronts

The basic biological process at the front is the process of circulation which creates a persistent supply of new nutrients from the bottom layer to the next layer. However, with seasonal variation and time difference, after stratification, and the development of the spring bloom, there may well be a time delay when any productivity is reflected. This productivity is the basis for photosynthesis, increased zooplankton and increased fish production. Porpoises and other marine mammals may feed in this vicinity.

Flamborough Head front

In the summer, there is an almost continuous front from Flamborough Head (UK) to Friesland. This separates the North Sea into two areas. South of 54° N stratification is absent since depths are shallow and tidal currents strong, whereas to the north, both the east and west of the Dogger Bank stratification was observed. On the Dogger Bank, less than 20m deep the water column did not stratify (but stayed well mixed). Although the two stratified regions appear separate, they were connected further north, beyond the Dogger Bank.

The meandering of the flow off Flamborough Head for example may thus depend on low friction conditions that may occur only during neap tides. However, the total length of the frontal interface between tidally mixed and summer stratified water on the northwest European continental shelf is at least 1500 km (Hill *et al.* 1994). Along the length of these fronts important dynamical and biological processes take place which influence nutrient availability for primary production.

The Flamborough Head front is a well-studied front (Pingree *et al.* 1978). It runs roughly parallel to the north Yorkshire coastline (UK) for a considerable distance before branching eastward at Flamborough Head (Matthews *et al.* 1993). It is present as a strong surface temperature boundary separating a colder coastal regime from warmer offshore waters. The complete Flamborough frontal system consists of three parts. The first part is the Flamborough Head front, 10 km offshore parallel to the coast, and then there is the part offshore to and around the Dogger Bank, with a southern branch situated over the Outer Silver Pit. Even though the role of the Flamborough front in the North Sea remains uncertain, it most probably acts as a barrier inhibiting summer transport between the northern and southern North Sea. The frontal jet will transport contaminants offshore at Flamborough into the northern front. Whether the front acts as a real barrier to fish or porpoise movements still remains to be seen. Evans reported the regular sightings of porpoises and dolphins off Flamborough Head particularly between July and October (Evans 1995a).

Another frontal system is the Dogger Bank (van Aken *et al.* 1987). It extends from the southern part of the bank right across the North Sea. Off Denmark, there is another well-known front called the Jutland coastal front (Pedersen 1994). Porpoises are known to be near this area especially in the summer time (Hammond *et al.* 1995).

6.2.2 Fronts in the North Sea as indicators of fisheries risk areas

Tidal and frontal parameters can influence porpoise abundance and behaviour. Porpoises are known to feed on the tide (see Chapter 2). Frontal zones typically maintain a strong convergence of surface currents: in addition fronts limit the distribution of fish. Fishermen are also widely known to use the presence of fronts to locate dense aggregations of fish (Bowman and Esaias 1978).

6.2.3 Baroclinic model

In order to study these parameters in more detail, a 3D baroclinic model for the North Sea (developed by the Proudman Oceanographic Laboratory) was used. Data from an extensive hydrographic survey carried out in 1988 and 1989 for the whole of the North Sea, and an archive of high frequency meteorological data (from the UK Meteorological Office) indicated where such fronts normally occur. By using the difference between sea surface temperatures (SST) and near seabed temperatures, fronts could be detected as they moved across the southern and central North Sea. In general terms, the data show a front emerging in the spring months (Annex 3: Figure 6-1 to Figure 6-4) remaining in place across the Dogger Bank from June to August (Annex 3: Figure 6-5) when it becomes most pronounced and then slowly disappearing by the end of September (Annex 3: Figure 6-6). The model can predict the strength of stratification in the summers and the depth of the thermocline (Holt and James 1999). Tidal fronts occur at the border of summer stratified and mixed water at many places on the northwest European continental shelf (Simpson and Bowers 1981). The position of these fronts has been successfully predicted on the basis of water depth and tidal current speed (Pingree *et al.* 1978).

6.2.4 OTHER ENVIRONMENTAL INDICATORS

Besides fronts, tides are also important parameters for porpoises. Shore based observation of Dall's porpoise and their behaviour with respect to tidal fronts have also been studied (Willis and Miller 1998). The authors observed that porpoise abundance was higher during early morning and flood tides and increased significantly with an index of relative current from strong ebb to strong flood. Some porpoises observed during front activity surfaced within the front. The presence within the front was significantly higher during periods of strong ebb. These periods are characterised by strong frontal upwelling, which decreases from peak ebb to peak flood. The authors also found that higher porpoise abundance occurred during early morning and evening than mid-day, but found no correlation between abundance and the direction or relative strength or tidal flow. They found a positive correlation between abundance and tide height, and suggested that direction/strength of tidal flow could be more important in influencing abundance in front–active regions than other areas. The high abundance, extensive milling and frontal interactions of porpoise suggested that such a region was important for foraging sub-adult/adult individuals. Tidal mixing studies in other parts of the North Sea, e.g. off the east coast of the UK (Hill *et al.* 1994) also show a strong spatial coincidence of fronts and with areas of intense fishing effort. By extension, frontal regions in the North Sea would also be areas where extensive foraging could occur in sub-adult and adult harbour porpoises.

Palka (1995a) found that harbour porpoise densities were related to a number of environmental factors, including sea surface temperature, depth, density of prey species and spatial location, by inspecting contour maps of kriged values of each factor and by fitting generalised additive models to all factors simultaneously. On a large spatial scale, high-density aggregations of harbour porpoise were located in the same general regions during the two years examined. However, on a smaller scale, exact location and magnitude of the aggregations were correlated with the small-scale distributions of environmental factors. High densities of harbour porpoises were associated with waters that had surface temperatures of 10-13.5° C, contained fish densities of 1.5-11 fish caught per minute of trawling, and were 30-70 fathoms deep. Palka also concluded that internal changes in surface temperature and fish density could have been the reason for changes in the distribution and abundance of harbour porpoises.

Given historical records of porpoise sightings and by-catches, in conjunction with the output of a range of tidal-mixing and 3D baroclinic models (Charnock *et al.* 1994) it should thus be possible to predict times of specific tidal conditions when high aggregations of porpoises are likely to occur inshore, and hence provide an indicator of 'risk-of-by-catch' areas.

6.2.5 OTHER AREAS AT RISK

1. Other areas at risk include known breeding or nursery areas. Sonntag *et al.* (1998) who having examined stranded animals from the island Sylt, along the North Sea coast of Schleswig Holstein and found that 72% of all animals were younger than one year, supported the idea that this coastal area was one such area at risk for juvenile harbour porpoises. Recently WWF-International has proposed Sylt as a Marine Protected Area (WWF-2001a).

2. Moreover, primary production is four times as high (higher chlorophyll and nutrient concentrations) in the German Bight than those off the English coast. In the German Bight the region has tidal stirring, stratification as well as freshwater runoff and anthropogenic nutrient enrichment (Tett *et al.* 1994). This makes it an ideal location for young fish and young porpoises.

6.3 Summary of the Main Fisheries

6.3.1 Location, main gear types, gear conflict

It has frequently been said that the North Sea is one of the world's richest fishing grounds (McIntyre 1988). The fisheries in the North Sea can be separated into demersal and pelagic, human consumption and industrial fisheries. Catches from industrial fisheries are used for the production of fishmeal and feed for animals. Human consumption species are usually cod, haddock and some pelagic species. (ICES 1999a).

Demersal or bottom fisheries target cod, *Gadus morhua*, haddock, *Megalogammus aeglefinus*, whiting *Merlangius merlangus* or a mixture of flatfish species (plaice, *Pleuronectes platessa* or sole, *Solea solea*) with a bycatch of round fish. A fishery directed for saithe exists on the shelf edge. The catch of these fisheries is landed for human consumption.

The pelagic fisheries target mainly herring, mackerel and horse mackerel. Although most of the landings of these species may be landed for human consumption purposes, part of the landings are used for fishmeal and fish oil. The catch of the industrial fisheries is principally made up of sandeel, *Ammodytes* sp. Norway pout, *Trisopterus esmarki* and sprat, *Sprattus sprattus.* The industrial catches also contain bycatches of other species including herring, haddock and whiting. There are also smaller fleets that fish for crustaceans including *Nephrops*, *Pandalus* and brown shrimp, *Crangon grangon* (ICES 1999a).

The demersal fisheries are mostly made up of otter trawls, pair trawls, seines and beam trawls. In the pelagic fisheries there are pelagic trawls and purse seines. In the industrial fisheries there are small mesh otter trawls, pelagic trawls and purse seines. Gillnets thus, are not a very important gear in the overall context of the total North Sea fisheries.

Some of the major technological developments which changed the fishery in the North Sea during and after 1960 was the development of the beam trawl fishery for flatfish, purse seines in the industrial fishery and large pelagic trawls to replace drift nets. The introduction of power blocks in the 1960s increased the fishing possibilities for the purse seiners (ICES 1999a). Also electronic equipment, such as satellite navigation, fish finders and sonar have greatly increased the fishing efficiency of the fleets.

Looking at the trends in landings over the past 25 years demonstrate that there are declining catches, especially of cod, haddock, whiting and saithe (Figure 6-3). Landings of Norway pout are also in decline, as well as sole and plaice. Only sandeel landings are on the increase (Figure 6-4).

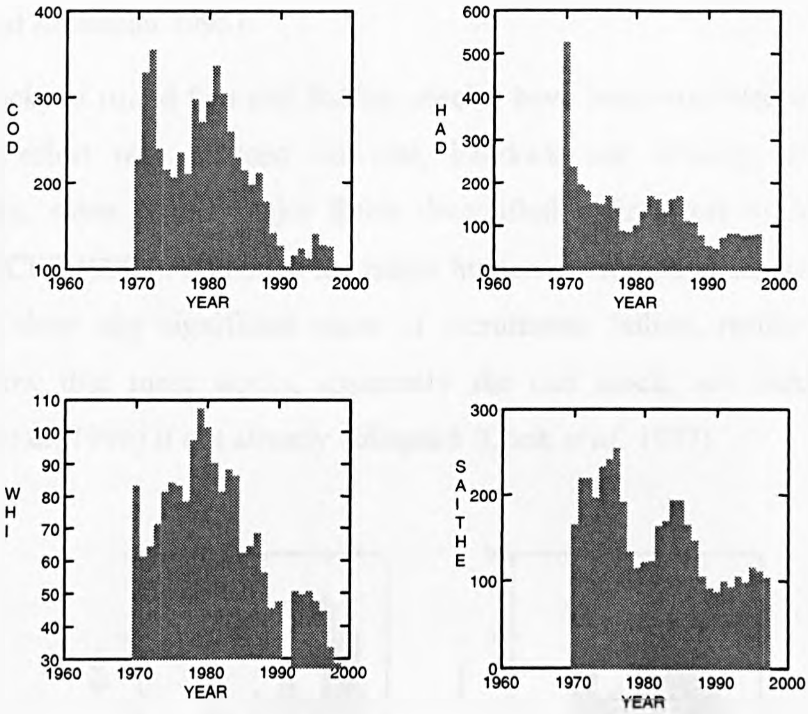

Figure 6-3. Landings of cod (COD), whiting (WHI), haddock (HAD) and saithe (SAITHE) in the North Sea by all nations for 1970-1997 (source: ICES 1999a)

The pelagic landings, dominated by herring, decreased to a minimum in the late 1970s, when the fishery for herring collapsed, but then increased in 1988 (Figure 6-7). Since then they have decreased again. The landings in the industrial fisheries increased to approximately 1.8 million t in the mid 1970s, and have fluctuated between 1 and 1.5 million t in recent years. These landings show the largest annual variations, due to the short life span of the species. The total landings reached 3.0 million t in 1974, and have been around 2.5 million t since the 1980s.

6.3.2 Overview of the main fisheries

In general, the fish communities today in the North Sea reflect the impact of more than a century of intensive fishing. The smaller, short-lived plankton – feeding species dominate, such as, sandeel, *Ammodytes* sp., dab, *Limanda limanda,* Norway pout, *Trisopterus esmarki*, herring, *Clupea harengus* and mackerel, *Scomber scombrus* (Stanners and Bourdeau 1995).

Since all stocks of round fish and flatfish species have been exploited to high levels, the fishing effort was reduced for cod, haddock and whiting (ICES 1999a). Consequently, some of the major fleets diversified their effort to *Nephrops* and anglerfish (ICES 1999a). Although the major human consumption stocks in the North Sea do not show any significant signs of recruitment failure, results from recent analyses show that most stocks, especially the cod stock, are certainly at risk (Robertson *et al.* 1996) if not already collapsed (Cook *et al.* 1997).

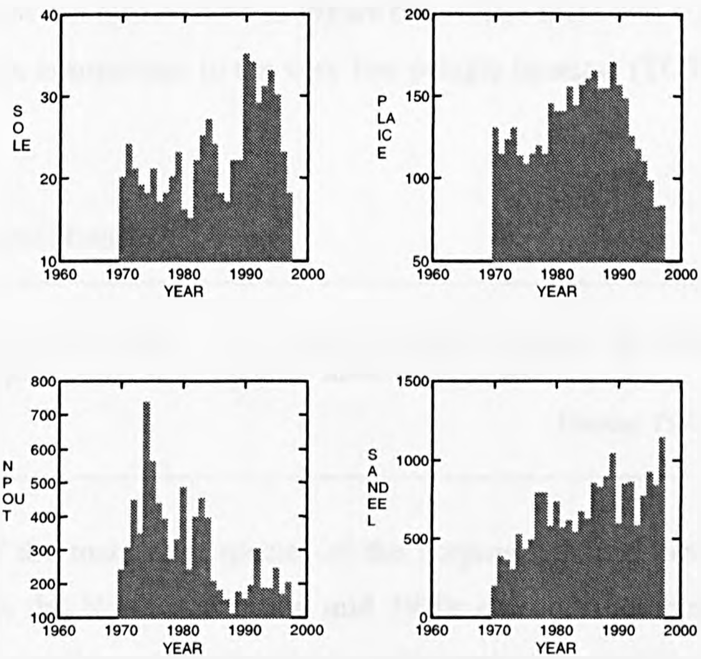

Figure 6-4. Landings of sole (SOLE), Norway pout (NPOUT), sandeel (SANDEEL) and plaice (PLAICE) in the North Sea by all nations for 1970-1997 (source: ICES 1999a)

The 'Gadoid' outburst

In the 1950-1980s, there was a sharp increase in cod, haddock, whiting, and Norway pout (also known as the gadoids). This phenomenon peaked during the 1960s (Mann and Lazier 1991) and is known as the 'gadoid' outburst. The total gadoid stocks increased by a factor of five and there were very few pelagic fishes (herring, mackerel and sprat) (Figure 6-5). It may have been as a result of a number of very successful year classes of cod but there is also evidence that a climate change occurred. During the period of enhanced northerly winds which led to a delay in events in the plankton community, and then resulted in an improvement in conditions for gadoid larvae (Cushing 1982). This was formulated as Cushing's match-mismatch hypothesis. In short it states that a year - class maximum matches the timing of the appearance of the larva requiring zooplankton as food. If not, then a mismatch occurs and the year class is weak. When Cushing related this to cod recruitment and the *Calanus* peak production, he found that when the zooplankton peak was delayed by three months after cod spawning, the next year's year-class was stronger. It is thus evident that late blooming plankton is favourable to cod larvae, creating a better match.

The gadoid outburst can also be seen in Figure 6-6, where there was a sudden surge of cod, and whiting in comparison to the very low pelagic biomass (TOTPEL) in Figure 6-9.

6.3.3 THE HERRING FISHERY

> *Porpoises give perpetual chase to the sardines, anchovies, mackerel and herring. Each individual porpoise devours an average of two barrels of fish per diem.*
>
> *Henbel, 1912*

Herring is one of the main prey species of the porpoise (Evans 1987). The herring stock collapsed in the North Sea in the mid 1970s due to a combination of heavy exploitation and use of new technology such as hydroacoustics but has recovered after a closure of the fisheries between 1977 and 1981 (ICES 1999a). In the mid 1990s it declined again. In 1996, effective management measures have been implemented to reduce the catches in both the human consumption and industrial fishery. These measures resulted in a considerable reduction of the fishing mortality (ICES 1999a). Herring used to be one of the main fisheries in Europe. The herring is still considered to be outside safe biological limits but it has recently recovered from an all time low.

Recent studies showed that herring prefer areas with cooler surface waters in the south rather than in the north at around 10° C. Areas with well mixed waters and transition zones between frontal and stratified waters consistently contained large concentrations of herring (Maravelias 1997).

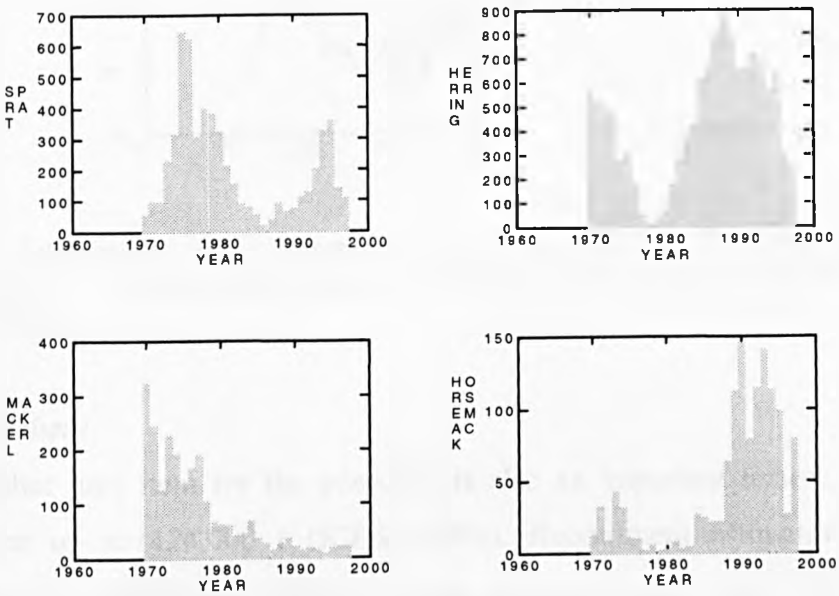

Figure 6-5. Landings of pelagic species, herring (HERRING), mackerel (MACKERL), horse mackerel (HORSEMACK) and sprat (SPRAT) in the North Sea for 1970-1997 (source: ICES 1999a)

The Sprat, Mackerel and Horse mackerel Fishery

The state of the sprat stock is not really known but the stock seems to have declined recently. The spawning stock of mackerel is still very small and recruitment is very low (ICES 1999a).

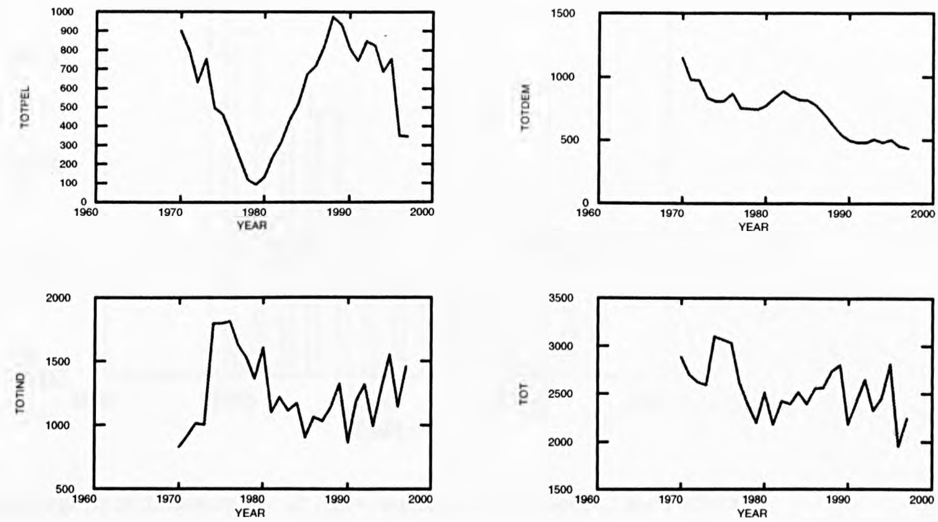

Figure 6-6. Total landings (TOT) in comparison with industrial landings (TOTIND) and total pelagic (TOTPEL) vs. total demersal species (TOTD) for the North Sea in 1970-1997 (source: ICES 1999a)

The Cod fishery

Cod, another prey item for the porpoise, is also an important fishery. Landings in 1997 were up to 124,000 t (ICES 1999a). Recruitment estimates predict that recruitment has been well below average in most years since 1985. This low recruitment may be another reason for the collapse of the European cod fishery (Cook *et al.* 1997). The cod spawning stock has been low in recent years but it is expected to increase further when the 1996 year class matures. However, a continuation of high fishing mortalities may cause a total collapse in the near future. Cod landings are low for Denmark (Figure 6-7) as well as the UK and Scotland (Figure 6-8).

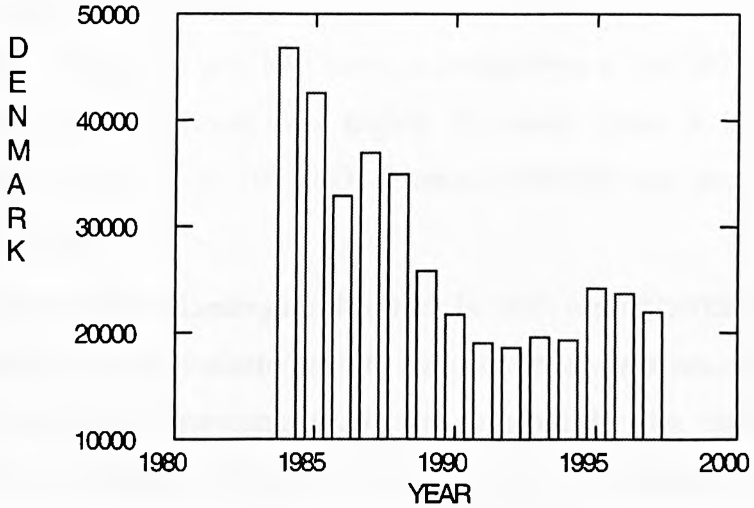

Figure 6-7. Cod landings (t) by Denmark for all gears combined in the North Sea 1985-1997 (source: ICES 1999a)

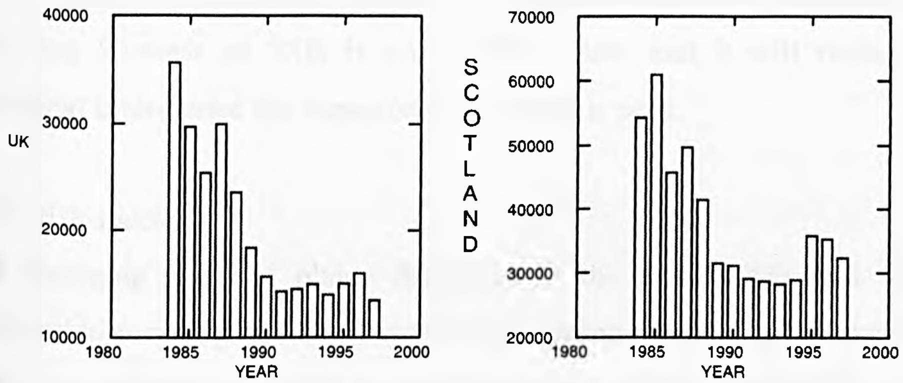

Figure 6-8. Landings (t) for cod only in tonnes for all gears combined in the North Sea by the UK and Scotland for 1985-1997 (source: ICES 1999a)

Cod biology is well described in Kurlansky (1998) and its fecundity is legendary (on average a female can spawn over a million eggs.). Despite the extensive work of Brander (1994) the exact spawning locations are still not known in the North Sea. The major areas for spawning are at depths of less than 50m and never beyond 200m, especially in the Bornholm basin (near Denmark), where egg density appears high in April and end of May (Cohen *et al.* 1990)

Saithe, Haddock and whiting

The stock of saithe is at a low level in comparison to the 1970s when it was lightly exploited and recruitment was higher. In recent years it has slightly increased. Landings in 1997 were 103 000t. Fishing mortality has declined considerably as compared to the 1980's.

Human consumption landings of haddock in 1997 were 82,000t. Historically the stock size has shown large variation due to the occasional occurrence of a very strong year class. The present spawning stock size is close to safe biological limits, but is expected to decrease in the short term because of a succession of poor year classes born in recent years.

Total landings of whiting have decreased since 1976 and the landings in 1997 are the lowest observed in the time series. The present assessment indicates that the stock spawning biomass or SSB is on a historic low and it will remain outside safe biological limits since the expected recruitment is poor.

Other fish species

The spawning stock of plaice decreased in the early 1990s and was the lowest observed historically in 1996 (Figure 6-4). Fishing mortality still remains high. At the present exploitation rate there is a high probability that it will remain below the levels observed in the 1970s and 1980s. Sole landings also declined and are close to the lowest observed historically. The stock is outside the safe biological limits but fishing mortality is still high (ICES 1999a).

The spawning stock of Norway pout was very high in 1998. The landings were among the highest in the time series, probably due to the good 1996 year class.

Over the years the spawning stock of sandeel, *Ammodytes* has fluctuated without a visual trend. There is a general pattern of an increase. *Ammodytes* can only live for two years and will provide a source of food which will fluctuate less than copepods, with a life span of 2 months (Steele 1994).

Although most of the commercially important fish species are in decline, many non-commercial species appear to be thriving or are stable (Daan *et al.* 1990, Daan *et al.* 1996, Heesen 1996, Rijnsdorp *et al.* 1996, Serchuk *et al.* 1996). This is true of the starry ray, although most ray species have been most sensitive to exploitation. Many other ray species have disappeared altogether from the North Sea (Walker and Heesen 1996).

Squid

Another prey item found in the porpoise stomach is squid (Pierce *et al.* 1998). Squid, *Loligo forbesi*, has a short life span of one year. Spawning occurs in Scottish waters in January to March and recruitment to the fishery occurs mainly in the autumn. Squid is taken mainly by demersal gear (Pierce *et al.* 1998). Analyses from research surveys show a peak distribution near the Rockall Islands and off Scotland. The correlation of squid and bottom temperature show that squid avoid temperature lower than 7°C. There is also a daily cycle of vertical movement of squid when survey abundance of squid was higher in daylight hours (Pierce *et al.* 1998).

6.3.4 Effects of fishing in the North Sea

Fisheries have the potential to change the overall species composition assemblage in an area (ICES 1999b). In the North Sea, stocks of mackerel, most rays and most demersal species have been greatly reduced in biomass (Rijnsdorp *et al.* 1996; Walker and Heesen 1996, Heesen and Daan 1996, Greenstreet and Hall 1996). It is likely that stocks of sandeel have increased (Sherman *et al.* 1981). These changes might be expected to affect diet, behaviour and possibly life history parameters of porpoises.

Fishing can have direct and indirect effects. Many recent studies have described the effects of fishing (Gislason 1994, Hall 1999). The direct effects, are the removal of biomass from the sea. If the removal exceeds the sustainable levels, then overfishing occurs with the resultant collapse of a stock. This in turn may change the composition of the community as recently described by Kaiser and de Groot (2000). Other effects are entanglements of seabirds with fishing gear. The indirect effects are the destruction of the habitat, especially by towed gear on the seabed, production of litter such as lost gear. Fishing, such as the use of heavy beam trawlers, also changes the habitat of benthos and other animals. In general, the North Sea fisheries have been greatly overexploited, especially in the past decades (Hagler 1995). ICES have recommended a reduction in effort and has reiterated again that the required reduction can only be achieved if included in the management (ICES 1999a).

Other resources, uses and resource-use conflicts

The North Sea's importance arises not only from the fisheries but also from a vast array of other natural resources, species groups and ecosystems, whose location, and concentrations are critical for the European nations (see BODC, McGlade *et al.* 1997).

The North Sea is one of the most heavily utilised marine areas in the world (Elliott and Ducrotoy 1994) and thus activities such as shipping, offshore mining, oil exploration and military use all lead to visual and acoustical disturbance to porpoises. While it is widely recognised that there is an increase in noise, the actual impact on the ecosystem and resulting porpoise distribution is uncertain. In general, there are increased noise levels such as ferry traffic since the 1980s (Salomon *et al.* 1988) as well as increased fishing activities in the North Sea. All these activities will affect the porpoise distribution.

Effects of climate change on the North Sea

Recent reports have recorded an increase in water temperature. This has brought warm water fish species into the North Sea, and may also have had effects on increased algal blooms. FAO, (in Globefish December 1999) reported that this warming is threatening the availability of cod and whiting. The temperature of the North Sea has risen by four degrees Centigrade over the last six years. This seems like a very great increase. If the cod and whiting stocks are affected, then porpoises may be forced to switch prey species, and change foraging behaviour, as well as move to cooler waters.

Conclusion

The porpoise is known to feed heavily on commercial fish species (ICES 1999c). This interaction leads to bycatch, since the prey is concentrated in fishing gear. The fisheries in the North Sea are described above. The demersal fisheries are experiencing reduced levels of cod, haddock, and whiting. The herring stock is decreasing. Herring used to be a major prey item for the porpoise and its demise may have caused changes in foraging behaviour. The state of the North Sea fisheries is mixed, with the exception of the Norway pout which was very high in 1998 (ICES

1999a). It is known that intensive fisheries in the North Sea have changed the size and age structure of fish populations (Pope *et al.* 1987, Gislason and Rice 1996).

The North Sea is also an area of heavy naval, ferry and boat traffic. All these will have an impact on the noise levels and may influence porpoises and their distribution (see review IWC 1998). The North Sea is a habitat for resident porpoises, and females and their calves will spend long times there. Although it is not known for sure how many populations or sub populations exist in the North Sea, it is still an important area for them.

Chapter 7

Unravelling Fisheries and Marine Mammal interactions:

Effort analyses of the Grimsby fleet in the North Sea

Hypotheses are nets: only he who casts will catch. — *Novalis*

In this chapter, I analyse fisheries and porpoise interactions by looking in detail at the distribution of fishing effort over 15 years of the Grimsby fleet. The Grimsby fleet, a relatively small fleet of only a dozen gillnet vessels, is nevertheless the largest component of the English wreck net fishery operating in the central North Sea (Bravington *et al.* 1997). Its fishing effort and distribution have not been analysed before. Assuming that high bycatches coincide with areas of high distribution of fishing activities, I propose a framework for risk analysis of bycatch of porpoises.

7.1 SPATIO–TEMPORAL DISTRIBUTION OF THE FLEET

7.1.1 ANALYSIS OF THE FISHERY

The main information about fishing activities are the catch and effort data collected by the Ministry of Agriculture, Food and Fisheries, (MAFF) also known as CEFAS in Lowestoft. All vessels over 10m are required by law to fill in logbooks stating the location of fishing, date, species fishing and number of day at sea. Data from 1983 to 1997 inclusive were provided from CEFAS for this study of vessels using gillnets from Grimsby, landing in England and abroad. I collated the data for all these years and then reformatted and analysed using Excel Microsoft and SYSTAT. All vessels were given a fictitious number to protect the confidentiality of their landings and earnings. The only identifying characteristic was the total length of the vessel.

It became immediately evident that looking at aggregated data is entirely different from disaggregated data. The total landings and effort data provide an incomplete aspect. For example through time, a number of vessels enter and then leave the fishery over the years. The total number of vessels varied considerably, despite the strict entry regulation. In this analysis, landings per vessel were plotted on ICES rectangles, which are 30 by 30 square miles.

7.1.2 Total landings

Total landings per individual trip, per vessel were obtained for 1983-1997 for gill-net vessels fishing out of Grimsby (Table 7-1). Total landings per vessel varied from a low of 1.4 tonnes (vessel B13 in 1992) to a high of 277 tonnes by vessel B24 in 1985. What is interesting to note is the variability of landings: B8 and B9 were able to significantly increase their landings over the space of one year, before dropping out of the fishery; and B9 re-entered the fishery in 1995 and landed 15 tonnes (t)[1].

7.1.3 Average landings

Average landings of all species per vessel were calculated in order to estimate the potential earning power per vessel. High average landings were obtained by vessels with more fishing experience; the highest total landings were obtained by vessels whose skippers had from 7 to 12 years' fishing experience in gill-netting (B5, B18, B19, B24, B30, B31, B34), with vessels B5 and B18 landing on average 202t and 160t per year (Table 7-2). Only B21 showed anomalous behaviour, in that after 10 years' gillnetting he still only landed an average of 23t per year. The 'successful' fleet was composed of vessels B5, B14, B18, B34, B36, B19, B30, B31 and B24; their average landings per year were higher than 100t.

7.1.4 Annual variations in total monthly landings

An analysis of total landings by month for the period 1985-1997 (Figure 7-2) shows that monthly landings from September - December remained relatively stable, but that a winter fishery in January - February has emerged in recent years. The analysis by individual vessel for all species (i.e. cod (*Gadus morhua*) pollock (*Pollachius virens*) plaice (*Pleuronectes platessa*) turbot (*Scophthalmus maximus*)) was made for 1985, 1990 and 1995 (Table 7-3, 7-4 and 7-5). The amount of cod in the total catch was also calculated in order to estimate the importance of cod in the individual fisherman's choice. Overwhelmingly, the percentage of cod was high, from 84 to 97%; fishermen from this fleet actively target cod and search for it over other fish species. Given this,

[1] One metric tonne, usually abbreviated t, is 1000 kg, approximately 2,205 lbs.

the fleet analysis in relation to bycatch analysis undertaken in this part of the study, concentrated on cod as the target species.

	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	TOTAL
B1	0	0	0	0	0	0	0	0	0	0	3.7	20.2	0	23.9
B3	114.4	22.5	3.4	5.5	0	0	0	0	0	0	0	0	0	145.9
B4	0	0	0	0	0	0	98.3	137.3	110.1	156.6	0	155	0	657.5
B5	0	0	0	0	0	0	129.7	114.6	87.5	122.6	318.5	224.7	120.4	1118.3
B6	0	0	0	0	26.0	106.0	188.7	140.4	108.5	91.1	0	0	0	660.9
B8	0	0	0	0	0	0	1.7	11.6	0	0	0	0	0	13.3
B9	0	0	0	0	0	0	2.8	6.9	0	0	14.9	0	0	24.7
B12	0	0	0	0	0	0	0	132.4	72.5	0	0	163.2	0	368.2
B13	0	0	0	0	4.1	0	2.4	1.3	0	0	0	0	0	7.9
B14	0	0	0	0	0	88.7	105.7	114.2	114.1	113.7	144.6	174.7	83.3	939.3
B15	0	0	0	0	6.7	0	0	77.1	73.8	14.8	85.1	188.8	139.8	586.3
B16	0	0	0	0	0	0	0	0	0	0	2.1	6.2	14.5	22.9
B18	0	0	0	0	0	175.8	243.5	159.6	177.4	221.6	217.1	250.1	171.5	1616.9
B19	0	0	0	125.3	130.4	161.8	142.1	120.9	109.4	131.3	131.3	194.0	50.0	1296.9
B20	0	0	0	0	6.2	0	0	0	93.1	150.0	185.5	230.5	104.5	768.0
B21	32.4	7.7	42.4	16.4	22.5	4.6	41.0	46.6	6.1	11.9	0	0	0	232.0
B23	0	0	0	0	0	0	0	0	0	0	11.6	87.6	67.3	166.6
B24	276.9	173.7	198.0	180.9	191.1	111.6	120.2	0	106.1	121.1	117.5	134.3	132.5	1864.4
B30	181.6	143.2	174.1	190.3	212.2	169.0	134.1	0	122.4	174.9	71.5	0	0	1573.7
B31	143.6	115.2	146.2	114.5	150.4	0	87.3	0	38.0	79.3	79.4	182.2	129.0	1265.7
B33	0	0	0	0	0	0	0	0	103.3	137.3	30.4	0	0	271.0
B34	158.5	100.2	100.6	91.8	159.3	0	131.2	0	83.8	138.9	125.7	0	0	1090.4
B36	162.7	124.1	169.8	109.3	153.7	0	155.3	0	67.6	90.7	115.2	120.2	0	1269.2
B39	0	0	0	48.5	24.1	0	52.6	0	0	0	0	0	0	125.4
B41	0	0	0	0	116.2	0	180.6	0	135.2	74.6	166.0	189.6	125.6	988.2
B43	0	0	0	0	78.4	0	137.9	0	9.0	0	0	0	0	225.5
B46	0	0	0	0	0	0	161.7	0	135.8	49.4	0	0	0	347.1
	1070	687	835	883	1282	818	2118	1064	1755	1881	1819	2322	1140	17671

Table 7-1. Total landings (t) of all species by individual vessel (B1-B46) for 1985 to 1997

Vessel	B1	B3	B4	B5	B6	B8
Total	23.92	145.85	657.49	1118.34	660.90	13.36
Ave/yr	11.96	36.46	131.49	159.76	110.15	6.68
Yrs fishing	2	4	5	7	6	2
Vessel	B9	B12	B13	B14	B15	B16
Total	24.78	368.25	7.98	939.34	586.35	22.91
Ave/yr.	8.26	122.75	2.66	117.41	83.76	7.63
Yr. fishing	3	3	3	8	7	3
Vessel	B18	B19	B20	B21	B23	B24
Total	1616.99	1296.99	768.04	232.06	166.69	1864.40
Ave/yr.	202.12	129.70	128.00	23.20	55.56	155.36
Yr. fishing	8	10	6	10	3	12
Vessel	B30	B31	B33	B34	B36	B39
Total	1573.74	1265.78	271.06	1090.44	1269.22	125.41
Ave/yr.	157.37	115.07	90.35	121.16	126.92	41.80
Yr. fishing	10	11	3	9	10	3
Vessel	B41	B43	B46			
Total	988.24	225.54	347.13			
Ave/yr.	141.17	75.18	115.71			
Yr. fishing	7	3	3			

Table 7-2. Total (t) and average landings per year of all species by individual vessels (B1-B49) from 1985-1997, and fishing experience of skipper (years)

7.1.5 Analysis of the directed cod fishery

Cod directed landings were generally highest in the third quarter of year (Q3) for 1985 to 1995 (Table 7-6). In 1987, 1995 and 1997 highest cod landings occurred in the first quarter (Q1) and in 1988, in the last quarter. Cod spawn in January and February and a lucrative roe fishery had developed for this period of the year. However, the mean landings over 13 years showed that highest mean monthly landings occur in the summer from June to September, with July and August having almost identical mean monthly landings for cod. In the early 1990's there was a significant increase in landings, with maximum landings of 2241t occurring in 1996.

7.1.6 Location of the cod fishery

Data from the individual vessel logs and cod landings data, showed that one or two areas, designated by ICES rectangles (see Chapter 6, Figure 6-1) were always heavily fished, whatever time of the year. Maximum cod landings from 1990 to 1994, occur in June, July and August (Table 7-7). In recent years, more cod were taken at the beginning of the year, in January and February. There had also been a tendency to fish closer to Denmark and further south. In 1996 the highest levels of cod were taken from areas 37F2 and 37F1. In the first quarter (Q1), maximum landings were obtained at 34F3, in Q2 in 36F3 and in the latter part of the year (Q3 and Q4) in 37F2. In 1997, most cod in Q1 was taken south in 35F3, then 36F2 and 37F2 for the remainder of the year.

1985	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total all	Total cod	% cod
B3	7.15	7.04	1.07	0	10.05	13.50	20.47	17.80	3.10	19.75	7.60	6.86	114.40	109.85	96.0
B21	5.89	0.23	0	0	0	0	0	1.59	10.49	8.35	2.51	3.32	32.40	31.36	96.8
B24	18.76	41.06	21.69	3.65	24.68	27.35	26.57	34.82	34.72	18.25	11.52	13.80	276.92	264.96	95.7
B30	14.00	13.72	27.54	13.74	9.44	7.28	12.25	16.76	23.96	13.22	9.80	19.86	181.64	174.22	95.9
B31	10.32	9.52	12.17	5.66	14.23	8.84	19.32	16.71	17.09	12.46	5.24	12.06	143.67	138.24	96.2
B34	31.24	12.48	8.32	5.79	5.06	0	9.12	4.55	21.20	27.06	8.70	25.00	158.56	152.89	96.4
B36	11.81	18.93	6.33	11.82	0	5.43	21.42	48.43	7.55	16.33	2.98	11.70	162.79	137.18	84.3

Table 7-3. Landings (t) by individual vessel (B3-B36) for all species combined per month in 1985

1990	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total all	Total cod	% cod
B6	2.22	7.52	2.42	5.47	0	19.02	19.26	10.46	16.50	11.69	5.78	5.68	106.07	103.67	97.7
B14	0	0	0	0.38	0	17.65	20.67	13.02	12.00	9.74	11.04	4.22	88.76	85.21	96.0
B18	0	0	0	18.77	25.29	21.88	26.99	36.24	24.64	5.42	15.34	1.21	175.80	159.10	90.5
B19	0	0	24.14	17.12	15.36	26.68	14.48	24.65	14.08	16.51	4.93	3.89	161.87	156.34	96.6
B21	0	0	0.23	0	0	0	4.04	0	0	0	0.42	0	4.69	4.43	94.6
B24	5.82	10.99	17.04	11.33	7.58	6.23	7.33	17.12	12.08	0.92	6.20	9.01	111.69	108.37	97.0
B30	26.53	18.00	7.11	11.01	11.93	21.07	22.67	15.30	4.70	17.07	10.53	3.06	169.04	162.37	96.1

Table 7-4. Landings (t) by individual vessel (B6-B30) for all species combined per month in 1990

1995	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total All	Total Cod	% cod
B1	0	0	0	0	0	0	0	0	0	0	0	3.71	3.71	3.71	100.0
B5	10.43	45.44	31.83	26.13	33.23	31.35	27.80	17.33	33.20	23.79	23.16	14.84	318.58	313.37	98.3
B9	0	0	0	0	0	0	0	14.99	0	0	0	0	14.99	1.52	10.1
B14	5.92	17.38	14.73	11.61	17.45	9.05	13.55	18.12	12.42	11.00	6.60	6.75	144.63	136.59	94.4
B15	0	0	0	0	10.34	23.51	4.73	8.45	6.96	11.67	11.26	8.17	85.11	78.27	91.9
B16	0	0	0	0	0	0	0	0	0	2.17	0	0	2.17	2.09	96.4

B18	23.16	30.36	25.05	15.23	15.50	17.45	15.98	27.31	20.11	11.80	7.51	7.68	217.19	202.91	93.4
B19	0	9.00	19.16	7.78	7.01	23.88	17.87	21.72	14.47	0	0	10.43	131.37	129.80	98.8
B20	3.55	20.10	26.14	6.68	28.55	22.16	26.55	0	18.97	17.03	5.15	8.60	183.51	180.52	98.3
B23	0	0	0	0	0	0	0	0	5.47	6.17	0	0	11.65	10.84	93.1
B24	13.36	29.69	11.43	0	0	6.02	16.85	14.22	11.42	0	7.75	6.74	117.52	114.91	97.7
B30	2.86	25.91	23.72	13.46	4.40	1.17	0	0	0	0	0	0	71.55	70.65	98.7
B31	2.62	11.93	5.85	4.20	9.26	4.16	6.19	0	11.28	3.93	10.53	9.42	79.42	76.10	95.8
B33	4.56	10.75	15.08	0	0	0	0	0	0	0	0	0	30.40	29.90	98.3
B34	0	18.03	18.39	11.50	13.13	12.14	6.48	21.63	14.23	2.63	7.55	0	125.74	123.64	98.3
B36	4.30	19.69	8.34	6.70	15.29	4.94	6.32	12.98	22.82	0	0	13.78	115.20	104.77	90.9
B41	0	24.19	15.28	0	10.28	16.01	28.15	21.15	16.85	10.28	11.81	12.03	166.07	165.60	99.7

Table 7-5. Landings (t) by individual vessels (B1-B41) for all species combined per month in 1995

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1985	94.55	98.14	73.82	40.05	61.85	58.22	106.32	114.33	111.45	112.56	47.38	89.99	1008.7
	9.37	9.73	7.32	3.97	6.13	5.77	10.54	11.33	11.05	11.16	4.70	8.92	%
		Q1	26.42		Q2	15.88		Q3	32.92		Q4	24.78	%
1986	59.58	42.02	37.11	26.29	39.23	90.66	77.16	45.13	98.13	93.26	17.65	27.60	653.86
	9.11	6.43	5.68	4.02	6.00	13.87	11.80	6.90	15.01	14.26	2.70	4.22	%
		Q1	21.22		Q2	23.89		Q3	33.71		Q4	21.19	%
1987	143.60	135.43	6.44	32.78	42.97	41.43	53.85	91.12	92.17	23.00	56.94	60.30	780.08
	18.41	17.36	0.83	4.20	5.51	5.31	6.90	11.68	11.82	2.95	7.30	7.73	%
		Q1	36.60		Q2	15.02		Q3	30.40		Q4	17.98	%
1988	82.90	74.11	17.66	30.41	59.21	87.36	41.62	98.93	117.05	98.64	172.95	60.42	941.29
	8.81	7.87	1.88	3.23	6.29	9.28	4.42	10.51	12.44	10.48	18.37	6.42	%
		Q1	18.56		Q2	18.80		Q3	27.37		Q4	35.27	%
1989	113.98	52.93	43.50	101.83	120.14	147.72	141.97	138.93	110.29	60.43	74.34	109.03	1215.09
	9.38	4.36	3.58	8.38	9.89	12.16	11.68	11.43	9.08	4.97	6.12	8.97	%
		Q1	17.32		Q2	30.42		Q3	32.19		Q4	20.06	%
1990	31.25	35.61	50.21	63.50	56.26	111.07	113.17	107.16	82.46	54.50	49.19	25.10	779.53
	4.01	4.57	6.44	8.15	7.22	14.25	14.52	13.75	10.58	6.99	6.31	3.22	%
		Q1	15.02		Q2	29.61		Q3	38.84		Q4	16.52	%
1991	134.76	132.06	195.1	108.29	227.08	186.21	294.91	240.52	161.02	89.83	83.60	106.39	1959.74
	6.88	6.74	9.96	5.53	11.58	9.50	15.05	12.27	8.22	4.58	4.27	5.43	%
		Q1	23.57		Q2	26.61		Q3	35.54		Q4	14.28	%
1992	99.30	91.25	79.08	79.06	86.92	110.47	104.64	124.96	97.39	75.88	36.33	7.62	992.96
	0.88	10.12	8.77	8.77	9.64	12.25	11.61	13.86	10.80	8.42	4.03	0.85	%
		Q1	19.78		Q2	30.66		Q3	36.27		Q4	13.29	%
1993	102.71	188.89	109.86	106.20	111.93	194.73	159.58	133.55	157.38	146.90	148.42	48.621	1608.89
	6.39	11.74	6.83	6.60	6.96	12.10	9.92	8.30	9.78	9.13	9.23	3.02	%
		Q1	24.96		Q2	25.66		Q3	28.00		Q4	21.38	%
1994	156.37	200.61	88.23	111.36	175.52	158.92	154.27	205.33	162.16	142.63	139.62	105.08	1800.15
	8.69	11.14	4.90	6.19	9.75	8.83	8.57	11.41	9.01	7.92	7.76	5.84	%
		Q1	24.73		Q2	24.77		Q3	28.98		Q4	21.52	%
1995	68.79	252.76	213.58	99.97	161.34	167.53	166.91	159.37	176.92	92.62	86.57	98.86	1745.26

	3.94	14.48	12.24	5.73	9.24	9.60	9.56	9.13	10.14	5.31	4.96	5.66	%
		Q1	30.66		Q2	24.57		Q3	28.83		Q4	15.93	%
1996	197.17	264.57	168.07	221.01	291.51	193.99	206.47	201.56	95.87	145.38	130.03	125.62	2241.29
	8.80	11.80	7.50	9.86	13.01	8.66	9.21	8.99	4.28	6.49	5.80	5.61	%
		Q1	28.10		Q2	31.52		Q3	22.48		Q4	17.89	%
1997	193.76	112.51	64.27	57.97	142.12	113.11	88.608	57.962	92.018	78.93	77.16	36.11	1114.55
	17.38	10.09	5.77	5.20	12.75	10.15	7.95	5.20	8.26	7.08	6.92	3.24	%
		Q1	33.25		Q2	28.10		Q3	21.41		Q4	17.25	%

Table 7-6. Total landings of cod (t, %) by month and quarter for the Grimsby fleet from 1985 to 1997

	B1	B3	B4	B5	B6	B8	B9	B12	B13	B14	B15	B16	B18
Len (m)	20	15	15	15	15	15	15	20	15	15	20	15	15
1985	0.0	1.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0
1986	0.0	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0
1987	0.0	1.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0
1988	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0
1989	0.0	0.0	0.0	0.0	6.2	0.0	0.0	0.0	3.0	0.0	8.0	0.0	0
1990	0.0	0.0	0.0	0.0	7.9	0.0	0.0	0.0	0.0	5.7	0.0	0.0	5.7
1991	0.0	0.0	6.0	6.5	7.0	9.0	14.0	7.7	4.0	5.7	9.0	0.0	5.2
1992	0.0	0.0	6.6	7.0	7.4	9.7	13.0	8.3	5.0	6.8	8.5	0.0	5.6
1993	0.0	0.0	6.7	7.5	7.3	0.0	0.0	7.7	0.0	7.9	9.0	0.0	4.3
1994	0.0	0.0	5.4	6.3	6.5	0.0	0.0	0.0	0.0	7.7	10.0	0.0	5.8
1995	4.0	0.0	0.0	7.4	0.0	0.0	15.0	0.0	0.0	8.0	8.1	7.0	5.7
1996	6.0	0.0	5.2	6.6	0.0	0.0	0.0	6.3	0.0	7.0	8.0	0.0	5.7
1997	0.0	0.0	0.0	5.9	0.0	0.0	0.0	0.0	0.0	6.4	7.5	5.7	5.9
Total	10	5	30	47	42	19	42	30	12	55	68	13	44
Ave/yr.	5.0	1.14	5.95	6.73	7.04	9.34	14.0	7.48	4.00	6.90	8.51	6.34	5.51
Yr. Fishing	2	4	5	7	6	2	3	4	3	8	8	2	8

Table 7-7. Average number of days per trip per vessel from 1985 to 1997 by length category and fishing experience (years)

	B19	B20	B21	B23	B24	B30	B31	B33	B34	B36	B39	B41	B43	B46
	20	15	15	15	15	15	15	20	15	10	20	15	10	15
1985	0.0	0.0	2.9	0.0	6.1	6.5	7.1	0.0	7.2	7.0	0.0	0.0	0.0	0.0
1986	0.0	0.0	2.1	0.0	6.5	7.1	7.2	0.0	6.9	8.1	0.0	0.0	0.0	0.0
1987	0.0	0.0	2.7	0.0	6.3	7.5	7.2	0.0	7.7	7.8	0.0	0.0	0.0	0.0
1988	9.7	0.0	1.4	0.0	6.4	6.4	7.3	0.0	6.2	6.8	4.7	0.0	0.0	0.0
1989	7.9	7.0	2.3	0.0	5.4	5.7	6.4	0.0	5.7	5.6	5.0	6.2	5.1	0.0
1990	7.3	0.0	3.2	0.0	5.5	6.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1991	6.9	0.0	5.1	0.0	5.0	6.1	5.6	0.0	6.1	6.3	4.8	6.6	4.9	7.0
1992	7.4	0.0	4.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1993	9.6	7.9	4.8	0.0	5.3	6.3	6.8	11.2	6.7	7.8	0.0	6.2	6.1	6.2
1994	9.5	8.0	3.7	0.0	5.5	7.2	8.3	8.3	7.3	7.3	0.0	6.6	0.0	6.6
1995	9.2	7.7	0.0	5.7	6.3	6.5	7.7	7.9	7.0	6.0	0.0	6.3	0.0	0.0
1996	7.2	6.6	0.0	8.9	5.5	0.0	6.8	0.0	0.0	6.1	0.0	5.7	0.0	0.0
1997	7.6	7.6	0.0	6.3	6.3	0.0	6.4	0.0	0.0	0.0	0.0	6.8	0.0	0.0
Total	82	45	33	21	70	65	77	27	61	69	14	44	16	20

Ave/yr.	8.22	7.46	3.27	6.95	5.83	6.55	6.99	9.11	6.74	6.86	4.82	6.34	5.36	6.58
Yr. fishing	10	6	10	3	12	10	11	3	9	10	3	7	3	3

Table 7-7. con't

Year	Q1	Q2	Q3	Q4	Total days	Total no. of ICES rectangles with fish landings	No. of vessels	Days/ vessel	ICES rectangles/ vessel
1997	35F3	36F2	36F3	37F2	1133	99	17	66.65	5.82
1996	33F3	36F3	37F2	37F2	2010	99	20	100.50	4.95
1995	36F3	36F2	36F2	37F2	1901	98	27	70.41	3.63
1994	33F3	37F4	37F3	36F2	2399	97	24	99.96	4.04
1993	34F3	34F3	36F2	36F2	2470	93	25	98.80	3.72
1992	33F3	36F2	37F1	37F1	2702	85	19	142.21	4.47
1991	35F3	35F3	37F4	37F2	2416	76	27	89.48	2.81
1990	36F2	34F2	37F1	37F0	1636	58	13	125.85	4.46
1989	33F2	36F2	33F1	33F2	1308	50	24	54.50	2.08
1988	37F1	36F2	37F2	37F1	1070	45	19	56.32	2.37
1987	37F1	36F2	37F1	37F1	892	39	15	59.47	2.60
1986	37F1	36F2	36F1	37F1	976	39	17	57.41	2.29
1985	36F0	36F1	37F1	37F0	1278	35	19	67.26	1.84
1984	36F0	37F1	36F0	36F0	1201	30	?	0.00	0.00
1983	36F0	37F2	38F0	36F0	1196	26	?	0.00	0.00

Table 7-8. Summary table of the results of the effort analysis from the Grimsby fleet for 1983-1997 indicating the ICES rectangle where maximum effort occurred in each quarter, total number of days at sea and number of ICES rectangles with fish landings, number of vessels and CPUE indices (days/vessel; area/vessel)

7.2 Effort analysis

Effort data are recorded by MAFF/CEFAS from fishermen's logbooks. Missing effort data are then apportioned in the CEFAS office to estimate number of days at sea per species. In this analysis effort data were plotted by ICES rectangles to help identify which fishing areas were most densely occupied and when. The results were compared with areas of highest fishing success, observations of porpoise migration, patterns of bycatch derived from interviews and other environmental phenomena, in order to identify areas and times of increased risk of harbour porpoise bycatch. The total number of days at sea, as well as the number of trips, were used. Although the two values are likely to be auto-correlated, both were used to ensure that biases caused through mis-reporting or incomplete log-book entries could be identified; porpoise bycatch data were also available on a trip by trip basis. Rather than estimating bycatch from thousands of hours fished, or nets set, which can vary much more than the simple measure of days or trips, the average number of trips per vessel was calculated.

The average number of days per trip per ICES rectangle per quarter per year from 1985 to 1997 for the fleet was calculated; from these statistics an overall average for each vessel for all species was derived (Table 7-7). Days per trip varied from one day to more than 15 days, although in the interviews, most fishermen stated that a normal fishing trip was about 5 to 7 days. Individually, most vessels were remarkably consistent in the number of days spent on each trip. Effort given by the length of trips, increased from 4.69 days in 1985 to 6.53 in 1997.

Taking all the effort data (50 vessels) it was evident that some vessels made only one trip, to try gillnetting and then dropped out of the fishery. The number of trips per year from 1985-97, whether regular gill-netters or not, ranged from one trip a year to a high of 38.5 trips per year; the overall average was 15 trips per vessel. The overall number of trips declined from 317 (in 1985) to 179 in 1986 but increased again in 1989 –1996 to over 300. However, in 1997 trip numbers declined drastically.

7.2.1 Total Fishing Effort Indices

There are many ways to calculate an index of effort: by gear type, hours fished, number of nets set or trips. In this case, the number of trips and days at sea were estimated to be important as this measure would indicate the time that a vessel might come into contact with harbour porpoises during fishing operations. In the initial analysis (taking all vessels of a certain gear category i.e. 50 vessels) the total number

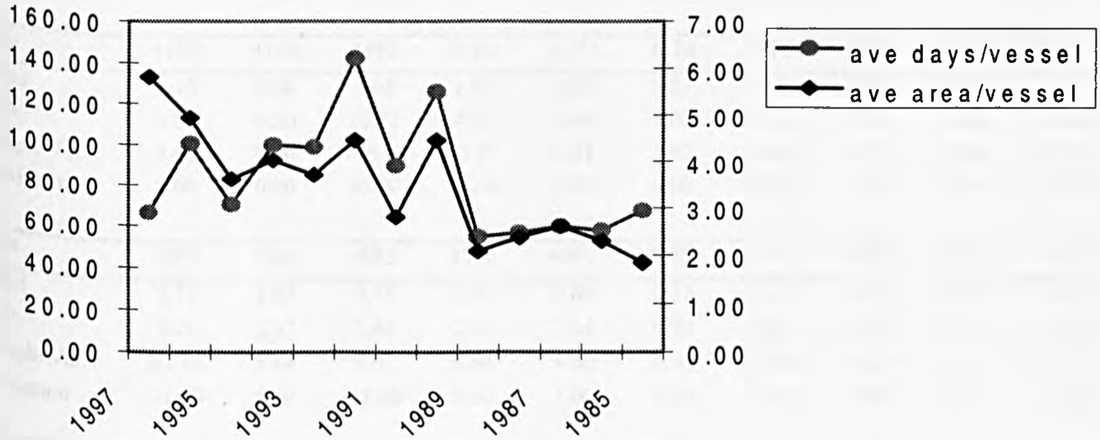

Figure 7-1. Effort indices for the fleet in average days and ICES rectangles fished per vessel for 1985-1997

of days at sea was estimated from the simple sum as well as the total number of trips taken by each vessel. Two types of effort statistics were generated: days at sea divided by the number of active vessels and the average effective area fished (measured in ICES rectangles) divided by the number of vessels (Table 7-8).

If the impact of porpoise bycatch on fisheries is to be assessed, the mortality of porpoises per fishing set must be estimated. Since actual bycatch data were scarce or non-existent, data from the fleet were analysed in order to estimate the most probable area and time of porpoise encounter rate. There are two statistical components that determine porpoise mortality level: i) the total number of fishing sets made by a fisherman in a year (a low number of sets has a low probability of bycatch) and ii) the average mortality of porpoises per set (Hall 1996, 1998). This last component is highly dependent on the duration of the soak time of a net. Mortality levels have not been measured but if a porpoise encounters a net, it gets entangled and probably dies within minutes. Since there were no data on bycatch per trip, the numbers of trips with bycatch, were derived from interviews.

In 1985, the effort totalled 1278 days, and the 19 vessels fished over an area covering 30 ICES rectangles. If searching time is an important indicator of CPUE, then it is evident that the total area searched has more than doubled from 26 rectangles in 1983 to 99 rectangles in 1997. The same has happened with days at sea: in 1983 there were 1196 days spent at sea, and in 1996 there were 2010 days, with a maximum number of days in 1993 of 2470. The number of vessels in the fishery fluctuated from 27 in 1991 and 1995 to 13 in 1990. In recent years the number of vessels declined to 12.

Area	41E9	41F0	41F1	41F2	41F3	41F4	41F5	40E9	40F1	40F2
Mean	1.13	0.00	5.93	1.87	0.93	0.27	2.40	0.27	1.67	8.27
S. D.	3.00	0.00	12.12	4.16	2.49	1.03	4.87	1.03	3.50	10.60
Sample Var.	8.98	0.00	146.78	17.27	6.21	1.07	23.69	1.07	12.24	112.35
Maximum	9.00	0.00	45.00	14.00	8.00	4.00	17.00	4.00	10.00	35.00

Area	40F3	40F4	40F5	40F6	40F7	39E9	39F0	39F1	39F2	39F3
Mean	3.13	1.07	0.73	0.93	0.80	0.27	2.13	2.20	10.07	4.40
S. D.	8.21	2.37	2.84	2.58	2.14	0.70	5.04	3.78	10.70	6.39
Sample Var.	67.41	5.64	8.07	6.64	4.60	0.50	25.41	14.31	114.50	40.83
Maximum	31.00	8.00	11.00	9.00	7.00	2.00	18.00	9.00	32.00	18.00

Area	39F4	39F5	39F6	38E9	38F0	38F1	38F2	38F3	38F4	38F5
Mean	7.73	2.87	0.33	0.40	9.27	11.73	4.80	5.53	8.40	7.80
S. D.	10.91	5.42	1.29	1.55	11.50	13.35	9.81	7.26	12.00	10.64

Sample Var.	118.92	29.41	1.67	2.40	132.21	178.35	96.31	52.70	143.97	113.17
Maximum	37.00	15.00	5.00	6.00	35.00	44.00	36.00	20.00	33.00	26.00
Area	38F6	38F7	37E9	37F0	37F1	37F2	37F3	37F4	37F5	37F6
Mean	0.27	1.27	0.13	4.07	18.20	42.73	40.60	13.33	11.53	2.47
S. D.	1.03	4.91	0.52	6.61	15.16	30.97	18.47	23.61	19.84	8.51
Sample Var.	1.07	24.07	0.27	43.64	229.89	958.92	341.26	557.38	393.70	72.41
Maximum	4.00	19.00	2.00	24.00	56.00	106.00	71.00	88.00	60.00	33.00
Area	37F7	36F0	36F1	36F2	36F3	36F4	36F5	36F6	35E9	35F1
Mean	0.87	1.13	14.07	17.53	33.93	15.67	5.20	1.27	0.67	2.53
S. D.	2.64	4.39	23.45	17.84	21.12	14.78	9.90	2.76	1.91	5.22
Sample Var.	6.98	19.27	549.78	318.12	445.92	218.52	98.03	7.64	3.67	27.27
Maximum	10.00	17.00	67.00	48.00	78.00	41.00	33.00	9.00	7.00	16.00
Area	35F2	35F3	35F4	34F1	43F2	34F3	34F4	33F1	33F2	33F3
Mean	14.73	27.07	5.67	4.73	4.60	15.13	5.07	1.60	6.40	14.73
S. D.	14.14	16.01	9.71	11.32	6.57	16.32	5.65	4.29	8.53	17.71
Sample Var.	200.07	256.21	94.38	128.21	43.11	266.41	31.92	18.40	72.69	313.78
Maximum	50.00	58.00	34.00	43.00	20.00	51.00	14.00	14.00	24.00	61.00
Area	33F4	32F1	32F2	32F3	32F2					
Mean	3.93	0.47	0.93	1.87	0.80					
S. D.	8.89	1.81	2.71	3.98	3.10					
Sample Var.	79.07	3.27	7.35	15.84	9.60					
Maximum	33.00	7.00	10.00	14.00	12.00					

Table 7-9. Fishing area, mean, Standard Deviation (S.D.), sample variance and maximum fishing effort in number of days at sea during Q3 for the fleet in Grimsby 1983 to 1997

7.2.2 DETAILED EFFORT ANALYSIS

In order to examine the causes of high risk of porpoise bycatch, fishing by the Grimsby fleet was examined in detail. To see where the maximum fishing occurred, the assumption was made that the area associated with the highest fishing effort in days was an area of high probability of bycatch. This high effort by quartile by year for the whole fleet was then mapped on a grid and coloured a different hue in order to distinguish the areas of maximum effort from areas of lower effort. In Annex 4: Figure 1 to Figure 15 show that fishing effort expanded over the years but the centre of maximum effort remained the same, and was always located in 36 or 37F1 or 37F2. The average amount of effort per ICES area over 15 years was calculated to see which ICES rectangle was the most important (Table 7-9). The area with the highest average days was 37F2, then 37F3, and 36F3.

7.2.3 Histograms

In order to quantify this initial observation, histograms were generated. Since in an

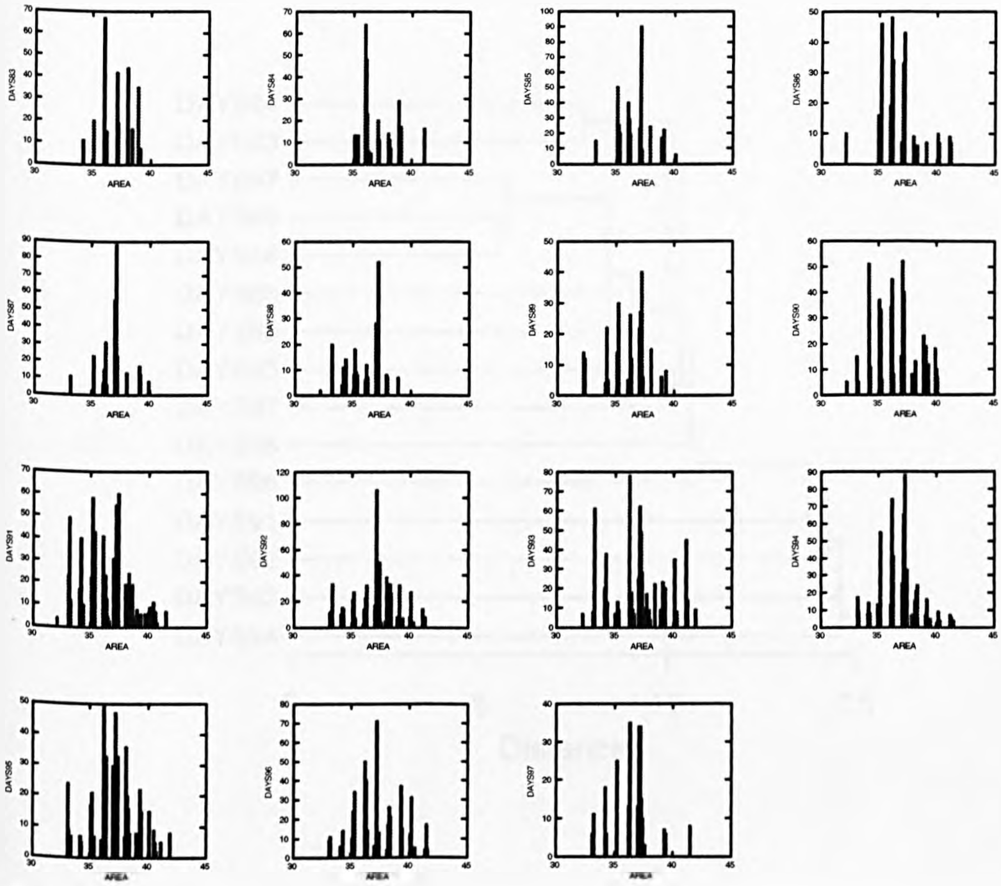

Figure 7-2. Histograms of fishing effort per area in Q3 for the Grimsby fleet 1985-1997

earlier observation, it was established that the most important season for fishing was Q3, using the same data per ICES rectangle for the whole fleet, the histograms show that certain areas were always fished and that there was an increase in effort but only during certain years (Figure 7-2). This indicates that fishing days in 1992 –1993 were different from 1983-1984. It is evident from these plots that days in 1983, 1984, 1985 are similar. In 1990, 1991 and 1992 an increase occurred which lasted until 1993 to 1994. In 1985, 1996 and 1997 effort declined. Cluster analysis was then attempted.

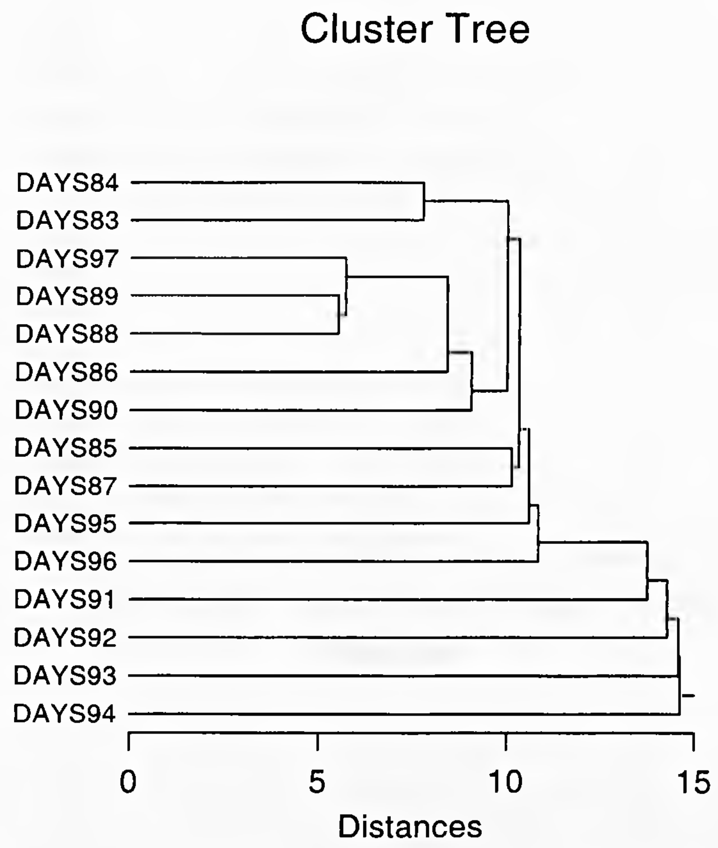

Figure 7-3. Results of cluster analysis and effort per area in Q3 for 1985-1997

7.2.4 CLUSTER ANALYSIS

Since cluster analysis or 'hierarchical clustering' is a multivariate procedure for detecting natural groupings in data, in order to find those variables that are highly correlated and similar to each other and exclude from clusters those variables that are unlike, it was decided to analyse the effort data using this technique. The same data was selected and using SYSTAT software (Version 9.0 SPSS Inc. 1996) an analysis on raw untransformed days fishing in Q3 data was applied (Figure 7-3).

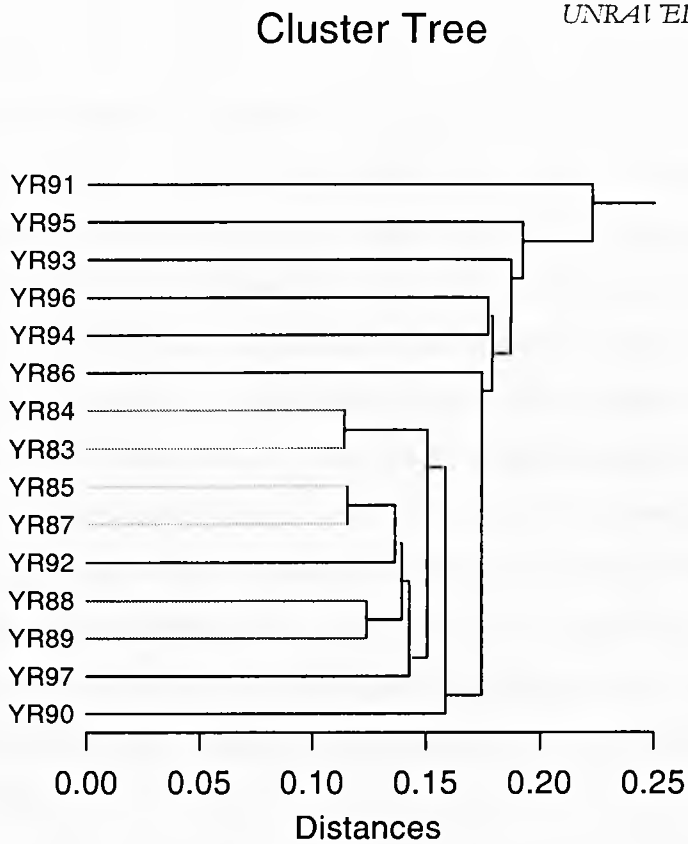

Figure 7-4. Results of transformed cluster analysis and effort per area in Q3 for 1985-1997

However, since fishing effort data are noisy and highly variable and a great amount of error exists, the data were transformed. Since the purpose was to identify a pattern over the years or over the areas, the maximum area of effort was given the value of 1. A proportion was then calculated from each area per year and then these 'ratios' were again submitted to cluster analysis. A slightly different pattern was obtained (Figure 7-4). This dendogramme shows the similarities of years 1983-1984 and 1985-1987 which are less similar than 1991, 1993, 1995 and 1996. Again the year 1997 was similar to years 1983-1984. The earlier years were different from 1993 and 1991-1995. The year 1991, a year of high effort was the most different, and 1997, a year with low effort was similar to earlier years in the 1980s.

The transformation of data is an important factor in the case of fisheries data: the examination of the areas' relative importance rather than comparison of actual numbers may provide a more realistic and robust estimate of the fishing pattern. Even from the positive results of the cluster analyses, some of which are strongly grouped, cluster analysis is best used in conjunction with ordination. When the clusters are plotted on an ordination plot, any relationship between the groups will be displayed and therefore PCA was attempted. All data were analysed again in order to find a pattern. The fishing effort per Q3 for 15 years was placed in a matrix. Each area was classified as a variable and a PCA or ordination of factor analyses was made. The first run was made on untransformed data. This resulted in only 20.25 percent of the variance explained. This means that although a pattern was seen using the cluster analysis, any variation by area could not be explained by more than 20.259 percent, i.e. non- significant.

7.3 ESTIMATES OF AREAS AT RISK

In order to examine areas at risk for bycatch, total landings (of all species) were sorted by year and by individual ICES rectangles. It was assumed that despite the change in total number of vessels each year, a fishing pattern would become evident. In the first years of fishing, for example, 1985-1989, most of the effort was concentrated on a few rectangles. In later years the effort was distributed over more rectangles. Up to 69.2% of all landings in a year was taken from certain rectangles.

These ICES rectangles represent the areas with the most catches, long soak times for the nets and probably the highest risk of bycatch. Other rectangles have less than 1% landings per year. The main rectangles fished are 36F2, 37F1 and 37F2. If the landings per month and per ICES rectangle are then examined and percentages are calculated to estimate risk associated for each month in each area the following table can be produced (Table 7-10).

In order to attempt a type of risk assessment, the fishing areas were designated as low, medium or high risk of bycatch. Fishing areas of high intensity were assumed to be areas of high bycatch.

ICES	1985	1986	'198	'88	'89	'90	'91	'92	'93	'94	'95	'96	'97
33F1							6.1						
33F2					10.1	3.4	4.3		3.9				
33F3							3.2	8.0	2.2	3.9	3.2	5.4	5.1
34F2						17.0	5.1		2.5	6.1	4.0	4.9	6.1
34F3						5.0			1.8			6.5	4.5
35F2					7.8	5.6	6.8	2.8	1.2				4.1
36F0	14.4									4.2			3.5
36F1	13.0	12.1	8.8			3.8	2.1						
36F2	9.1	12.4	9.4	13.1	13.0	9.1	2.9	4.1	4.9	9.5	8.1	6.0	10.3
36F3						1.7	1.4	6.0	3.1	2.9	4.4	7.0	6.9
37F0				11.0	6.2	2.0	1.8		1.3				
37F1	26.3	22.4	33.3	15.6	8.0	10.9	2.4	7.1	4.9	4.0	1.4	2.0	4.2
37F2	5.6	12.1	11.8	18.1	14.7	6.8	6.8	11.0	7.3	6.8	12.2	10.3	8.5
37F3						1.4	2.3	5.8	4.8	9.1	7.1	5.5	6.9
37F4						1.2	5.6		2.3	4.5	3.1	3.9	2.9
38F1			9.4			1.3	1.2		1.3	2.0	2.9	2.4	1.9
38F3							3.8	7.6	1.7	3.0	3.6	3.5	1.7
%	68.4	59.0	72.7	57.8	59.8	69.2	55.8	52.4	43.3	56.0	50.0	57.4	66.6

Table 7-10. Percentage of landings per ICES rectangle per year for the Grimsby fleet for 1985-1997

High or H was designated as areas with landings of 10 percent of the total above for 1985-1999. The annual landings per year each month are shown in Annex 2: Tables 10-24. Medium (M) risk was calculated as being the percentage of 5 - 9.99 percent of total. Landings below 5 percent were classified as 'low'. Zero catches were not classified and are shown as blanks. Some areas were not fished at all. In Table 7-12 it can be seen that there are certain high risk areas for porpoise bycatch. Area 36F2 can be classed as such an area for all months of the year, but especially during January, May and June. Another area at risk is 37F1, especially in January, February, November and December. The same is true for area 37F2, where the months most at risk would be from July onwards. The table shown (Table 7-12) is only part of the data. There are many more rectangles that were classified as 'low' risk (approximately 124 rectangles). This can be said to be the result of the change in the fishing effort as shown by the previous analysis, in that the fleet has extended the effort over more areas, resulting in lower catches per area.

Area	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
33F1	Low	Low	Low	Low	Low	Low	Low	Low	Low			Low
33F2	M	M	Low	Low	Low	M	M	Low	Low	Low	Low	Low
33F3	M	H	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low
33F4						Low	Low	Low			Low	
33F5			Low								Low	
34F0			Low							Low		
34F1	Low		Low		Low	Low	Low	Low	Low	Low	Low	
34F2	Low	Low	Low	Low	Low	M	M	Low	Low	Low	Low	Low
34F3	Low	M	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low
34F4		Low	Low	Low		Low	Low	Low	Low		Low	Low
35F0	Low		Low	Low	Low	Low	Low	Low			Low	
35F1	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low
35F2	Low	Low	Low	Low	M	M	M	M	M	Low	Low	Low
35F3	Low	M	M	Low	Low	Low	Low	Low	Low	Low	Low	Low
35F4	Low	Low	M	Low	Low	Low	Low	Low	Low	Low	Low	Low
36F0	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low
36F1	M	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low
36F2	H	M	M	M	H	H	M	Low	M	M	M	M
36F3	Low	Low	M	M	M	M	Low	Low	Low	Low	Low	Low
36F4	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low
36F5	Low	Low	Low	Low	Low	Low	Low		Low	Low	Low	
36F6				Low	Low	Low	Low	Low				
36F7				Low	Low	Low	Low				Low	Low
36F8				Low			Low					
37E9	Low	Low	Low					Low	Low	Low		Low
37F0	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low
37F1	H	H	Low	Low	Low	Low	Low	M	M	M	H	H
37F2	M	M	M	M	M	M	H	H	H	H	H	H
37F3	M	Low	M	M	M	Low	M	M	Low	Low	M	M
37F4	Low	Low	Low	M	M	Low	Low	Low	Low	Low	Low	Low
37F5		Low	Low	Low	Low	Low	Low	Low		Low	Low	Low
37F6		Low	Low	Low	Low	Low	Low		Low	Low	Low	
37F7	Low	Low	Low	Low	Low	Low			Low		Low	Low
37F8					Low							
38E9				Low	Low		Low	Low	Low	Low	Low	Low
38F0			Low	Low	Low	Low	Low	Low	Low	Low	Low	Low
38F1	Low	Low	Low	Low	Low	Low	Low	Low	Low	M	M	Low
38F2	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low
38F3	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low

Table 7-11. Estimated risk of bycatch per ICES rectangle calculated from 15 years' fishing data (where Low is low risk, M is medium and H represents a high risk of bycatch)

7.3.1. Observer programme data

An observer programme was undertaken in 1996-1998 (S. Northridge, *pers. comm.*, Sea Mammal Research Unit, St Andrews University, UK). Observers, placed on UK commercial fishing vessels, recorded observed bycatches of harbour porpoise.

Area	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Total
32F2		0	0										0
32F3		0											0
33F2			0				0	0					0
33F3		0	0				0	0					0
34F2							1	0	0				1
34F3							0	0					0
35F2								0	0				0
35F3				0					0				0
36F1									0				0
36F2				0			0		0				0
36F3				0			0	0					0
36F4				0				0					0
36F5								0					0
37F1									0				0
37F2		0		0			0		0				0
37F3		0	1	0			0	0	0				1
37F4								0					0
38F1									0				0
38F2							0			0			0
38F3			2				0		0				2
38F4							0						0
39F1								0	0				0
39F2									0	1			1
39F3								1					1
40F0								0					0
40F1								0	1				1
40F2							0	0	1	0			1
40F3									0				0
41F0							0						0
41F1							0	0					0
41F2								0	0				0
47E6				0									0
48E6				0									0
48E7			0	1									1
49E6				0									0
49E7				0									0
50E7				0									0
Total		0	3	1			1	1	2	1			9

Table 7-12. Number of bycaught porpoises by month and ICES rectangle from the observer programme

Out of the 18 trips observed in total, the recordings of bycatch in the Grimsby fleet were: April in ICES rectangle 48E7 (1 animal), March in 38F3 (2 animals) and 37F3 (1 animal), July in 34F2 (1 animal), August in 39F3(1 animal), September in 40F1 and 40F2 (2 animals), October in 39F2 (1 animal). If the porpoise bycatch obtained by observers in the Grimsby fleet are examined the following observations can be made. From the two tables (Tables 7-11 and 7-12) it can be correctly estimated that area 34F2 is at medium risk of bycatch in July. Area 37F3 is also a medium risk area for almost every month of the year. The neighbouring areas, 37F2 and 37F1 are both high risk areas. However, during the observer programme there were no bycatches recorded. According to fisheries data there is a risk of bycatch. Area 38F3 is another low risk area. Unfortunately, the observer programme was not representative of the fleet's activities. The allocation of observers for 1997-1998 was determined on the basis of expedience (Northridge and Hammond 1999). The observers were not placed on many vessels and thus were not able to observe all seasons. Ideally observers should have been reporting on the high risk areas (i.e. 36F2 in January to February) and May to June. In another high risk area, 37F1, only one trip was observed. In summary, this analysis presented areas at risk but it would have been more complete with more observer data.

Conclusion

From the historical analysis for the Grimsby fleet, it can be shown that fishing effort is mainly concentrated in specific areas close to the Dogger Bank. In the past few years, effort however has declined considerably. Fishing in Grimsby over the past decade has changed in many respects. The fishing effort increased in 1990-1992 but then declined. The search patterns changed as well. From a small and localised fishery, the gillnet fleet has expanded its search pattern to include many more areas. There are also newer and larger vessels (20-25m) with greater capacity. These changes in fishing and searching will affect the catchability and thus the bycatch. By looking at the historical patterns of fishing, areas of high risk of bycatch were identified and therefore seasonal closures could be implemented in order to avoid bycatch.

Chapter 8

Estimates of Porpoise Bycatches in the North Sea

You buy out a man whose father and grandfather were fishermen and you are wiping out a hundred years of knowledge. A fisherman is a special person. He is a captain, a navigator, an engineer, a cutter, a gutter, an expert net mender, a market speculator. And he's a tourist attraction.

Kurlansky, 1997

In order to obtain an estimate for porpoise bycatch in the Grimsby fleet, data from observer programmes, fisheries statistics and data such as interview estimates were combined. Interview data from Denmark were also analysed in order to obtain a comparative estimate.

In the absence of empirical data on porpoises, interviews were made with gillnet skippers. Fishermen's knowledge must be considered a primary source despite potentially biased perceptions (Mackinson and Nottestad 1998). Fishermen have detailed knowledge about fish distribution and behaviour, acquired to optimised catches while minimising effort. Therefore they tend to observe those environmental features which are linked to fishing success: seasonal movements, and habitat preference for example. Fishermen know porpoise presence and distribution but may not always be willing to impart this knowledge. Interviews were made with UK and Danish gillnet fishermen since their local knowledge on bycatch had not yet been incorporated and their estimates would provide baseline date for this investigation.

8.1 ESTIMATES OF PORPOISE BYCATCH

8.1.1 ESTIMATES OF PORPOISE BYCATCH FROM UK INTERVIEWS

During the interviews with fishermen, questions about bycatches of porpoise and other animals were posed. Most skippers claimed that there was no problem with porpoise bycatch in this fishery. Their estimates are provided in Table 8-1. Two skippers mentioned that they had no problems but they were involved in pelagic fishing (seining) in the southern North Sea. Fishermen directing their efforts at turbot leave their nets in the water for a longer time, and this may also increase bycatch.

	Fisherman	Number of Birds	Number of Seals	Number of Porpoises	Number of Whales	Maximum porpoises per year	Maximum Porpoises per trip
1	Ex trawler fisherman	1	0	0	1	0	0
2	Ex deepwater trawlerman	0	0	0	0	0	0
3	Ex trawler fisherman	0	1	0	1	0	0
4	Crew Gill-netter	>20	0	6-12/yr.	0	12	0
5	Representative North Sea F.O.	0	0	2/18 month	0	1.3	0
6	Skipper Gill-netter	0	1/yr.	2/trip	0	0	2
7	Skipper gill-netter	0	0	3-4/month	0	48	0
8	Skipper gill-netter	>10	1-2/yr.	1-2/yr.	0	2	0
9	Skipper Anchor seiner	0	0	0	0	0	0
10	Skipper Gill-netter	2	0	1/yr.	/	1	0
11	Skipper Gill-netter	>5	1/5 yr.	2/yr.	/	2	0
12	Skipper Gill-netter	0	5/3 month	2/3 months	1	8	0
13	Ex skipper anchor seiner	0	0	0	/	0	0
14	Skipper Gill-netter	0	0	2-3/dead		0	3
Maximum Estimates						48/yr	3/trip

Table 8-1. Summary of bycatch estimates per year and trip in the UK study fleet

To estimate the total porpoise bycatch in the gill-net fishery, the individual values of the 8 gill-net skippers listed in Table 8-1, plus the representative of the Fish Organisation, were all included; for this sub-sample of the fleet the estimate lay between 86 and 107.

The fleet size was 17 in 1997 and 10 in 1998. Thus in 1997 the estimate of porpoises taken as bycatch in the gill-net fishery per year would have been between 162 – 202, and for 1998 between 95 – 118. This number accords remarkably well with the average estimate of 142 obtained from the analysis of observer and fisheries data, but is higher than the number for 1997, when the fisheries effort dropped off dramatically.

Estimates of porpoise bycatch based on fisheries data

In the analysis of effort presented in the previous chapter, two periods of fishing behaviour were detected; one from 1983 to 1989 and one from 1990 to the present. By assuming that the relationship between fishing and bycatch within each of these time periods remained constant, it is possible to estimate levels of bycatch for at least the period when observers were used, i.e. 1990-1997. It is however important to note that significant changes in effort (e.g. from 1996 to 1997) need to be understood. In 1997, the Grimsby fleet was composed of 17 vessels; the total number of trips (i.e. total number of days at sea/ average number of days per trip) for the year was thus approximately 1133/7 or 162 (from Table 7-8 in Chapter 7).

If six trips out of the 18 observed had a bycatch, then assuming a constant probability of encounter, harbour porpoises would have been caught on 54 trips in 1997. If the average number of porpoises caught on any one trip was 1.5, then the estimate for 1997 for the Grimsby fleet would be 81 animals. However, the catch per unit effort in 1997 was very low compared to the previous five years. Those skippers interviewed indicated that lower catch rates earlier in the year, forced some vessels to leave the fishery; those that remained, individually fished over a wider number of the main areas. However, those with observers on board had bycatches within the epicentre of fishing activity for the period. Given the above, estimates of harbour porpoises caught as bycatch by the Grimsby gill-netting fleet for the period 1990-1997 are 117, 173, 193, 176, 171, 136, 144, 81, with an average of 149 porpoises per year. If the number of porpoises caught on one trip was 3 per trip (a maximum estimate provided by one skipper) then the total estimates for the same period are 234, 345, 384, 351, 342, 270, 288, 162 with an average of 297 porpoises per year.

8.1.2 Estimates of porpoise bycatch from Danish interviews

An estimated 5000-10,000 harbour porpoises have been estimated to be taken annually in the Danish gillnet fishery (Teilmann *et al.* 1998). However, the only scientific estimate of bycatch available for the Danish fisheries was made in 1993 by Vinther (1994, 1995a, 1995b). At that time bycatches were counted by observers on board Danish gillnet vessels whilst fishing in the North Sea: the vessels came from the same ports as those employed in this study. A total of 117 porpoises were recorded from 51 trips by 20 vessels. However, the programme had some problems, in that the study under-represented the whole fleet. By simple extrapolation, an estimate of 4629 porpoises for 1993 in sole, turbot and cod fisheries was obtained. Although this was the best scientific advice available, Lowry and Teilmann (1994) considered that it must be treated with caution, until more extensive surveys with scientific based sampling design and strategy are carried out.

Interviewees were asked to estimate the total number of porpoises taken as bycatch per year and, on how many trips per year these porpoises were present, as well as the maximum porpoises that they had ever caught (Table 8-2). The interviews provided an estimate of the extent of the bycatch problem, since many fishermen exploit different areas, at different depths and over different times. There were many fishermen who were aware of the issues and declared that porpoise bycatch was a real problem, however, they did stress that many times they had no bycatch whatsoever. The peak times occurred during the summer season, June, July and August. Some fishermen claimed not to see any pattern at all. Total bycatch estimates range from 346 – 442 porpoises per year: given that 10% of the fleet were interviewed, the overall estimate from the gill-net fleet ranged between 3500-4500. The upper range of this estimate is similar to that derived from the observer programme undertaken by Vinther (1994, 1995a, 1995b). However, these figures appear conservative in comparison to Vinther's re-analysis in 1999. He obtained an average annual estimate of 6785 porpoises (Vinther 1999).

The highest bycatches were associated with the turbot fishery where the combination of large mesh sizes and long soak times appear to play a significant role in catching porpoises.

Target species						Porpoise Bycatch per trip					
Vessel (m)	No.	Cod	Pla	Sol	Tur	Total / yr	Max/trip	Number/ trip	Number/ set	Trips with	Max
20-24	28	Cod	Pla		Tur	3-4		Every2/3 trip			
20-24	15	Cod	Pla			1-2		1-2		1-2	
20-24	19	Cod		Sol		<5		1		<5	
20-24	17	Cod		Sol		10-15		1-2		10	
20-24	22	Cod	Pla		Tur	30-40		5-6		5-6	40
20-24	11	Cod	Pla		Tur	1-0					
Max						30-40		5-6		10	40
17-19.5	4	Cod	Pla		Tur	8-10				6-8	
17-19.5	16	Cod	Pla	Sol		3-4		0,3-4			
17-19.5	7	Cod	Pla		Tur	100	30	100/3 months		6-7	
17-19.5	20	Cod	Pla	Sol		20		2-3			20
17-19.5	3	Cod			Tur	50-100		0, 10-15	10-15/set		
17-19.5	2	Cod				1				1-2	
17-19.5	5	Cod		Sol	Tur	10	100				100
17-19.5	18	Cod		Sol		25		1		15	25
17-19.5	21	Cod	Pla	Sol	Tur	5		<2		10	
17-19.5	25	Cod				2	0				
Max						50-100	100	33.3	15	10	
14-16.7	29	Cod	Pla			4-5					
14-16.7	6	Cod	Pla	Sol	Tur	3				3-4	
14-16.7	24	Cod		Sol		0	0				
14-16.7	27	Cod	Pla		Tur	40-60					15
14-16.7	8	Cod	Pla			24		0		4-5	24
14-16.7	13	Cod	Pla	Sol				10/trip		1-2	
Max						24		10		4-5	
10-12.4	26	Cod	Pla	Sol	Tur	1	0				
10-12.4	10	Cod				0		0			
10-12.4	9	Cod				0		0			
10-12.4	14	Cod	Pla			1-2 or seldom					
10-12.4	23	Cod	Pla		Tur	2		0, 2, 10		2	
<10	30	Cod	Pla			1	0	0			
Max						2		10		2	

Table 8-2. Summary of the bycatch estimates (where Pla is plaice and Sol is sole and Tur is turbot directed fishery) obtained from interviews with the Danish gillnet fishermen

It was therefore of interest to ask the fishermen in Denmark whether they had noticed any particular environmental parameters associated with porpoise presence. Some comments are listed below: 'You see them in calm weather.' 'You see them just before a storm.'' Two days before a storm you see them.' Two days before a storm. There are high bycatches.' One fisherman thought that with the wind and gale before a storm, the fish come close to shore, acting as a magnet for the porpoises.

When asked if the porpoise population was increasing, there were a variety of answers. Fifty-five percent of the skippers interviewed said that they thought the population of porpoises was increasing. Only one skipper (45 years of experience) said definitely that in his opinion the population was not increasing. One skipper (with 20 years' experience in fishing) said that 20 years ago there were many more porpoises than today.

8.1.3 Bycatch comments from fishermen determined from interviews

- Not in the North Sea. I caught a dead one. A porpoise. We had a dead one, the trip before last. It was dead. It had been down there, the flesh was falling off.
- Dolphins? Same as porpoises. We very rarely see dolphins in the net. They've been dead. Not even that. I've had one live porpoise in 22 years. The rest of the time we pick up dead ones off the bottom. We can see, we haven't caught them and they die in the net...they've decomposed and everything.
- It's hard to say, last trip we had 2 or 3, then we hadn't seen one for years. It's hard to say.
- You see them but you won't catch them (porpoises). It is impossible to catch them. The only nets that catch them are pelagic nets.
- In the 17 years I've been fishing, I've never seen one caught.
- Gillnets, when you set with the tide, the nets are on the bottom, or close to the bottom, where the fish are moving about, but there are no porpoises.
- Bycatch, it's not even a statistic.
- Bycatch? No seals. No dolphins. Yes, two birds, seagulls. I saw two basking sharks while herring fishing and a beagle shark off Lowestoft. I never caught anything else.

- I had a vicious seal once, it took two hours to get rid of him. We were only two miles offshore.

- Two harbour porpoises in three months.

- No, that was the first one (porpoise) in a long time. We used to catch a lot of them, things like that, when we were in deep water, Spitsbergen, sea lions.

- It's hard to say, last trip we had 2 or 3 (porpoises), then we hadn't seen one for years. It's hard to say.

- Porpoises. The occasional one. We actually have a chap, a young lad come aboard as an observer.

- Two per trip? Two per year.

8.1.4 SYNTHESIS OF FISHERIES, OBSERVER AND INTERVIEW DATA

The Danish interviews provided further indications of areas at risk. Many fishermen stated that porpoise (and seal) bycatch was a real problem, however, they did stress that many times they had no bycatch whatsoever. Most skippers admitted to having porpoise bycatch. Skippers with the larger gillnet vessels (14-20m) claimed to have a maximum of 24-100 porpoises in the season. The skippers of smaller vessels (<10m and 10-12.4m) claimed to take 1 or 2 porpoises in a season. They were all convinced that the height of the nets and the soak time played a significant part in determining the number of porpoises caught. 'We have a big problem with porpoises.' 'It's a problem, we do not want to catch them.' 'They (porpoises) are present in June to July, but mostly in June in the turbot nets.' 'In Norway, no net is allowed to soak for more than 24 hours, and they have no discarding and look at their fishery!' These comments were reinforced by information from the trawler fleet, which fished the same areas but had not experienced a bycatch problem. One trawlerman reported that in his 25 years of fishing he had only had a total of 10 by-caught marine mammals: sometimes, when the porpoises were abundant, such as summer and autumn and especially in September, he saw adult animals. However, he claimed that the noise and vibrations of trawling prevented the porpoises from being caught. Some fishermen were asked if they ever caught porpoises that were still alive. Most said no - it was usually too late, and they had already drowned; and one fisherman said he would reset the nets to let any porpoises out.

Those fishermen who fished close to shore generally saw them in shallow depths; one skipper reported that in 1977 he recorded groups of 100 or more porpoises in areas close to shore. Another major area where bycatches occurred was in the deeper waters at the edge of the Danish sector where they fished for turbot. Two skippers stated that they knew exactly when and where porpoises were to be found, yet were unable to avoid them when fishing. They also identified wreck netting for cod as a possible 'risk of bycatch' area.

Conclusion

From this analysis it can be seen that fisheries data (effort, observer data) as well as interviews can provide estimates for porpoise bycatch areas. Estimates were combined for interviews and observer programmes on a trip by trip basis. This was a new approach since the usual method is to extrapolate bycatch per 10,000 net km. hrs hauled (Bravington *et al.* 1997, Vinther 1999). However estimates of porpoise numbers were only possible for the few years when data from interviews and observer programmes were available, that is 1996-1998. Retrospective analyses had shown that the fishing effort changed in Grimsby and any extrapolations of the interview and observer data to previous years is not possible.

Although observer programmes give the best available estimates of bycatch, it should be noted (as described in Chapter 3) that there is always a negative bias associated with the estimates (Bravington *et al.* 1997). Many small gillnet vessels are often not investigated and unless interviews or substitute programmes exist, bycatch estimates remain unrecorded.

The most reliable, comprehensive estimates of bycatch using interviews according to Lien *et al.* (1994) were made by face to face contacts with fishing crews who were known from past contacts. Lien also discussed the limitations of interviews and demonstrated that fishermen are influenced by interview methodology. He suggested the maintenance of logbooks by volunteers, followed by end of season *in situ* interviews is probably the best monitoring method (Lien *et al.* 1994).

Interview data therefore can provide estimates of bycatch and it is not clear that any single method is best. In the case of the selected case studies these data can be used as baseline data of current bycatch levels.

Chapter 9

Possible Governance Solutions to the problem of Bycatch in the North Sea

> *How does nature govern? Nature does not govern with policy. Nature governs with rules that are embedded within it at the edges, and not at the centre. And yet it manages to create not only order, but ever increasing growing order against the never-ending tug of entropy.* *John Barlow*

Since one of the oldest traditions in fisheries is the unrestricted right to fish (Pearse 1996) and bycatch is the by-product of fishing, I examine the origin of property rights, and how it relates to fisheries in Europe. I also discuss the types of property regimes, and how the 'tragedy of the commons' relates to the bycatch issue. This is followed by a review of recent fisheries management approaches, including the effectiveness or measures to control bycatch. The chapter is concluded by suggestions for reducing bycatch levels, based on interviews with fishermen and analysis of their information obtained during this study.

9.1 Marine resource ownership, exploitation and governance

A property right is the legal right or interest with respect to a specific property. A type of resource ownership by an individual is called an individual right, or by a group, it is called a communal right. A property right is considered by many to be the basis for all incentives systems (North 1992, Crean and Symes 1996).

9.1.1 Are the seas and its resources public or private property?

Fishing traditions and the 'freedom of the seas', as well as how the fishing industry is organised, how fishermen are paid, give fishing much of its distinctiveness among industries (Pearse 1996). The prevalence of these traditions is probably due to the fact that fishing is one of man's oldest economic activities, and historically it has been isolated, geographically and socially from land based activities. Most governments have recognised this tradition and have respected it. However, recently with the global fisheries crisis, these regimes are about to change.

The principle, that fish in the sea are available to anyone was established by two major events. The first one occurred in 1215 whereby King John endorsed the Magna Carta and the crown stopped to grant fisheries as private interests and established the 'public right of fishery' (Megarry and Wade *cited* in Pearse 1996). Scholars suggest that this explains why private property in tidal fisheries never evolved in England and countries that adopted English law, in sharp contrast to the evolution of private property in other natural resources.

The other event was when Hugo Grotius, four centuries later who declared '*mare liberum*' or the freedom of the seas. Grotius argued that property could exist only if the holder was able to defend and exclude others. Since no one could occupy, defend and exclude others from the oceans beyond a narrow coastal band, the high seas were '*res nullius*', or no property. This reasoning, according to Pearse, supported by ancient Roman law that the sea is by nature common and not susceptible to possession, meant that the fisheries were open to everyone. Neither individuals nor governments could claim them; fish belonged only to those who took possession of them by catching them. Fish and whales were exploited with these principles. England and Holland, both emerging maritime powers, embraced Grotius' doctrine of 1609 and began to impose it in the world. Gradually, claims of sovereignty over oceans were reduced to coastal states' claims to a territorial sea, typically bounded by a line three nautical miles offshore (the range of a cannon). Beyond that, the principle of freedom of navigation and free access to fish became the rule.

Governments could pass laws and regulate their own fishermen on the high seas, but they could not control fishermen from other countries, except through international treaties. It meant that everyone had a right to fish in his country's territorial sea and a right shared with people of all nations, to fish the high seas as well. This remained the general rule until recently. With the overfishing problem, overcapacity of certain fleets and a dwindling resource, the problem of access and property rights has become the centre of international conflict.

9.1.2 Different property rights and regimes

There are four types: open access (Berkes 1989) private property, communal property and state property (Table 9-1). Open access is the complete absence of property rights: the resource is open to all, and the resource is not owned. Until recently, most marine resources outside of 3-, 12-, or 200- mile coastal zones fell into this category.

Property Rights	Private or Public Property	Characteristics
Open access	Public	Absence of enforced property rights
Group property	Private	Resource rights held by a group of users who can exclude others
Individual property	Private	Resource rights held by individuals (or firms) who can exclude others
Government property	Private	Resource rights held by a government that can regulate or subsidise use

Table 9-1. Types of property rights systems used to regulate common-pool resources (adapted from Ostrom et al. *1999)*

Under private property, rights to the resource are held by an individual who manages the resource as he or she sees fit. In the fisheries context, aquaculture and mariculture fall into this category. Private property also includes partnerships, not solely individual rights.

Under communal property, the rights to the resource are assigned to an identified group of users who may exclude others from harvesting the resource and manage its use among members of the group. This type of property rights regime, common among traditional artisanal fishing communities is still found in a number of contemporary coastal fisheries throughout the world. This includes Atlantic Canada, Brazil, Japan, Micronesia (Baines 1989, Johannes 1978 *cited* in Feeny *et al.* 1996). In Brazil, for example, informal ownership of fishing spots is determined by individuals or communities that establish ownership with outside competitors (Begossi 1995, 1996).

Finally, under state property, the government regulates access to and the utilisation of the resource. This regime is found within coastal economic zones of today. These are ideal categories: in practice resources are often held in overlapping combinations of these regimes (see Pinkerton 1994 *cited* in Feeny *et al.* 1996).

According to Feeny *et al.* 1996, it is also important to distinguish *de jure* from *de facto* regimes. *De jure* fisheries within the 200- mile limit are state property. In practice, in many cases fisheries within that boundary are *de facto* open access to the citizens of that state. The state has the authority to regulate access to the fishery.

9.1.3 Tragedy of the commons

What is meant by a common resource? Berkes *et al.* (1989, 1991 *cited* in Feeny *et al.* 1996) define a common property resource as a 'class of resources for which exclusion is difficult and joint use involves subtractability'. Most marine resources fit this definition. The catch taken by one fisherman affects the future productivity of other fishermen (Feeny *et al.* 1996). The bycatch taken by one fisherman thus affects the future fishing operations of other fishermen.

The 'tragedy of the commons' is the expression often referred to as the environmental degradation expected when many individuals share common resources. This observation was made by Hardin when there is no care for the resource and each person maximises his gain without regard to the others nor for the resource (Hardin 1968).

Hardin argued that users of a commons are caught in an inevitable process that leads to the destruction of the resources on which they depend. Hardin's ideas have been used by government and policy makers to rationalise central government control of all common pool resources (Ostrom 1990, Ostrom *et al.* 1999). However, Hardin (1968) was not the first modern analyst of the commons, although he is the most quoted. Aristotle (384-322 B.C.) observed that 'what is common to the greatest number has the least care bestowed upon it. Everyone thinks chiefly of his own, hardly at all of the common interest' (Politics, Book II, Ch. 3).

Questioning the tragedy of the commons

It has almost become conventional wisdom that unlimited entry to the marine domain leads to overfishing and that state intervention or privatisation provide solutions to this problem. Yet there is overriding empirical evidence that users of marine resources held as common property in many cases have developed rules and rights leading to their sustainable use (Kooiman *et al.* 1999). Ostrom also provides new insights (Ostrom *et al.* 1999). For thousands of years people have self organised to manage common-pool resources and users often do devise long term sustainable institutions for governing these resources. Therefore, although Hardin's main ideas are true there are still some exceptions.

Feeny *et al.* (1996) also described how access to common-pool resources is rarely open to all. This is not to deny that tragedies of the commons exist. While overexploitation will occur under certain conditions, this is not necessarily always attributable to the rapacious behaviour of fishermen.

9.1.4 Governance and mode of operation

Governing, according to Kooiman (1993), are all those activities of social, political and administrative players that can be seen as purposeful efforts to guide, steer, control and manage the sector. Governance is the pattern that emerges from governing activities of these persons, so that governability is a balancing process of coming to grips with the tensions between governing needs on the one hand and governing capacities on the other hand.

As Kooiman *et al.* (1999) states, because of the diversity, dynamics and complexity of the world we live in, fisheries and associated bycatch problems must be addressed in more than the traditional way. Traditionally it was only an economic problem in the harvesting sector caused by fishermen's behaviour. By contrast, the governance approach takes into account the fact that the fishing industry forms an integral part of the ecosystem embedded in institutions, social networks, stakeholders, and culture.

Modes of governance

Most government institutions around the world were built on the understanding of the times as the world created order for an industrialised society. The challenge today is how to make a transition from an industrialised model of big government, centralised, hierarchical, and operating in a physical economy, to an entire new model of governance, adaptive to a virtual, global, knowledge based, digital economy and with fundamental societal shifts (Caldow 1997). This especially applies to fisheries as the industry moves away from a centralised and almost old fashioned one to governance based on digital technology.

In a world where governance is increasingly operative without government, where lines of authority are increasingly more informal than formal, where legitimacy is increasingly marked by ambiguity, citizens are increasingly capable of holding their own by knowing when, where and how to engage in collective action. Recently a powerful environmental group sued the US government to protect the harbour porpoise in US waters. The Centre for Marine Conservation (CMC) and the Humane Society of the United states (HSUS) filed suit in the US District Court for the district of Columbia on 21 August 1998, charging that the US Department of Commerce and the National Marine Fisheries Service (NMFS) have failed in their legal responsibility to protect the Gulf of Maine harbour porpoise from death or injury to incidental take in New England gillnet fisheries (US Newswire 202-347-2770). This is an example of the pressures and actions that the public may apply when it is concerned about environmental issues.

In managing natural resources it is possible to choose between governing structures. None of the structures are intrinsically good or bad for allocating resources authoritatively or for exercising control and co-ordination, and the choice is not inevitably a matter of ideological conviction, but rather one of practicality.

More recently the governance term has been extended to include natural resources and endowments such as the oceans. A recent example is the Lisbon Principles of Sustainable Governance of Oceans (Costanza *et al.* 1998) which lists the following principles: responsibility, scale-matching, precaution, adaptive management, full cost allocation and participation. All these principles are of relevance to the issue of bycatch of porpoises.

9.2 Existing approaches to fisheries governance

9.2.1 Overall approach in the North Sea and Europe

Biological principles have governed most of fisheries science. Beverton and Holt (1957) developed their yield model for plaice in the North Sea, which was built on assumptions that fish stocks are stable, behave predictably under moderate levels of exploitation and tend towards equilibrium. Stock assessment was a simple straightforward scientific calculation. For a given equilibrium, it was simply necessary to calculate the proportion of the adult stock that could be extracted through fishing without endangering its sustainability, the Total Allowable Catch or TAC (Crean and Symes 1996). The concept of maximum sustainable yield or MSY thus became a key reference point for fisheries management. However, it faced considerable criticism in recent years (Larkin 1996).

In the North Sea, community management has been the management regime. In Europe the fisheries policy had been one of the individual country for a long time. However, when the UK decided to enter the EC, the access became common access. Sandberg (1996 *in* Crean and Symes 1996) asked the question for whom are these resources common? If they are common to the EU (European Union) as a whole, the resulting institutions will produce a set of strategic choices on the part of fishermen. If it is common to a nation state or to a region within a state, the resulting institutions produce different strategies from fisheries. If the resource is common only to one or several coastal communities, this again implies very different social institutions and very different strategies and outcomes for fishermen.

Fisheries have been managed with the use of total allowable catch or TACs. However, the TAC in the EU with problems such as discarding, high grading and the 'race to fish' has become unpopular with UK fishermen (Fairlie 1995, Symes 1995). Fisheries management may have to change with the new CFP in 2002.

9.2.2 The Precautionary Approach and its application to bycatch

One of the key principles in dealing with the bycatch of porpoises relates to precaution. The concept of the precautionary approach was enshrined in

Principle 15 of the Rio Declaration of the UN Conference on Environment and Development in 1992 which states:

> *"In order to protect the environment, the precautionary approach shall be widely applied by States according to their capabilities. Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation."*

The implications of the precautionary approach for capture fisheries have been intensively studied (FAO 1996a, 1996b, 1996c, 1997a, 1997b) the guidelines summarises them as follows (FAO 1997c):

'1.6 The precautionary approach involves the application of prudent foresight. Taking account of the uncertainties in fisheries systems and the need to take action with incomplete knowledge, it requires *inter alia*: Consideration of the needs of future generations and avoidance of changes that are not potentially reversible'.

The 1995 FAO Code of Conduct dedicates Article 7.5 to the precautionary approach (FAO 1995). The code requires that those critical factors which constitute the social and economic dimensions of the management system be understood, especially in terms of how revenues vary with the level of exploitation and relate to dynamic market forces, and how individuals or groups of fishermen behave in relation to the resource upon which they depend. Social and economic factors are of course intertwined, and changes in the distribution of income, the type and amount of employment and the degree to which interest groups can influence decision-making will all have an effect on the management regime. There may also be instances where socio-economic dimensions can conflict in the short-term with environmental concerns.

9.2.3 EFFECTIVENESS OF CURRENT MEASURES REGULATING BYCATCH

How can the effectiveness of the measures currently regulating bycatch be described? ASCOBANS has made bycatch an important issue over the past years. At a recent meeting, (ASCOBANS 2000a) ASCOBANS reiterated the issue of bycatch reduction, but stated that it is now up to the individual nations to translate this into action (ASCOBANS 2000a). Unlike the US whereby the

MMPA provides the state with the authority to act, the situation is more complex in the North Sea due to the number of countries involved. It is evident that each individual nation will solve the bycatch problem in their own way. The EC is not a party to ASCOBANS and the targets adopted by the parties of this agreement may differ from those of the Commission (M. Wallström *pers. comm.*).[1]

9.3 SUSTAINABLE INSTITUTIONAL DESIGN

The problem of bycatches of small cetaceans is more than just an issue of better fisheries management, although the mechanisms and the causality lie within fisheries. Rather it is connected to the substantive issue of human perceptions of the ecological value of a group of animals and the institutions in place to regulate the system. Concerns about bycatch arise from ethical as well as environmental arenas and potentially place the future of a small number of humans in conflict with a slightly smaller number of marine mammals. Problems arising from fisheries are like games – the essence of them is impossible to characterise. An approach suited to solve discarding or the sale of illegal fish is often inadequate to address over-exploitation. And an approach suited to cutting back on fishing effort is of little help when questions concerning the reduction of under-size fish or unwanted bycatch have to be addressed. The essential point is that controls on over-exploitation are generally dealt with at a national and regional level, whereas reductions in illegal sales of fish evokes a solution at the local level. A global framework in which such local level solutions is still required, but many of the actions need to be made on a finer scale. Thus households, vessels, city governments, national governments and international agencies or combinations thereof can all act as appropriate administrative units for different fisheries problems, and the jurisdictional authority can lie anywhere between a vessel's claim on a wreck on which to fish to the whole ocean. Without the right scales, any system of governance will fail (McGlade and Metuzals 1999).

It is important to examine the institutional framework within which the industry is situated. Real people interact with each other; buyers and sellers continuously adjust their behaviour patterns according to responses to the rules that they

[1] Answer given by Margot Wallström, EC Commissioner for the Environment on behalf of the European Commission 16 October 2000.

themselves have helped to evolve. It is about how the players respond to the rules. For example, when fishing for cod on wrecks, or wreck fishing, most fishermen in the interviews replied that they would investigate before going to the grounds who had been fishing there before. The unwritten rule was 'first come first served'. All fishermen followed this behaviour and it can be described as a type of governance with its own rules and rights. When the Danish fishermen were asked whether they had any problems with Grimsby fishermen, they unanimously replied that they had none, except for three Grimsby fishermen that even the English authorities themselves had difficulty to control.

It is clear that the real problem is not one of fundamental mistrust but rather a need to acknowledge where the different burdens of risk lie. For example, the fishermen in Grimsby were asked how they would manage their fisheries if offered to do so themselves, what their opinions were as to the CFP or Common Fisheries Policy, and options if the fisheries they were involved with became non-viable. All fishermen expressed their dissatisfaction with the current management of the fish stocks, they all wanted to see simpler regulations applied across the board and more say in the decision making concerning local issues. Regarding the bycatch problems, none of the fishermen wanted to catch porpoises in their nets, and they were aware that it was causing problems in the scientific community. But fishing was their livelihood and as with any 'hunting' activity' there was an inevitable risk of bycatch and waste. There were no alternatives to fishing for most of the local Grimsby people, unemployment levels were already at 13.5%: so most would seek to leave the area if necessary. Given the numbers of people involved in the industry (approximately 200 directly and indirectly) and the current level of landings, then the loss of revenues would exceed several million pounds sterling per year.

As with the UK, the Danish fishermen did not want bycatches of porpoises, but there were concerns that if bycatches were to be dealt either through technological means or constraints of fishing, then individual fishermen would have to meet the cost from within the current market price. Comments included: 'Give turbot fishermen new nets. There are only a few fishermen left fishing for turbot. If there is such a big problem with catching porpoises, give them compensation.' 'Who has the benefit of a high porpoise population? We only want sustainability.' 'Why should fishermen pay for 'pingers[2]'? Let someone else pay.' 'I would like compensation for the nets damaged by porpoises!' 'Any shape of 'pingers' is alright as long as it is easy to work with.' 'Porpoises are a problem for us (fishermen) but it seems to be a bigger problem for the biologists.'

Devolved management systems are already under discussion in Denmark (Vedsmand *et al.* 1995; Vedsmand *et al.* 1996, Nielsen *et al.* 1996). Alternative models have been examined; these look at different ways in which there can be enhanced involvement of user-groups in the decision-making process, given different considerations of resource and market. Currently the Danish decision-making process is centralised, with industry participation restricted to consultation through advisory boards (Nielsen and Vedsmand 1997). Devolvement of authority and responsibility for monitoring, control and enforcement is a sensitive issue. Hallenstvedt (1993) has argued that fishing is now a privilege for a few rather than a right for many. As with all such public privileges, there is an obligation to protect this resource from over-exploitation. The absence of fishermen from the formulation and implementation process of regulations appears to be one of the main reasons of non-compliance. Even though many barriers exist to the devolution of management, it is clear from the interviews in this study and the suggestions given below that examples of enhanced co-operation among user-groups is already emerging.

9.3.1 Suggestions from fishermen determined from interviews

During the interviews, a number of suggestions were made on how to reduce by-catches. They included:

a ban on certain types of gill-net fishing; Most fishermen knew the type of fishing that would take many porpoises (turbot fishing) and they suggested the ban but with compensation to be paid to the fishermen involved.

some technical measures such as increased mesh sizes, or the use of the square mesh and always with some compensation for loss of earnings. This was

[2] Acoustic deterrents used on gillnets nets.

considered by the fishermen to be better than a complete ban on fishing or complete compensation or social payments. Fishermen suggested closures: spawning seasons should be protected and no fishing should occur at this time. However, if closures were to be in enforced, then closures would have to be effective for all fishermen regardless of gear or nationality. Many fishermen voiced their concern about the disparities in regulations across the North Sea. The fishermen who admitted that bycatch was a problem also reported that porpoise juveniles were present in the summer.

experimental studies; In order to come up with more accurate estimates more gillnetting trials should be undertaken, in close association with the fishermen involved and in the season when the porpoises are present in the area. A number of Danish fishermen noted that some experimental trials had been conducted when there were no porpoises in the area. Trials should be made during the summer months between May to July.

technological measures; the use of pingers and other acoustic deterrent devices. The fishermen in Denmark wanted the pingers to be supported by the government or paid for in part at least by fishermen's associations. Other more original measures, such as the use of different types of nets or example, should be considered and examined in collaboration with the users.

simpler regulation; there should be regulations across the North Sea with no exceptions. Fishermen wanted to see the same regulations applied to all countries. It was thought unfair that Danish fishermen had minimum regulations and just a few boat lengths away there were fishermen of a different nationality fishing in the same area but using smaller mesh. To the fishermen interviewed it seemed illogical and unfair.

Overall it was clear from the interviews that both the UK and Danish fishermen wished to become far more actively involved in the decision-making at a local and regional level.

9.3.2 COMMENTS FROM FISHERMEN DETERMINED FROM INTERVIEWS

- I don't think the quota system is working at all, I mean it's totally ludicrous.
- What I don't agree with in the CFP.... With response to our area in the North Sea, we're mainly affected by Belgians, Brits, Danes, and French. I don't see why the Italians, Greeks, Spanish should be voting on areas that we live on. Greeks on plaice quotas in the North Sea. I mean, they haven't a clue.
- In terms of conservation? Well, I think certain technical measures, mesh sizes should be increased, and we've got to move away from small fish.
- Stop and listen, I think, cut down on the massive laws and legislation, 'keep it simple'. There are beamer regulations. The logbooks now, the fishermen used to go away to sea to catch fish, now you've got to be a lawyer, accountant, bookkeeper…
- I think we should stop fishing in the spawning season. With compensation of course. You can't tie a fishing vessel up…
- Increase mesh sizes. If you're fishing and you dump fish because of the type of fishing that we do.
- I don't mind them saying to me, you was allowed 50 tons last month. You're only going to get 25 tons this month, all right, I'll go, but let them double up the prices of the fish. It can go for a minimum.
- I don't mind that but why should I lose out from my earnings? I still have a mortgage to pay and a house to run and things. We're all bloody family men aren't we? But that is the thing about it, all these quotas, you're not going to catch fish, you still got bills to pay, ships' repairs. If you get a shipright or blacksmith onboard for repair, he's not going to say, oh because you got your quota cut in half, I'm only going to charge you half price.
- I would like more meetings held not only say with Grimsby but with other ports on a more regular basis.

- We hold them only every six months. Darby, somewhere like that, there's a next one coming up. Basically, to me, the Ministry is out of touch with us, what can happen in a trip, imagine what can happen in six months. I would like more close contact with them. So we can discuss whatever Brussels says we have to do…
- Yes, to discuss it, to get it all together, but at the moment, we got a voice in Scotland, we got voices here in England, and they're all doing it. with different voices, surely if we all got together with one big strong voice 'fisherman power'. You've got 'girl power', that was the Spice girls, if you like, let's have 'fisherman power'.
- I would like to see the EU stop doing deals involving fishing for the benefits outside fishing…

9.3.3 MARINE PROTECTED AREAS

Further studies on the distribution of harbour porpoises and the presence of aggregations in relation to environmental parameters should be undertaken with a view to building predictive models of areas at risk of bycatch. Another idea would be the establishment of a marine protected area (MPA). MPAs have become the flagships of marine conservation programmes in many parts of the world (see review in Gubbay 1995, 1995 and Roberts 1998). It was suggested that the island of Sylt, off Germany's coast could be such an area for the North Sea harbour porpoise (Sonntag *et al.* 1998, ICES 1999b). Recently Germany established a special protected area off the islands of Sylt and Amrun in the fall of 1999 (R. Strempel *pers. comm.*).

9.3.4 OTHER MEASURES TO PREVENT BYCATCH

Other measures, not obtained from the interviews are listed below. They are modification of the gear, such as placing passive reflectors on the nets so that they would be more visible to the porpoises. At the moment University of Loughborough and the University of Stockholm are working on 'pinger' or devices that emit sound to act as deflectors. There have been a number of studies that have shown that pingers placed on nets can be successful (Schneider 1996, Andersen *et al.* 1999). All of these measures are partial solutions and may affect the fishing efficiency of the gillnets. Breakaway designs can also be developed (Nelson and Lien 1996). Chemical tracers could also be used to increase the detectability of gear by making it visually or chemically obvious to porpoises (Nelson and Lien 1996).

A self-governing body, established by the regulatory authorities to enable the fishermen to monitor themselves. Such a programme now exists in the Bay of Fundy. Since there is a good working relationship between the fishermen and scientists, scientists help to release captured porpoises, then tag and track them for their own research programmes (Read 1999a).

Another idea would be to establish a system whereby decentralised management occurs through the explicit accounting of the value of uncaught fish (Gavaris 1996). This is a management method whereby the fishermen themselves earn a share of the fish, caught or uncaught, and in the case of porpoises, calculate the cost of bycatch.

In summary, however incomplete the knowledge about the levels of porpoise bycatch in the fisheries in Denmark or the UK sector of the North Sea, it is important to accept that there is a problem. In the case of the gill-net fisheries this may well mean fishing with shorter nets, restricting the number of nets, reducing the total soak time to less than 24 hours as in Norway. At the moment there are no restrictions for the turbot fishery in Denmark. The main point is to minimize encounter rates with high aggregations of porpoise by switching fishing areas at different times of the year in relation to porpoise breeding and nursery areas, and patterns of behaviour.

Conclusion

In examining these aspects of governance it is becoming increasingly evident that governments are less involved in governing fisheries. The suggestion is not for the abandonment of central decision making (Crean and Symes 1994). In the EU, it is ICES, an international policy making body which will still have overall responsibility. Rather, it is the implementation of the principles of bycatch and discard prevention that should be devolved to competent regional organisation.

Regulation of the inshore fisheries in the UK for example, should be undertaken locally through co-management institutions involving representation from the regional administration, the inshore fisheries industry and the scientific communities, but the detailed design of such institutions should reflect the prevailing political and fisheries cultures of the regions concerned (Symes 2000).

Beyond the 12 nm, the offshore fisheries would continue to be controlled mainly through the system of quota management and indeed, rights–based management (Symes 2000).

Within the EU, the basic infrastructure for regional self management of quotas already exists in the form of Producer's Organisations, (POs) one of which is in Grimsby.

The trend in Denmark is now of co-management in fisheries (Nielsen *et al.* 1996). Co-management systems, based on devolved responsibility and self regulation may provide the key to resolve some fisheries problems (Symes 1997, Lane and Stephenson 1998). Co-management has also evolved since 1978 between the Alaska Eskimo Whaling Commission representing Inupiat whalers, and the National Marine Fisheries Service (NMFS) representing the US Department of Commerce, to regulate the harvesting of bowhead whales in the Bering Sea. It promises improvement over earlier management practices in that user groups and public authorities jointly establish ways to articulate and implement management systems (Young *et al.* 1994).

There is also an increase of environmental awareness not only in the public but also in the power distribution. NGOs, or non-Governmental Organizations and environmental groups have become increasingly visible and at scientific meetings these groups have obtained observer status (ASCOBANS 2000a).

The whole of society is changing rapidly and irreversibly. In our computer-based society, there is an increase in the Internet access and information, which forcibly impacts on the public. Virtually every public policy area is going to be affected in this new Information Age from security, privacy, intellectual property, copyright protection, and universal access across networks that largely ignore any kind of political border (Caldow 1997). Thus it becomes evident that there will be a number of policy changes in government especially related to natural resource policy.

Any bycatch solutions whether creating a protected area for porpoises or implementing technical measures must originate with the fishermen. Crean and Symes call this 'local accountability' (Crean and Symes 1994). Fishermen, although they develop their own rules and rights must be actively involved in any policy. If given property rights over the resource, a better understanding of bycatch issues will result in increased responsibility. If they feel that they own the resource, they may manage quite differently. But without this implicit right, they will not do so.

Chapter 10

Discussion and Conclusion

> *While other environmental problems such as acoustic disturbances and marine pollution pose potential problems for small cetaceans in the Baltic and North Sea, incidental entanglement in fishing gear, so- called bycatch, is considered the most important threat to porpoises and dolphin populations throughout the ASCOBANS area. This situation requires immediate action. Otherwise the high mortality coupled with relatively low reproductive rates will cause a continued decline in harbour porpoise populations and make their recovery impossible. For this reason, ASCOBANS is focussing on the development and implementation of bycatch mitigation measures.*
>
> *Ruediger Strempel, Secretariat*
> *ASCOBANS, 24 May 2000*

The purpose of this thesis is to review one of the most significant issues affecting fisheries management today, the bycatch. Not everyone perceives this issue in the same way. For some, the incidental mortality of species which are long-lived and have low reproductive rates is a conservation problem that has affected, marine mammals, sea birds, sea turtles, sharks, etc. Bycatch can also affect the biodiversity of marine ecosystems through the impacts on top predators of the system, through the removal of individuals from many species, or through the elimination of prey biomass (Dayton *et al.* 1995; Hall 1999). For others, the bycatch issue is one of waste; the millions of tons of protein dumped in the ocean (Alverson *et al.* 1994; Alverson, 1998), and the waste of animal lives is condemned on moral grounds. For the economist, it generates additional costs, without affecting the revenues, and it may become a hindrance for the profitability of a fishery (Boyce 1996; Hoagland and Jin 1997; Pascoe 1997). For the fisherman, it is a series of problems: it causes conflicts among fisheries, it gives fishermen a bad public image, it generates regulations and limitations on the use of resources, and frequently it has negative effects on the resources harvested through the mortality of juvenile and undersized individuals of the target species before they reach their optimal size, and before they reproduce (Hall *et al.* 2000).

For the ecologist, bycatch is an extremely complex set of issues that needs to be addressed as a scientific problem, rather than an economic, political, or moral one. Although only a few fisheries include bycatches of the target species in their stock assessment (e.g. Pacific halibut, Clark and Hare 1998), it is clear that bycatch management of the target and other species will become an integral part of the future ecosystem management schemes.

Bycatch can create a conservation problem when endangered or threatened species such as the porpoise are affected, or when the level of the take is not sustainable for the non-target species. They can affect the biodiversity of an area.

10.1 Evaluation of the Methods

I have used a combination of methods in this thesis in order to calculate bycatch levels. Data were taken from fisheries catch and effort statistics. Traditional ecological and local knowledge were incorporated from interviews with fishermen. The annual porpoise bycatch level was then estimated from taking this interview data by trip and averaging over the fisheries data. Next, the information was extrapolated an compared to the results of observer programmes. The environmental parameters in the North Sea were examined and frontal areas were described to identify potential bycatch areas. Using this approach was unique in that a number of different available data sources were used. However, the main deficit in the method was the fact that neither absolute porpoise abundance nor porpoise distribution is known.

The benefits of interviews are also important in order to establish and consolidate networks with fishermen and the industry. The bycatch problem concerns the whole community, and by using interviewers, a more direct and personal aspect can be created (Lien *et al.* 1994). Interviews should be repeated every season, if they are to be effective. Likewise, it is also possible to establish a surrogate time series by interviewing elderly members of the community (Tregenza *pers. comm.*). Tregenza interviewed patients and asked them about the state of the stocks a number of years ago (Tregenza 1992). He was able to establish that a great decline had occurred in the porpoise population from sightings in

Cornwall. However, interviews have to be carefully evaluated since often absolute values or estimates may be difficult to interpret.

I have presented a framework for risk assessment. By identifying areas and times of high fishing effort, I was able to partially relate them with bycatch data obtained by observers. Unfortunately, the observer data was incomplete and the estimate of porpoise abundance was not of the same accuracy as the fishing data collected by ICES rectangle (Harwood 1999b). Without doing a real risk assessment, which I have not attempted, I have tried to indicate the 'areas at risk' of bycatch.

This study has shown the value of fishermen's knowledge. Since fishermen have unique knowledge about stocks and the ecosystem as a whole, this can help direct research, check the accuracy of past research and provide a basis for practical problem solving (NFCC 1999). There is now baseline data about porpoise bycatch in the North Sea. The next step is to produce statistically sound estimates of total bycatch with more recent stock size estimates and thus obtain a time series over the years (Bravington and Bisack 1996).

10.2 Evaluation of the Results

Surveys were conducted in the summers of 1997 and 1998 to provide estimates of bycatch from fishermen's interviews. Over 26 people were interviewed and of these, 14 were gillnet skippers fishing out of Grimsby in the North Sea. Bycatch estimates ranged from a low of 1-2 porpoise per year to a maximum of 3 per trip. Combining the estimates from interviews with the number of fishing trips made per year provided an annual estimate of 149-297 porpoises. Using the results of 30 interviews made with gillnet skippers in Denmark in 1998, an estimate of 3500 to 4500 bycaught porpoises was made. The estimate of 4629 reported by Vinther for 1993 matched the upper level of the range (Vinther 1994, 1995a). From these data it is evident that porpoise bycatch is a problem off the western Danish coast but bycatch in UK waters by the Grimsby fleet is not as high. Thus, the main area of concern is the west coast of Denmark during the summer months, which makes this an 'area at risk'.

The simulations using the model PorpSim illustrate the necessity to calculate population dispersal rates. PBR, on the other hand is a more direct and simple calculation. I calculated PBR for the North Sea, and since the estimated bycatch levels are higher than the PBR it is urgent to instigate recovery plans for the porpoise. Today, marine mammal assessments in the US use PBR to determine stock status (Read and Wade 1999, Taylor *et al.* 2000).

The US also relies mainly on fleet coverage with observer programmes in order to estimate cetacean bycatches (Wade and Angliss 1997, Read 2000). However, this is costly. Not all observer programmes, no matter how costly, can provide a representative estimate of the bycatch since there are a number of sources of bias (Read 1999b, Bravington *et al.* 1997). A skipper may alter his usual fishing pattern. Observers may miss porpoises that drop out of the net. And also, certain small inshore vessels may not have space for an onboard observer. Such vessels' activities are not monitored, and may cause an underestimation in the results. Interviews, questionnaires and logbooks can be alternative methods in these cases. For a much lower cost, but more labour intensive, questionnaires and interviews can be used. This study has shown that similar results can be obtained using interviews rather than observer programmes.

10.3 CONSERVATION OF MARINE MAMMALS

The ecological problem caused by bycatch of porpoises is central to the conservation of marine mammals. So the question I ask is why conserve the porpoise? The rational for protecting them is found in the Convention of Biodiversity[1]. The species is threatened and vulnerable to extinction if incidental capture continues at this rate. Society also wants special protection for this charismatic animal.

10.3.1 THE VALUE OF A PORPOISE

In actual fact, the value of a porpoise is diverse. For the fisherman from the UK or Denmark, it is a problem and a nuisance and can be the cause of damage to nets and lost fishing time, as mentioned above. To the scientist, a porpoise is an

[1] See IUCN webpage@phocoena.org

apex predator and thus a valuable and important element in understanding how the marine ecosystem functions. It may be considered as an indicator species of contaminants. This status as an indicator species is also important and may serve the same purpose as the 'canary in the mines'.

However, to the tourist, porpoises can be a commercial attraction. The aesthetic, ethical and ecological value cannot be evaluated in a conventional sense (Costanza *et al.* 1997, 1998) yet may be of immense importance (Meffe *et al.* 1999). The local income generated by sightings to a community, for example may be worth more than the fishing activities of a dozen small vessels.

10.3.2 Some problems with the management of marine mammals

One of the difficulties in managing porpoises is the fact that they are both a coastal and wide ranging species. This means that the IWC does not make management decisions nor provide advice on their status (Gambell 1999). Another difficulty is the national sovereignty of the 200 nautical mile EEZ (Economic Exclusive Zone). Some countries (including Japan and Norway) do not accept that the IWC Scientific Committee deals with these smaller species. Other governments (US and UK among others) believe it must (Gambell 1999). Nevertheless, there is a movement underway for proper management, which insists that IWC Scientific Committee must consider these species since porpoises are now under threat from both directed and incidental catches. ASCOBANS must now make certain decisions, as well as make funds available to improve the management and reduction of bycatches of porpoises. (ASCOBANS 2000b).

10.3.3 The necessity for a systematic survey

How can porpoises be managed? Much more needs to be understood in terms of stock structure, distribution, and abundance to determine ecological importance of porpoises. At present there is a real need for a systematic survey especially since the last one (SCANS) was in 1994 when the abundance and relative density of porpoises was mapped out for July (Hammond *et al.* 1995). Any subsequent estimate of bycatch, whatever method employed, is compared to this one estimate taken in this one month. But as Hammond *et al.* (1995) point out, to detect population declines promptly, surveys need not be frequent but population estimates should be precise. More effort should be made to monitor this population and obtain a minimum estimate of absolute abundance.

In this thesis I have described a variety of methods that are used around the world to assess marine mammals. There are many organizations and networks of volunteers that are involved in marine mammal observations. Volunteers can make significant contributions to science only if they receive training in the scientific method.

Marine mammals rate highly in the public's perception at the moment–it seems everyone wants to help save the whales. From the media, it is evident that the power of environmental groups is great. In the US, the MMPA was established because of public pressure with the resultant authority and more funding for research. The MMPA was a legislative triumph and a step forward in marine mammal assessments (Northridge and Hofman 1999). No such legislative undertaking has yet been enacted for the North Sea, although some progress is being made by ASCOBANS and some EU environmental groups (WWF 2001a).

But in order to make an assessment of porpoise abundance in the North Sea, now is the time for another survey[2]. As Gray has said so well: 'What we need is more science, not less and better integration between science, the green movement, legislators and managers' (Gray 1999).

10.3.4 How can bycatch estimates be improved?

Bycatch can be estimated in a number of quick and relatively inexpensive ways, such as telephone calls, questionnaires, and dockside interviews. In the UK it was decided that an observer programme will be continued in the North Sea (as described in Chapter 3) (Northridge *pers. comm.*). However, there are many inshore vessels that are too small to carry an observer. In order to obtain information from these vessels, they should be required to fill out a logbook. An example of a suggested format for such a proposed logbook is attached to this discussion (Table 10-1).

[2] At the time of writing, ASCOBANS is organising a SCANS II survey for 2002-2003 which will include the Baltic Sea (R. Strempel, Secretariat *pers.comm.*).

Proposed Logbook for Marine Mammals

(one logbook per fisherman per season)

No name		
Country Affiliation		
Vessel Overall length	Year built	Wooden/steel hull
Season		
Maximum speed		

DAILY RECORD SHEET

Date	

Activity Searching, fishing hauling:	*Time porpoises, dolphins seen or reported	Position found	Number seen and no. of groups	Position found

	REMARKS

Table 10-1. Proposed Logbook for Marine Mammals such as porpoises in the North Sea

10.3.5 THE IDENTIFICATION OF A CRITICAL VARIABLE

In the study of the porpoise and its population dynamics in the North Sea (as described in detail in Chapter 4), the critical variable must be identified. This may be the fecundity, the size at first maturity, longevity of females, dispersal or migration. In addition, very little is known about the critical porpoise habitat. Until this critical value has been found, identifying areas or seasons at risk from fisheries statistics may be the only method available. But this is only one interaction for porpoises. Another approach would be to establish a Marine Protected Area near the nursery area of the Danish coast and thus eliminate all critical factors.

10.3.6 SUSTAINABILITY OF MARINE MAMMALS

In order to manage marine mammals effectively, certain conservation principles must be applied. Meffe *et al.* (1999) stressed that the maintenance of a 'healthy' population of wild marine mammals is important. Although this is a principle generated from the Brundtland Commission (Our Common Future) and again in 'Caring for the Earth: A Strategy for sustainable living' (IUCN/UNEP/WWP1991) in practice this may be difficult. With increasing demands of a growing population, consumption of natural resources will also increase. But will sustainable development succeed?

Sustainable development probably will not work for small cetaceans according to Perrin (1999). Porpoises have low rates of natural increase, are very difficult to study, are long lived animals and it will take many years to get an estimate with these low rates of natural increase. Absolute population estimates are also very costly and difficult to obtain. It is also difficult to monitor trends in population size at spatial and temporal scales useful to management (Perrin 1999). All these factors make it difficult to manage porpoises in the North Sea.

10.3.7 THE USE OF THE PRECAUTIONARY PRINCIPLE

The Precautionary Principle is a theory, which has come from soft law into hard law, and in spite of the fact that it is not yet customary international law, is one of the fundamental environmental principles. The origins of the Precautionary Principle are to be found in Germany, where it formed one of the basic tenets of environmental strategy. Since the mid 1970's, together with the co-operation principle and the 'polluter pays' principle (von Moltke 1992), the V*orsorgeprinzip*, is a policy whereby a difference is made between human behaviour which causes dangers on the one hand or risks on the other. This principle is of relevance in the situation of the bycatch of porpoises in the North Sea. In order to protect the ecosystem from possible damaging and irreversible effects, it is necessary to apply the Precautionary Principle and thus conserve the porpoise.

SUMMARY

In conclusion, the solution to the bycatch problem in the North Sea is not easy. If human impacts on the ecosystem are to be managed, then it must be accepted that all forms of life modify their environment to some extent (Meffe *et al.* 1999). Yet, it is important to minimise the effects of fishing technology and at the same time to be aware of the potential reduction or loss of biodiversity. Clearly, the more that is known about porpoise life history and ecological interactions, the better management decisions can be made.

I have looked at the Grimsby gillnet fleet as a case study. In Chapter 7, I have identified geographical areas and seasons that are heavily fished and must be avoided if a healthy porpoise population is to be maintained. But further resources should be made available to protect them. Local populations need to be safeguarded from damage, so that the whole population can survive (Meffe *et al.* 1999). Parts of the North Sea may act as a 'sink' for a meta population in the Atlantic. Since porpoises are mainly dependent on the distribution of commercial fish for their survival, management of these factors should also be taken into account.

Uncertainty about the lack of biological information regarding the animal, or the secondary effects of bycatch, stochastic variation in the population and environmental perturbation, all these should not be an excuse for inaction (Meffe *et al.* 1999). Using the Precautionary Approach instead, may possibly prevent irreversible degradation in the North Sea ecosystem.

Most of the solutions for bycatch can be obtained with minor changes in gear and procedures, rather than dramatic ones. Probably setting nets in a different area, over less time and avoiding certain seasons may achieve the improvements sought after. Already some of the Danish gillnet fishermen in the North Sea have voluntarily changed to longlines. The Danish fishermen, although they approved of 'pingers' felt that pingers were not the best solution. Rather they suggested that other modifications to fishing gear would have to be considered. The fishermen themselves were beginning the evaluation of a new net that was more acoustically 'visible'. These reflective nets have a substance, barium sulphate added to the nylon that reflects sound. Fishermen in Canada are also testing these reflective nets (Trippel 1999, Read 2000).

The case study here does not cover all the bycatch issues, but it provides a broad sketch of the direction in which the programs to mitigate their impacts are moving. Attempts are being made to keep a viable fishery. Fishermen must play a major role in developing and testing the gear and procedure modifications proposed.

The main threat to porpoise numbers is probably the bycatch mortality, and unless it is reduced the population(s) in the North Sea may well become extinct.

The opportunity is here now provided by the present information needs: fishermen, managers, scientists and environmental organizations need to cooperate to improve porpoise conservation and thus eliminate the bycatch issue.

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ANNEX 1

THE PROGRAM PORPSIM

EXPLANATION OF THE PROGRAMME

The program runs the following equation:

$$N_s^{t+1} = N_s^t + rN_s^t\left(1 - N_s^t / K_s\right) - M_s^t - C_s^t$$

where the following parameters are set:

N_s^t is the abundance for a substock(s) at any time, and this is calculated per year. N is the number of animals calculated for the stocks. The initial numbers are set (I used 269,000 animals as a starting point) and then the next year's numbers are calculated using the equation with neither migration nor bycatch (C=0), r and K. This is the starting population number.

The *r* is the per capita growth rate or rate of increase. It is a value obtained from the literature (Woodley and Read 1991, Barlow and Boveng 1991, Caswell *et al.* 1998). Caswell *et al.* (1998) resampled other mammal mortality schedules and rescaled the distributions to the age of first reproduction. ASCOBANS decided to use a value of 0.04 because there was no empirical data for porpoises (Read 1999b). I have adopted this.

K_s is the carrying capacity of the substocks. The maximum net productivity level for marine mammals is generally believed to occur between 60 and 70% of K (Read 1999b). The ASCOBANS working group agreed that a value of 60% should be used (Read 1999b). Harbour porpoises have relatively short life spans and higher reproductive rates than most cetaceans, and are thus more r-selected (Read 1999b). ASCOBANS suggest that porpoises may have a maximum net productivity value closer to 50% of K than other cetaceans. I used values of 50-60% of K.

M_s^t is migration. There is evidence that porpoises move into and out of the Baltic Sea and around the North Sea (Andersen *et al.* 1999, Tiedemann *et al.* 1996). There is however no empirical data to calculate migration across the North Sea, and migration is estimated as the overall loss or gain of individuals in any one substock per year. It is calculated in the model using four rates. The first rate is D1x N, where D1 is the fixed dispersal and this is the most conservative estimate of dispersal at 0.01. This rate is thus 1% of the initial starting population. This means that very little movement occurs in or out of the stock. D2, D3 and D4 are variations on dispersal rate calculations. The dispersal rate is a hypothetical dispersal of animals per stock per year depending on the number of substocks and their carrying capacities. Negative dispersal denotes emigration and positive dispersal is immigration or the total number of incoming animals to the stock. Dispersal rates are used in order to illustrate the effect of bycatch on management objectives (Taylor 1995). It can then be seen that below a threshold dispersal rate, if recruitment (incoming young animals) is less than removal (or C the bycatch) this means that $r < 0$ and the population will become extinct. If $r > 0$ the population will grow. At any dispersal pattern, the population grows in number until the bycatch is added.

C_s^t is the mortality caused by bycatch in numbers of animals per year. The estimates are zero, 2000, 3600, 5000 and 7000. These values were arbitrarily chosen. The maximum value (7000) is close to the value of 6785 bycaught animals obtained by Vinther (1999) for the Danish stock in the North Sea.

The model is the discrete time logistic, with the addition of migration (D1 to D4) and bycatch or C options.

THE PROGRAM PORPSIM

PROGRAM FUNCTION

RUNNING THE PROGRAM

The program (written by R. Nieder and used with permission) must be run in a Microsoft Windows environment. The following files are required in the working directory: **porpsim.exe** (program file), and **p_ini.txt** (parameters file). A file **popstat.txt** is written to the working directory saving the data as the program is run. Before running the program, make any changes to the parameters file and save it.

A note about dispersal

Models 2, 3 and 4 calculate an actual dispersal rate from a substock from an initial maximum dispersal rate. This is because the actual rate is a function of the maximum rate and substock density (see on the next page). The value that you enter in the parameters file is used as the maximum rate to calculate the actual rate. Thus all references to the dispersal rate that follow and the results all refer to the maximum possible dispersal rate from a substock, not the actual dispersal rate that is calculated therefrom.

Setting the substock number and subsequent values that must be initialised

1. go to the line entitled NumberOfSubstocks and set it equal to the number of substocks
2. Enter the initial substock sizes (N) under the heading **Substocks** with the following lines:
   InitialSizeOfSubstock1 = 100000 (enter your own values here)
   InitialSizeOfSubstock2 = 150000
   InitialSizeOfSubstock3 = 120000
3. Similarly, enter values for the corresponding carrying capacities under the heading **K** for each of these substocks with the following lines:
   K1 = 400000 (enter your own values here)
   K2 = 400000
   K3 = 500000
4. Enter the **growth rate** under the heading **PBR**
5. Finally, enter the allocation of the bycatch to the substocks under the heading **Removals**, for example,
   Catch from = 0.5,0.3,0.2 will allocate 50% of the bycatch to substock 1, 30% to substock 2 and 20% to substock 3. Make sure that these add up to 1.0 (100%) and that you have a figure for each substock. If you want automatic allocation of bycatch to substocks enter 0.0 for each substock. Then the allocation will depend on the relative sizes of the substocks.

Setting the model to run for a specified number of years

1. Enter the number of years the program is to run to (we'll assume 100 for this example)
   under the heading **MainParams** set **Year** =100. Note that the program will stop running if one population becomes extinct.
2. Ensure that the program is set to run over years rather than until it reaches a certain stability level
   under the heading **MainParams** make sure that **StopCriterion** = 1.

Setting the model to run until the populations all stabilise

1. Enter the level of stability that you want the populations to reach (we'll assume 0.005). For each substock this is calculated as

   $$\left(N_{t+1} - N_t\right)\big/K$$

   under the heading **MainParams** set **Stability level** to 0.05. Note that the program will stop running if one population becomes extinct. Note that problems were encountered with this option during testing because one or more of the substocks oscillated and never reached the stability set.
2. Ensure that the program is set to run reaches a certain stability level by setting **StopCriterion** = 0 under the heading **MainParams**.

Calculating the PBR and setting required parameters

This will cause the program to ignore any data pertaining to incremental catches etc. The program will calculate the PBR according to equation 8 and equation 9.

Set RunType = 0 under the heading MainParams

1. Set values for **Z value**, **CV** and **Recovery factor** under the heading **PBR** (the remaining setting, **growth rate**, should be set anyway)

Setting a fixed dispersal rate

This will cause the program to run for the given dispersal rate for a fixed number of years or until the substocks have stabilised (see above) according to the setting of **StopCriterion**. The result shows the change in the substocks over time. If the dispersal rate is fixed, the program will run as though the catch were also fixed, only using the value that **min** is set to.

1. Choose the dispersal model that you want to apply

2. Enter the dispersal rate that will be applied throughout the execution of the program (we'll assume 0.004)

    under the heading **Dispersal** see that the line **Dstart**=0.004 is present.

    see that **Dstop** is set to some larger value, e.g., 0.4

    see that **Dstep** is set so that the following is true (**min+step>max**), e.g., 1.0

Setting an incremental dispersal rate

The program will run for a range of values, starting with that entered for **Dstart**, each time adding **Dstep** to it, until **Dstop** is reached. For each value, the program will run for a fixed number of years or until the substocks have stabilised (see above) according to the setting of **StopCriterion**. The data that is saved depends upon whether the catch is fixed or incremental (see below).

1. Choose the dispersal model that you want to apply.
2. Set the range of dispersal values (we'll assume 0.0001 to 0.02 step 0.0005)

    under the heading **Dispersal**, set **Dstart** to 0.0001.

    set **Dstop** to 0.02

    set **Dstep** to 0.0005

Setting a fixed catch (not PBR)

This assumes that you have not fixed the dispersal rate. If you have, the following will not apply. Setting a fixed catch will allow you to run the program for a range of dispersal values, showing the all the final substock sizes for each dispersal value after either the specified number of years has elapsed or the substock has stabilised, depending upon the setting of **StopCriterion**. If one of the substocks goes extinct, no result is generated for that dispersal rate.

1. Set **RunType** = 1 under the heading **MainParams** so that a user defined catch is used instead of calculating the PBR
2. Enter the size catch that will be applied throughout the execution of the program (we'll assume 4000)

    under the heading **Catch** see that the line **min**=4000 is present.

    see that **max** is set to some larger value, e.g., 4500

    see that **step** is set so that the following is true (**min+step>max**), e.g., 10000

Setting an incremental catch (not PBR)

This assumes that you have not fixed the dispersal rate. If you have, the following will not apply. Setting an incremental catch causes the program to run over a range of catch values and a range of dispersal levels for after either the specified number of years has elapsed or the population has stabilised, depending upon the setting of **StopCriterion**. A range of dispersal rates must also be set. The output for each catch value shows the lowest dispersal rate and the highest dispersal rate required to keep all substocks extant (within the range of **Dstart** and **Dstop** - see "A note about dispersal" above). If a dispersal rate will not maintain the populations, no value for that rate is output.

1. Set **RunType** = 1 under the heading **MainParams** so that a user defined catch is used instead of calculating the PBR
2. Enter the size catch that will be applied throughout the execution of the program (we'll assume 4000)

    under the heading **Catch** see that the line **min**=4000 is present.

    see that **max** is set to some larger value, e.g., 4500

    see that **step** is set so that the following is true (**min+step>max**), e.g., 10000

COMMENTS ON THE DISPERSAL MODELS

The application of dispersal rates is more complicated in this multisubstock scenario than would initially appear from Taylor's paper (1) 1. This is mostly because the substocks have very different carrying capacities. For this reason, her first two models, which do not take into account the density of the target substock, result in the smallest substock increasing in size beyond the carrying capacity. These are models 1 and 2 in this program. Model 3 takes into account the density of the target population - as it reaches carrying capacity, the actual dispersal rate from the home substock to the target substock approaches zero. This was adopted in preference to model 3 described by Taylor because of the differences in substock carrying capacities; her third model which accounts for the density of the target population is:

Equation 1

$$D1 = D\frac{N1}{K1}$$

describing 2 substocks, where
D1=dispersal rate of substock 1
D= maximum dispersal rate
N1= abundance of substock 1
K1 = carrying capacity for substock 1
and

Equation 2

$$D1' = D1\left(Y - \frac{Y-1}{K2}N2\right)$$

where
D1' = maximum dispersal rate of substock 1. Substitute this result into D in Equation 1
D1 = dispersal rate when target substock is at K
Y = multiplier of the dispersal rate when the target population is at zero (set to 2)
The problem with this model, using Y=2 as stated in her paper is that with different values for K, the maximum dispersal rate from the home substock to the target substock is too big and the target substock grows beyond the carrying capacity. Thus the model was modified so that as the target substock approaches K, so the dispersal rate from the home substock decreased to 0. Model 4 takes into account the different sizes of the carrying capacities of the substocks. After initial testing, it does not appear to be very robust; small changes to parameters cause the substocks to suddenly collapse.

THE PARAMETERS FILE

An example of a parameters file can be seen. Here the parameters will be described individually and the consequences will be outlined. The default values are selected when the parameter cannot be found in the file under the correct heading. If values are entered that are not required because of other options set in the file, there is no harm done. For example, if it is stated that there are 2 substocks and there are 5 values for N and K, only the first 2 values will be used. Similarly, if the option is to use a fixed catch with min, max and step set, it doesn't matter if values required to calculate the PBR are to be found in the file as well. A summary of the options selected is provided in the output file. Note also that any line that starts with a ";" is regarded as a comment and will not be read.

MainParams

NumberOfSubstocks is the number of substocks for which the model should be run. The default is 2 and the maximum (for which there is no error check) is 10.
RunType may be 0 (zero) or 1 (one). A value of 0 means that the bycatch will be calculated as the PBR and no bycatch value will be read from the file. A value of 1 means that a bycatch value will be read. The default value is 0 (zero). There is no error checking for this field.
StopCriterion may be 0 (zero) or 1 (one). A value of 0 means that the substocks will be run over time *t* until they all reach a level of stability specified in the file (**Stability level**).(**Note: under test conditions, it was found that with some parameter values, substock sizes oscillated and never reached stability**). A value of 1 means that the program will run until a specified number of years have elapsed. The default value is 0 (zero). There is no error checking for this field. Note that the iterations will terminate when one population becomes negative.
Year is the maximum number of years for which the program will run before termination if **StopCriterion** = 1. The program will stop iterations if one population falls below zero.
Stability level is the level of similarity of all populations between *t* and *t*+1 that must be reached before the iterations terminate if **StopCriterion** =0. The program will stop iterations if one population falls below zero.

Substocks

The initial size of the substocks are described under this heading, with the following format:
InitialSizeOfSubstockN = 999999

where N is the substock number and 999999 is the initial size of the substock. There should be a separate line for each substock and the number of entries should be the same as the value entered for **NumberOfSubstocks**. There are no defaults and no error checking is performed.

K

The carrying capacities of the substocks should be given here, with the following format:

Kn = 999999

where n is the substock number and 999999 is the carrying capacity for that substock. Each value should be on a separate line and there should be a value for each substock. Thus n=value entered for **NumberOfSubstocks**. There are no defaults and no error checking is performed.

Catch

This heading has the following fields:

min, **max** and **step**. Here you have the option to set a fixed catch and thus run the program for a range of dispersal values for this catch only, or enter a minimum and maximum catch, running the program over a range of dispersal values and a range of catches.

1. *set fixed catch*. Enter the catch of your choice in the **min** field. Enter any value that is greater than this in the **max** field. Enter a value for the **step** field so the following condition is true **min+step>max**

    Example

    min = 4000
    max = 4500
    step = 10000

    This will run the program for catch = 4000, save the results and stop.
2. *increment catches*. Enter the starting value in the **min** field. Enter the value to which you wish to run the program in the **max** field. Enter the catch interval in the **step** field.

    Example

    min = 4000
    max = 4500
    step = 100

    This will run the program for catch = 4000, save the results, run the function for catch = 4100, save the results and so on until catch = 4500.

Default values for **min**, **max** and **step** are 0, 5000 and 5 respectively.

PBR Calculations

Values required to calculate the potential biological removal are entered here.

Z value is the desired percentile from the Z-distribution. The default value is -0.842, the lower 20th percentile.

CV is the coefficient of variation of the abundance estimate (note that this is the same (only one value) for all substocks). The default is 0.3.

Recovery factor is F_R, a recovery factor used in the calculation of the PBR. The default is 0.5.

growth rate is the maximum intrinsic rate of growth and is used in the logistic growth equation. r_{MNPL} used for the calculation of the PBR is set as (**growth rate**)/2. The default is 0.04.

Dispersal

Under this heading, the dispersal model and the dispersal range are set in the following fields:

dispersal model is where you select the model. The models are described above. Enter 1 to choose model number one, 2 to choose model number two and so on. There is no error checking for this field. The default model is 2.

Dstart, **Dstop** and **Dstep**. Here you have the option to fix the dispersal rate and run the program for the number of years (set with **Years** - see above) or to a stability level (set with **Stability Level** - see above), or set a minimum and maximum dispersal rate and run the program over the range.

1. *fixed dispersal rate*. This will allow you to run the program for (we'll assume **StopCriterion** = 0) a number of years. The result is the relative population densities $\left(N/K\right)$ for each population for each year at a given dispersal rate. To do this, enter the dispersal rate that you want to examine in the **Dstart** field, enter some value larger than this in the **Dstop** field and enter a value in the **Dstep** field such that the following is true: **Dstart+Dstep>Dstop**

    Example

    Dstart = 0.005
    Dstop = 0.01

Dstep = 1.0

This will run the program for a certain number of years (or until a population becomes negative) with a dispersal rate of 0.005, save the results and stop.

2. increment dispersal rate. Enter the starting value in the **Dstart** field. Enter the value to which you wish to run the program in the **Dstop** field. Enter the catch interval in the **Dstep** field.

   Example

   Dstart = 0.001
   Dstop = 0.06
   step = 0.002

   This will run the program for a maximum dispersal of 0.001, save the results, run the function for a maximum dispersal of 0.003, save the results and so on until the maximum dispersal reaches 0.06.

Removals

This is where the bycatch is allocated to the populations. You should have figures separated by commas for each substock, and these should add up to 1.0 (100% of the bycatch) or 0.0. In the latter case the program will calculate the bycatch allocation depending upon the relative substock sizes. If the value exceeds 1.0, an error message is generated. For example, if there are 4 populations and 20% of the bycatch comes from the first, 25% from the second, 25% from the third and 30% from the forth population, the data line should read **Catch from** =0.2,0.25,0.25,0.3.

OUTPUT FILE

This is a text file, **popstat.txt**. Approximately the first 25 lines summarise the options chosen in the parameters file, then the data can be found in columns. This format is very easy to import into a spreadsheet such as Microsoft Excel for analysis.

3.1 TECHNICAL NOTE

This software was written using Borland C++ in a Microsoft Windows 3.1 environment on a P75 processor. It will not run under DOS. It runs under Microsoft Windows 3.1 and Microsoft Windows for Workgroups 3.1.

A description of the complete programme is given below:

```
[MainParams]
NumberOfSubstocks = 3
;run type: 0=totalPBR, 1=totalCatch
RunType = 1              ;totalCatch
;RunType = 0
;stop criterion: 0=elapsed time, 1=stabilisation of pops
StopCriterion = 0  ;stabilisation of pops
Year = 250
Stability level = 0.0005

[Substocks]
InitialSizeOfSubstock1 = 110434
InitialSizeOfSubstock2 = 194064

InitialSizeOfSubstock3 = 5850
[K]
K1 = 230000
K2 = 400000
K3 = 11700
;K1=1104340
;K2=2000000
;K3=58500

[Catch]
min = 6600
max = 8000
step = 10000

[PBR]
Z value = -.842
```

```
CV = .4
Recovery factor = .5
growth rate = .04

[Dispersal]
;Dispersal models: 0- migration=DN
;                  1- migration=DN1(N1/K1)
;                  2- migration=DN1(N1/K1)(1-(N2/K2))
;                  3- migration=DN1*2K1/(K1+K2)
dispersal model = 2
Dstart  = 0.01
Dstop = 0.02
Dstep = 1.001

[Removals]
Catch from = 0.4,0.5,0.1
```

---

(1) 1Taylor,B. March 1995 "Defining 'Populations' to meet management objectives for marine mammals", Administrative Report LJ-95-03

ANNEX 2

Table 1. Landings (kg) by month by ICES rectangle for Grimsby fleet in 1985

1985	1	2	3	4	5	6	7	8	9	10	11	12	Total	%
33F3				4419									4419	*0.41*
34F4				4536									4536	*0.42*
35F0				1134									1134	*0.11*
35F1			5668	2011		8846	4275					918	21718	*2.03*
35F2			8419		8901		14561		1509			3727	37117	*3.47*
35F3					701								701	*0.07*
35F4										862			862	*0.08*
36F0	18718	19951	1685		10050	13503	20477	19397	3104	22913	13428	10863	154089	*14.41*
36F1	20813	10281	7559	4232	20385		1303	25172	34722	10850	1451	2756	139524	*13.05*
36F2	3475		1908	1828	10896	27351	17228	5840	13709	5951		9301	97487	*9.12*
36F3	789												789	*0.07*
36F5										862			862	0.08
37E9	14003	5490	7449					3936					30878	2.89
37F0				182	701		1850	911		3222	4836	11866	23568	2.20
37F1	30993	67297	24366	14429	7774	1196	30699	13537	29123	30550	9838	20954	280756	26.26
37F2			20099	2945	1574		3962	3729	3109	7936	1451	14734	59539	5.57
37F3							1638			862			2500	0.23
37F4												745	745	0.07
38E9							799	9267	15628	16097			41791	3.91
38F0								2366	3684	862			6912	0.65
38F1	8955				913	1219		2910		4052	17386	1294	36729	3.44
38F2				2564	1574	4866		4228				12292	25524	2.39
38F3				1602			7363					1294	10259	0.96
39E8							799	4962					5761	0.54
39E9									6041	4058			10099	0.94
39F1							3420	1455	2999	4784			12658	1.18
39F2				802			810			1593		1888	5093	0.48
40F1								1823	4499				6322	0.59
41F1								41163					41163	3.85
48E6						5436							5436	0.51
Total	97746	103019	77153	40684	63469	62417	109184	140696	118127	115454	48390	92632	1068971	100.0
%	9.14	9.64	7.22	3.81	5.94	5.84	10.21	13.16	11.05	10.80	4.53	8.67	100.0	

Table 2. Landings (kg) by month, by ICES rectangle for Grimsby in 1986

1986	1	2	3	4	5	6	7	8	9	10	11	12	Total	%
32F1								2364					2364	0.34
33F2								2364					2364	0.34
35F0					6897	9041							15938	2.32
35F2	4273			3975					18297				26545	3.86
36F0	6313		512			2899		3214	10128	3809	1018	2673	30566	4.45
36F1	5055	15411		16101			2786	4319	29117	8276	1905		82970	12.08
36F2	4128		6251	2647		54410	4831	11170	1746				85183	12.40
36F3			12486		817	5055	4505						22863	3.33
36F4			3462										3462	0.50
37F0	8647	9934	3848					3203		28440			54072	7.87
37F1	25028	7675	11473	3903	27783	1119	18149	7430	5115	19812	9982	16038	153507	22.35
37F2	5250	8098			2395	1702	36306	8741	12210	4073	3187	1343	83305	12.13
37F3					817		3229						4046	0.59
38E9										8143		2016	10159	1.48
38F0									3364				3364	0.49
38F1		3280				1119			2676	2727			9802	1.43
38F2	3834				817	3088	2144	1465		7445	2029	4717	25539	3.72
38F3								3275					3275	0.48
39F0									4955	4097			9052	1.32
39F1					817				1746	4062			6625	0.96
39F2						852	4843			2708		1404	9807	1.43
41F0						852							852	0.12
41F1									12433	3135			15568	2.27
41F2							7578	1465					9043	1.32
42F1						852							852	0.12
42F2				561		852							1413	0.21
48E6						14401							14401	2.10
Total	62528	44398	38032	27187	40343	96242	84371	49010	101787	96727	18121	28191	686937	100.0
%	9.10	6.46	5.54	3.96	5.87	14.01	12.28	7.13	14.82	14.08	2.64	4.10	100.0	

Table 3. Landings (kg) by month, by ICES rectangle for Grimsby in 1987

1987	1	2	3	4	5	6	7	8	9	10	11	12	Total	%
35F0				133		3275							3,408	0.41
35F2		2484											2,484	0.30
36F0	2234									1654	2190		6,078	0.73
36F1	44065					1673	1331		7175			18818	73,062	8.75
36F2	15684	7314	1739		23023	13035	11312	5051			1289		78,447	9.40
37F0		4864	4892	12769	5955		10501	12304	2754	1026		4809	59,874	7.17
37F1	68757	68644		5346			3143	36947	46400	3467	20356	25045	278,105	33.31
37F2		31667		1303		14179	27776	11262		3932	3148	4823	98,090	11.75
37F3						3719				1026	3306		8,051	0.96
38E9							4279						4,279	0.51
38F0				6697	6017			2240	16925		10874		42,753	5.12
38F1	20598	27094			2359			3440	11589	2338	4343	7070	78,831	9.44
38F2										1312	5822	4407	11,541	1.38
38F3				229									229	0.03
39E9								10613					10,613	1.27
39F0								2240	3895				6,135	0.73
39F1								8689	4782				13,471	1.61
39F2										1312			1,312	0.16
39F4				229									229	0.03
40F1										1312			1,312	0.16
41F1											10934		10,934	1.31
43E8										6964			6,964	0.83
47E6				1296									1,296	0.16
48E6				8789	15283	13281							37,353	4.47
Total	151,338	142,067	6,631	36,791	52,637	49,162	58,342	92,786	93,520	24,343	62,262	64,972	834,851	100.0
%	18.13	17.02	0.79	4.41	6.30	5.89	6.99	11.11	11.20	2.92	7.46	7.78	100. 0	

Table 4. Landings (kg) by month, by ICES rectangle for Grimsby in 1988

1988	1	2	3	4	5	6	7	8	9	10	11	12	Total	%
31F1			298			562							860	0.10
31F2					2411								2,411	0.27
32F1			234										234	0.03
32F2				9310									9,310	1.05
33F2							6531	9005				6628	22,164	2.51
33F4											12605		12,605	1.43
34F4								6225	842		1732	4754	13,553	1.53
35F0	1436				2491								3,927	0.44
35F1								5681					5,681	0.64
35F2			1748			8492	3929	3321	6209				23,699	2.68
35F3				4056	1116		4619			401	1888		12,080	1.37
35F4									5054	4752		7554	17,360	1.97
36F0	12510	5502			4770	5618							28,400	3.22
36F1	18551	11527			13737			13761			11921		69,497	7.87
36F2		5763		5965	12716	25439	5122	17129	14780	28398			115,312	13.06
36F3					14003	7932			1404				23,339	2.64
36F4									560			5547	6,107	0.69
37E9									3898				3,898	0.44
37F0		16223		1497	9309	5618	10681	15063	18795	12328	6032	1693	97,239	11.01
37F1	41313	29182	6232	2466	7722	5945	569	5698	8440	1969	13889	14171	137,596	15.58
37F2	12088		7624	2705		15078	12717	16812	43923	10230	19463	19072	159,712	18.09
37F3									1121		1930	1074	4,125	0.47
37F4									6936				6,936	0.79
38E9								5537	7205				12,742	1.44
38F0			1217					1846			11533	1604	16,200	1.83
38F1		8992	1217	5895		13376	293			17304	4712		51,789	5.87
38F2							293			9055	4817		14,165	1.60
39F1											965		965	0.11
39F4					4316	924							5,240	0.59
39F6										1485			1,485	0.17
43E8											2397		2,397	0.27
48E6						1940							1,940	0.22
Total	85,898	77,189	18,570	31,894	72,591	90,924	44,754	100,078	119,167	85,922	93,884	62,097	882,968	100.0
%	9.73	8.74	2.10	3.61	8.22	10.30	5.07	11.33	13.50	9.73	10.63	7.03	100.0	

Table 5. Landings (kg) by month, by ICES rectangle for Grimsby in 1989

1989	1	2	3	4	5	6	7	8	9	10	11	12	Total	%
31F2					6788								6788	0.53
32F2	14555					6881			4535				25971	2.03
32F3				24484			14339	6894			1619	11236	58572	4.57
33F1						9325	38970	19315	10434				78044	6.09
33F2	32647	6798	5193		7898	14515	15598	2466	5738	12268	16222	9967	129310	10.09
33F3					6004		3319					26519	35842	2.80
33F5											2399		2399	0.19
34F1						3931			2398				6329	0.49
34F2					3467	10405	9360	15356	5967				44555	3.48
34F3							1659				731		2390	0.19
34F4												1540	1540	0.12
35F0				1456	8120								9576	0.75
35F1								2466	7057		2894		12417	0.97
35F2				10715	35037	16225	11651	15063	9970		1134		99795	7.78
35F4	10730	6664											17394	1.36
36F0								6656				580	7236	0.56
36F1	25758		7589			3900	4115				4737	11295	57394	4.48
36F2		4101	18303	11075	17885	63931	22666	1829	5479	13994	5154	1708	166125	12.96
36F3				9728	5862		12266	361			405	5476	34098	2.66
37F0	16067	9977	1343	4447				11985	7605	9601	8516	9775	79316	6.19
37F1	6405	2050		6367	11891	10455	60	25542	13175	6257	9758	11111	103071	8.04
37F2	16443	26139	7802	38486	27766	14686	8128	10938	20628	10008	3815	3715	188554	14.71
37F3									7766				7766	0.61
38E9					4356				2678				7034	0.55
38F0								5386	9040	2545	5605		22576	1.76
38F1		2881	1343							2545	8097	7660	22526	1.76
38F2			1782								422	2874	5078	0.40
38F3										2225	1928	2874	7027	0.55
39E9					1452			5386					6838	0.53
39F0			1343							4357			5700	0.44
39F2									3415		508		3923	0.31
39F3							4351	12213			2578	6886	26028	2.03
42E8											730		730	0.06
Total	122605	58610	44698	106758	136526	154254	146482	141856	115885	63800	77252	113216	1281942	100.0
%	9.56	4.57	3.49	8.33	10.65	12.03	11.43	11.07	9.04	4.98	6.03	8.83	100.0	

Table 6. Landings (kg) by month, by ICES rectangle for Grimsby in 1990

1990	1	2	3	4	5	6	7	8	9	10	11	12	Total	%
31F1			7686	8389									16075	1.97
32F0								12287					12287	1.50
32F2			11848										11848	1.45
32F3			8390		4190								12580	1.54
33F2			13488	14317									27805	3.40
33F3				5940	8914				7423			1158	23435	2.87
34F2			1442	8701	15361	32922	16465	24656	14080	16510	4931	3898	138966	16.99
34F3	387					21880	18280						40547	4.96
35F1					7587	5853	1981	2279	15425		6208		39333	4.81
35F2	428			5324		7470	19650	5642	3342	3750			45606	5.58
35F3			1074	3212	1873		1291		3342				10792	1.32
35F4					955					386			1341	0.16
36F0				386							421		807	0.10
36F1	1409		925	2949			13440			7688	1606	3020	31037	3.79
36F2	26536	20807	3187	4079	3052	3885	4930			2061	4496	1158	74191	9.07
36F3				3722	5230	892		4327					14171	1.73
36F4						2978							2978	0.36
36F5					1536								1536	0.19
37E9									2692				2692	0.33
37F0		7529								4718	3702	248	16197	1.98
37F1	3833	2698	1929			9922	20235	21520	4701	7630	11536	5312	89316	10.92
37F2			965	147	824	17816	9407	965	13100	2516	2890	5663	54293	6.64
37F3						8939				2516			11455	1.40
37F4					10182								10182	1.24
38E9									2692				2692	0.33
38F0										1639	1565	5192	8396	1.03
38F1								4059		4718	1565		10342	1.26
38F2	1987									1280			3267	0.40
39F0											6430		6430	0.79
39F1								4805	12434			248	17487	2.14
39F3							9787						9787	1.20
39F6					472								472	0.06
39F7										2479			2479	0.30
40F0								17120					17120	2.09
40F1								19150					19150	2.34
40F2		5496											5496	0.67
41F1									4790				4790	0.59
41F4												1217	1217	0.15
41F6											2480		2480	0.30
42F1				6946									6946	0.85
44F3										1738			1738	0.21
45F2											6430		6430	0.79
45F3										1738			1738	0.21
Total	34580	36530	50934	64112	60176	112557	115466	116810	84021	61367	54260	27114	817927	100.0
%	4.23	4.47	6.23	7.84	7.36	13.76	14.12	14.28	10.27	7.50	6.63	3.31	100.0	

Table 7. Landings (kg) by month, by ICES rectangle for Grimsby in 1991

1991	1	2	3	4	5	6	7	8	9	10	11	12	Total	%
31F2				3513									3,513	0.17
31F3				3276									3,276	0.15
32F1							7279						7,279	0.34
32F2			22088			9853							31,941	1.51
32F3	7956	4156											12,112	0.57
33F1	11635	23759	16642	12778	21603	18507	15473		6144			3532	130,073	6.14
33F2	19900		7819		13022	9616	23590	16777					90,724	4.28
33F3	6753	11350	3418	6398	1428	10100		752	12730	6267	7681		66,877	3.16
34F1							8979		8433				17,412	0.82
34F2	14257	27480	1723			28273	27554	8614				1174	109,075	5.15
34F3	7946				3420	7060	3687					4687	26,800	1.27
34F4		12299	6174	2568				5044					26,085	1.23
35F0				146									146	0.01
35F1			1173	9528	32983	6469	2162	6122	13214	3329		4762	79,742	3.77
35F2	1806	1284	1917	1612	29655	15656	33003	17341	8981	12900	9327	9564	143,046	6.75
35F3	4766	11285	44162	21585	10409	20190	1050			1758		6636	121,841	5.75
35F4		15241	42592	5523	12607	2884	2989	3211	1539	2640	5603		94,829	4.48
36F0								1821		952		432	3,205	0.15
36F1	1651	1156	523		10752	6198	9768	2232	7833	4103		677	44,893	2.12
36F2	14534	6852	2898	1374	10021		4867	2449	6434	1371	510	10903	62,213	2.94
36F3		4561	725	2342			11845	6998		2771			29,242	1.38
36F4	4766	4273	725	1112	11315		9801	2429		4370			38,791	1.83
36F5		4433	4797		4824	1348	6041			3890			25,333	1.20
36F6				11817	13021		1134						25,972	1.23
37E9												677	677	0.03
37F0	3193	1319	819		6435	2809		5353	6895	3421	2749	4446	37,439	1.77
37F1	3442	785			779	3470	12520	5649	5948	2934	6398	9724	51,649	2.44
37F2	10781	4273	5582	4616	5618	2712	12083	36999	24569	10816	14991	9805	142,845	6.75
37F3	7650	4156	18747			8393	3320		1697			5051	49,014	2.31
37F4	3827		12373	1374	6307	13237	24837	34247	14395	2231	1541	4543	118,912	5.62
37F5				1374	2311	2251	1232	1677					8,845	0.42
37F6			3580		9554	2699				1361	4222		21,416	1.01
37F7				10514	5457	997							16,968	0.80
38E9							2069			1969	507		4,545	0.21
38F0						7253	2944	15001	1977	800	6403	677	35,055	1.66
38F1				872			1016	508	5948	6270	7409	2649	24,672	1.17
38F2	16644								1997	7054	507	10285	36,487	1.72
38F3			4278	2779	22847	10680	3238	9466	6120	2965	1433	15830	79,636	3.76
38F4											1433		1,433	0.07
38F5				2424	1550		4680						8,654	0.41
38F6						1702	3510	5476	2223				12,911	0.61
38F7				4101			270	542					4,913	0.23
39E9									108				108	0.01
39F0								10692	762	1443			12,897	0.61
39F1								1724	1402	1013	4541		8,680	0.41
39F2	1759									4509	2974	6403	15,645	0.74
39F3							9036				1541	2748	13,325	0.63
39F4									4123				4,123	0.19
39F5				495									495	0.02
39F7								568	625				1,193	0.06
40F0								22489					22,489	1.06
40F1								1917					1,917	0.09
40F2								1917					1,917	0.09
40F3			2407					1148					3,555	0.17
40F4				2925			15584	1148			2079		21,736	1.03
40F5				5639									5,639	0.27
40F6							8337						8,337	0.39

40F7				3021	1545		165						4,731	0.22
41F1										3978	1033		5,011	0.24
41F2										2537			2,537	0.12
41F3												2748	2,748	0.13
41F4											2079		2,079	0.10
41F5							2084						2,084	0.10
41F7				2220									2,220	0.10
42F3						7253	2772						10,025	0.47
42F4							11084						11,084	0.52
42F6										2988			2,988	0.14
43E8												854	854	0.04
43F0											1033		1,033	0.05
43F3										2988			2,988	0.14
43F4							7071				1033		8,104	0.38
43F5											1033		1,033	0.05
44F0								10230	8385				18,615	0.88
44F2							3394						3,394	0.16
44F3							6001		4793				10,794	0.51
45F0								8313	8385	679			17,377	0.82
45F1								12078	4793	2988			19,859	0.94
45F2							4788	6039	4793				15,620	0.74
Total	143,266	138,662	205,162	125,926	237,463	199,610	311,257	266,971	175,246	107,295	88,060	118,807	2,117,725	100.0
%	6.77	6.55	9.69	5.95	11.21	9.43	14.70	12.61	8.28	5.07	4.16	5.61	100.0	

Table 8. Total landings (kg) by month, by ICES rectangle for Grimsby in 1992

	1	2	3	4	5	6	7	8	9	10	11	12	Total	%
1992														
32F3	4771	3422	7714										15907	1.50
33F1					5945								5945	0.56
33F2	1833	1753		435		12756	5886						22663	2.14
33F3	36874	40130	3084		5198								85286	8.04
34F1			2333					1635					3968	0.37
34F2	4234					19435		2833					26502	2.50
34F3	6666	2664					1102		1659				12091	1.14
35F0				3483	670	1377							5530	0.52
35F1			3962		3415	2794	3676	1881					15728	1.48
35F2	2401				4247	10431	8365	4126					29570	2.79
35F3	1265	8774	11086	3864				1293	556		2876		29714	2.80
35F4		2657	6073	1841									10571	1.00
36F0				1506					605	902			3013	0.28
36F1	4572		3499				4599	3421			2764	14	18869	1.78
36F2	2401		1305	5066	3838	20387	2843	3291			4606	14	43751	4.13
36F3	10247	8651	3738		16854	7913	5323	1229	8385	902			63242	5.96
36F5			997	1837									2834	0.27
37F0		5084	2385	2454		942		1336	7101				19302	1.82
37F1	9688	10139	7210	9662			3558	14350	12673	5458	1568	1403	75709	7.14
37F2		5084	997	14258	15568	24343	21303	9442	8120	14635	2690		116440	10.98
37F3	4733	4106	638	2576	11699		15822	10845	3500	2759	3916	858	61452	5.80
37F4								8597	12419	3947			24963	2.35
37F6				5431									5431	0.51
37F7			4342	6245									10587	1.00
38E9								1789					1789	0.17
38F0			667	7420	13173	942	3619	12910		2142			40873	3.86
38F1							2310		1474	2142	3002		8928	0.84
38F2						475		2347					2822	0.27
38F3	20348	6569	13069	1841	2306	475	5540	19982	8717		1855		80702	7.61
38F4							14983		8321				23304	2.20
38F5											1855		1855	0.17
39F0										10433			10433	0.98
39F1						475		3503	918	2142			7038	0.66
39F2											11630	6593	18223	1.72
39F3	1265			1841		3679			1609	4671			13065	1.23
39F4				6470					10881	8174			25525	2.41
39F5									1609		1251		2860	0.27
40F1						475	10000		1930				12405	1.17
40F2			2244					1229					3473	0.33
40F5					6296								6296	0.59
40F7				1601									1601	0.15
41F0								1789		6260			8049	0.76
41F1								3343	8581				11924	1.12
41F2			850										850	0.08
41F6										681			681	0.06
42F1			850					2804					3654	0.34
43E8				948									948	0.09
43F2								2725					2725	0.26

43F3									1930				1930	0.18
44F0			850										850	0.08
44F2								2804					2804	0.26
44F3								3343	1930				5273	0.50
45F2			5799					6147		14726			26672	2.52
48E6				8565		15072							23637	2.23
Total	111298	99033	83692	87344	89209	121971	108929	128994	102918	79974	38013	8882	1060257	100.0
%	10.50	9.34	7.89	8.24	8.41	11.50	10.27	12.17	9.71	7.54	3.59	0.84	100.0	

Table 9. Landings (kg) by month, by ICES rectangle for Grimsby in 1993

1993	1	2	3	4	5	6	7	8	9	10	11	12	Total	%
31F1											4070		4,070	0.23
31F2										2923			2,923	0.17
32F2		9946					952						10,898	0.62
32F3		11367				1185							12,552	0.72
33F1	4789	8787	6866	8305			1663						30,410	1.73
33F2		3962			9875	13138	23723	7013	2799		3131	5107	68,748	3.92
33F3		8036	2730	1687	10891	10881	1663			2039	1689		39,616	2.26
33F4						1185							1,185	0.07
34F0										530			530	0.03
34F1					2706			7349	6433	9032	1314		26,834	1.53
34F2		1646				9655	19706	5686			7779		44,472	2.53
34F3	2732	19817	4478			2897	2088						32,012	1.82
34F4		457		1301		1185	1019				1442		5,404	0.31
35F0			1271				1045						2,316	0.13
35F1		1168			5118	10999		180	1322		2576		21,363	1.22
35F2	1474	2402	1833		1987	633	6352	6042			1732		22,455	1.28
35F3	7725	30832		1411		5083	1069	604			1803		48,527	2.77
35F4		2509	1214	1548		2147		2965					10,383	0.59
36F0	2034	1168								530			3,732	0.21
36F1	7268	376	471		935					1933	178		11,161	0.64
36F2		5837	10738	11401	5050	14348	12028	1518	8827	12027	4662		86,436	4.93
36F3	4044	12012	7770	824	8545	10301	4185		4083	3268	778		55,810	3.18
36F4			7353	824		4836	4869				586		18,468	1.05
36F5		2509	2537	1301					3710		3621		13,678	0.78
36F6				1301	13089	376	3183						17,949	1.02
36F7					2706						3621	2426	8,753	0.50
36F8				17433			12287						29,720	1.69
37E9			687						5113	873			6,673	0.38
37F0	2354	3288	2534				5523		7555		1264	710	23,228	1.32
37F1	16856	9326		6574	570	5515	4169	16859	3340	5377	8020	9127	85,733	4.89
37F2	12747	11174	652	3868	9124	11212	18190	20221	15764	8109	10500	6523	128,084	7.30
37F3	7159	8438	1775	15499	5309	4026		10385	6498	11083	13456	995	84,623	4.82
37F4	13967	1715	3052	7129	3857	4284			3222	2499	653		40,378	2.30
37F5		709								12400			13,109	0.75
37F6		2437		11026		7311			3104				23,878	1.36
37F7		1919		2556		26535			12932		19586	4802	68,330	3.89
38E9				1973				1522		873			4,368	0.25
38F0				1973				1820	961	16005	5722		26,481	1.51
38F1			1835			839	3949		3697	6627	6310		23,257	1.33
38F2	9786					839	1236	2621	1081	11806	9619	1877	38,865	2.21
38F3		8501		1858	2308	839			2670	11206	2931		30,313	1.73
38F4		3235				839		8865	6054		512		19,505	1.11
38F5											366		366	0.02
38F7			2477										2,477	0.14
38F8				2601									2,601	0.15
39E9			687							873			1,560	0.09
39F0				1052	570			1522		1403	1579		6,126	0.35
39F1						2290	1419	9192		1877	1359		16,137	0.92
39F2		4672						4200	5335	1583	1678		17,468	1.00
39F3	4185	1715	1123			839		7897	2803		653	1354	20,569	1.17
39F4			8506										8,506	0.48
39F5		2424											2,424	0.14

39F7												7024	7,024	0.40
40F0			5252						1697	1583	926		9,458	0.54
40F1			2900				9263	5781					17,944	1.02
40F2		2526	5252		570		2842						11,190	0.64
40F3		9680	6649						10239	8328			34,896	1.99
40F4											1785		1,785	0.10
40F7			4747										4,747	0.27
41E8								604					604	0.03
41E9									3078				3,078	0.18
41F0			6479				1419		2657				10,555	0.60
41F1		3219	2900			4333		3221	12687	3586	7079		37,025	2.11
41F2	20499	2768					6404		1606		1785		33,062	1.88
41F3			2534								1785		4,319	0.25
41F4						2703							2,703	0.15
41F5		2768								2450	3185		8,403	0.48
41F6			1164										1,164	0.07
41F7				4529								1396	5,925	0.34
42E8									3078				3,078	0.18
42E9			4301						3078				7,379	0.42
42F0									2376		2269	4021	8,666	0.49
42F1							1419		1906				3,325	0.19
42F2			2780	1431		719		5244					10,174	0.58
42F3			2900			10643		838					14,381	0.82
42F4			5635										5,635	0.32
42F5								838					838	0.05
43E7							1085						1,085	0.06
43F0								604			926		1,530	0.09
43F1								2379					2,379	0.14
43F2							4030	2379	1418	1787			9,614	0.55
43F3							10159			1787			11,946	0.68
43F4						7896							7,896	0.45
44E9											6063		6,063	0.35
44F0								2379					2,379	0.14
44F1								2379					2,379	0.14
44F2							4030		1418				5,448	0.31
44F3			5635			2420			1418				9,473	0.54
45E9											3012		3,012	0.17
45F0									11411	4795	6063	7672	29,941	1.71
45F1									2376		11019		13,395	0.76
45F2						2420			1418				3,838	0.22
45F3										7245			7,245	0.41
46F3			5635										5,635	0.32
47E6					25377	11730							37,107	2.11
48E6					7387	7142							14,529	0.83
48E7					7014								7,014	0.40
Total	117,619	203,345	135,352	109,405	122,988	204,223	170,969	143,107	169,164	156,437	169,087	53,034	1,754,730	100.0
%	6.70	11.59	7.71	6.23	7.01	11.64	9.74	8.16	9.64	8.92	9.64	3.02	100.0	

Table 10. Landings (kg) by month, by ICES rectangle for Grimsby in 1994

1994	1	2	3	4	5	6	7	8	9	10	11	12	Total	%
31F1												1518	1,518	0.08
31F2					7210								7,210	0.38
32F2	6367	8328		1658		15906							32,259	1.72
32F3			981	1774		853							3,608	0.19
33F1						9809							9,809	0.52
33F2	13192	9890	10841	17169	10926	3290	2362	4748	1234				73,652	3.92
33F3	28720	42630	8800	6620	7554	14879	4913	810				588	115,514	6.14
34F1								4527					4,527	0.24
34F2	14613		3193			3558	17239	6121			3746	1083	49,553	2.63
34F3	11346	5475	2668	2765	4603	1057	8592					2997	39,503	2.10
34F4		11669										6225	17,894	0.95
35F0							577	598			133		1,308	0.07
35F1											1672	90	1,762	0.09
35F2	293	8497		1644	2432	14720	22685	13261	1070	1262	12160	508	78,532	4.18
35F3		2315	1546	538	6071	10011						921	21,402	1.14
35F4			2938		4527							1457	8,922	0.47
36F0					2331			195			997	6	3,529	0.19
36F1		3567			3475			10073					17,115	0.91
36F2	20285	21712	4490	4322	19200	10580	31356	19957	10766	12851	16892	5515	177,926	9.46
36F3	2977	4216		6682	14535	6861	1190	7613	2789		4742	2678	54,283	2.89
36F4				803	7954	343		2725					11,825	0.63
36F5			1101										1,101	0.06
36F7				90			437						527	0.03
37E9									1089				1,089	0.06
37F0						1593				1359	2316		5,268	0.28
37F1	11299		6651		721			11466	7280	2720	15554	20109	75,800	4.03
37F2	5173	2415		3835	4271	8131	18376	18651	31610	20268	5610	9709	128,049	6.81
37F3	24565	14801	1506	6231	1446	8807	17568	32358	21729	20092	6483	15915	171,501	9.12
37F4		16694		23478	28423	5295		1136	3645	5323			83,994	4.47
37F5				777	9403	9436	15223	22419				11084	68,342	3.63
37F6				6107	8213	902					4866		20,088	1.07
37F7					12913						1261		14,174	0.75
37F8					642								642	0.03
38F0									2009		2943		4,952	0.26
38F1	1113			945					2168	9993	24139		38,358	2.04
38F2	8224	6654	21145	3428	5335	2787	2043		3010	3242	2142		58,010	3.08
38F3	6041		378			7657		6056	25069	6753	1608	2621	56,183	2.99
38F4					6265	1910		5898	13228	9428	4192		40,921	2.18
38F5						7983							7,983	0.42
38F6			8158	11165									19,323	1.03
39E9										20280			20,280	1.08
39F0											1356		1,356	0.07
39F1						589	2600	965	1077	2635			7,866	0.42
39F2			3470			3584	10166	5422	6323	8743	1798	2400	41,906	2.23
39F3			10333	11073				4430				6454	32,290	1.72
39F4		5433		1003									6,436	0.34
39F5		4324					1698		3395				9,417	0.50
39F6			6436			9547							15,983	0.85
39F7	3349												3,349	0.18
40E8				681									681	0.04
40F0								855			4071		4,926	0.26
40F1		5712						4118	4510		4929		19,269	1.02

40F2		12521	122						11600	14846			39,089	2.08
40F3		5922	273					5007					11,202	0.60
40F4		1893			2854								4,747	0.25
40F5		3932		736									4,668	0.25
40F6					6414								6,414	0.34
41F1										1308			1,308	0.07
41F2	2899								1284				4,183	0.22
41F3	1602	3840	1548						3905				10,895	0.58
41F4		4677	239							2204			7,120	0.38
41F5								3179					3,179	0.17
41F6						619							619	0.03
41F7			2506	1064	1196								4,766	0.25
42F0								649					649	0.03
42F1								8964	8395	1308			18,667	0.99
42F2											2358		2,358	0.13
42F3											6129		6,129	0.33
42F4		7053								947	1174		9,174	0.49
42F7					524								524	0.03
43E9					481								481	0.03
43F0								1236					1,236	0.07
43F1									1284	1308			2,592	0.14
43F2		1627						1318			412		3,357	0.18
43F3										1633	6087		7,720	0.41
43F4						990				1305			2,295	0.12
43F5					1169	1429				604			3,202	0.17
44F0								2234					2,234	0.12
44F2								4056					4,056	0.22
44F3				284									284	0.02
44F4					419								419	0.02
45F0											4243	13192	17,435	0.93
45F2				535	779								1,314	0.07
45F3												6189	6,189	0.33
46F1					353								353	0.02
Total	162,058	215,797	99,323	115,407	182,639	163,126	157,025	211,045	168,469	150,412	144,013	111,259	1,880,573	100.0
%	8.62	11.48	5.28	6.14	9.71	8.67	8.35	11.22	8.96	8.00	7.66	5.92	100.0	

Table 11. Landings (kg) by month, by ICES rectangle for Grimsby in 1995

1995	1	2	3	4	5	6	7	8	9	10	11	12	Total	%
32F2		33696	2094										35,790	1.97
33F1							28154		4376				32,530	1.79
33F2		28123	7433		7883	14297	2044						59,780	3.29
33F3		34073	14583	549	3925	1722			5547	10281		1365	72,045	3.96
33F4							1119						1,119	0.06
34F0			2184										2,184	0.12
34F2							9362		924				10,286	0.57
34F3	11274	11342	2245	2442	3943				3567		868	1605	37,286	2.05
34F4		2574											2,574	0.14
35F1	2094	23498					10508			2610	673		39,383	2.17
35F2			7114		939	1999	3788	934					14,774	0.81
35F3		30592	9416	1221	12348				1077	1432	465	1072	57,623	3.17
35F4			4554	1221					583				6,358	0.35
36F0							1713						1,713	0.09
36F1	2531			2232		12690							17,453	0.96
36F2	6489	11193	3971	18425	34351	34958	5553	5017	12872	8498	3965	1796	147,088	8.09
36F3	1304	16187	16395	11256	3842	17204		4903	6931		2112	548	80,682	4.44
36F4		4140		9794	7943	14877	3110	7063	1112				48,039	2.64
36F6								400					400	0.02
37F0				183				3133	6395	1024	604		11,339	0.62
37F1	4771		4769			2505			8748	863	952	2804	25,412	1.40
37F2	4446	4085	27216	10185	30815	22311	8606	20595	46083	26219	8964	11743	221,268	12.17
37F3	10438	17704	22845	7443	6122		1248	6591	11163	15457	13847	16949	129,807	7.14
37F4		934		5400	7197		8838	21172	9862	2635			56,038	3.08
37F5					15640			1562					17,202	0.95
37F6		9006											9,006	0.50
37F7				3429	3124								6,553	0.36
38F0								2389	3363	863	4629	1460	12,704	0.70
38F1			11304		916		12377	14550	1351	6127	3513	1839	51,977	2.86
38F2			3442			357	6607				575	3553	14,534	0.80
38F3	4308	15823	5856	1508	3970	10668	9923	12250	1662				65,968	3.63
38F4			19166	1390	3503		14099			5311			43,469	2.39
38F6	23160			8585	3418								35,163	1.93
39F0								4938					4,938	0.27
39F1							1180	3083		1326	7303		12,892	0.71
39F2			23430		1320		9758	999		3419	29216	25097	93,239	5.13
39F3			21712	3114	5242			10436	6960	2641	356		50,461	2.77
39F4		6777		2502							4913	8642	22,834	1.26
39F5					2114	4942							7,056	0.39
40F0					2058								2,058	0.11
40F1		12783							15200		5806		33,789	1.86
40F2							1199			10803		2258	14,260	0.78
40F3			3709				3675						7,384	0.41
40F4					3087			8335					11,422	0.63
40F5							1794	3588				3966	9,348	0.51
40F6							3206						3,206	0.18
40F7									289	1003			1,292	0.07
41E9									7857				7,857	0.43
41F1								3468					3,468	0.19
41F2				5763									5,763	0.32
41F5											1744		1,744	0.10
41F6							1321						1,321	0.07
41F7						833							833	0.05

42F2							1801						1,801	0.10
43F2							2685						2,685	0.15
43F3			1624										1,624	0.09
43F4				1495							862		2,357	0.13
44E6						4330							4,330	0.24
44F0									2552			6091	8,643	0.48
44F3				5205									5,205	0.29
45E9									2552				2,552	0.14
45F0									17717			7695	25,412	1.40
45F1					787			3878					4,665	0.26
45F2									9501				9,501	0.52
45F3												3721	3,721	0.20
45F5								567					567	0.03
46F1								13767					13,767	0.76
47E6						5876							5,876	0.32
48E6						12290							12,290	0.68
48E7						3988		9284					13,272	0.73
49E6								15023					15,023	0.83
49E7						6022	16858						22,880	1.26
Total	70,815	262,530	215,062	103,342	164,487	171,869	170,526	177,925	188,244	100,512	91,367	102,204	1,818,883	100.0
%	3.89	14.43	11.82	5.68	9.04	9.45	9.38	9.78	10.35	5.53	5.02	5.62	100.0	

Table 12. Total landings (kg) by month, by ICES rectangle for Grimsby in 1996

1996	1	2	3	4	5	6	7	8	9	10	11	12	Total	%
32F2				1745		1213							2,958	0.13
32F3			2648			612							3,260	0.14
33F1		8855				12283	2899						24,037	1.04
33F2	28475	20263	19619	24269	17786	9243	3585	2739					125,979	5.44
33F3	14534	76408	8437	1594	1996	3027		421				6313	112,730	4.87
34F1	446						3227						3,673	0.16
34F2	5783											2157	7,940	0.34
34F3	47815	61433	10495	592	1943	1213	18680					8099	150,270	6.49
35F0							6889						6,889	0.30
35F1							3843			1557		964	6,364	0.27
35F2					18041	12699	13330	14670			3223		61,963	2.68
35F3	4182	39466	1411	378	10147		16611	18152		14720	1835		106,902	4.62
35F4	10123	11709	14316								1190	7165	44,503	1.92
36F1	21									3113		3298	6,432	0.28
36F2	9686	3002	7844	2706	19912	25911	5437	12534	8649	8620	15959	13485	133,745	5.78
36F3	3687		12546	36700	4554	53541	23047	1620	3822	18201	3872		161,590	6.98
36F4			1373	10212	1394	8501	9622	9507		1443	4882		46,934	2.03
36F5					3556						2961		6,517	0.28
36F7						1556							1,556	0.07
37F0			204				622						826	0.04
37F1			4802	13127						1807	22959	2628	45,323	1.96
37F2	20797		9618	12319	16414	2899	54164	21407	16232	34231	30205	19121	237,407	10.25
37F3	11986		8750	11609	48459	2269	1188	10579	9782	5680	6993	9062	126,357	5.46
37F4			10674	18683	27901	16495		7954	4171	5051			90,929	3.93
37F5				2847	3230								6,077	0.26
37F6		10784		3465	18038								32,287	1.39
37F7						624							624	0.03
38F0										1792			1,792	0.08
38F1		16710	21652	9493	720		417			5402	930		55,324	2.39
38F2		1546		1551					14689			4784	22,570	0.97
38F3				11866	10274	14227	9508	15600		18063		1212	80,750	3.49
38F4			15019	27038			6637	15700			2994	5710	73,098	3.16
38F5	11390			3473	15385								30,248	1.31
38F6					6917	2327					11891	21789	42,924	1.85
39F1			894						1192		3547		5,633	0.24
39F2				137								971	1,108	0.05
39F3	4279			3703	4051		10197	20349	9160	11442	2892	15752	81,825	3.53
39F4	7364	10232	8506	17368	3542			16319	8845				72,176	3.12
39F5					16859								16,859	0.73
39F6						2233							2,233	0.10
40F1									7032				7,032	0.30
40F2								23739	8461				32,200	1.39
40F3	12864								3588	1295		4755	22,502	0.97
40F4										1906	5452		7,358	0.32
40F5	5725	8281						2401					16,407	0.71
40F6			5638					2401					8,039	0.35
41F2				3950			774		1795				6,519	0.28
41F3		2127								3129			5,256	0.23
41F4								3239		9617			12,856	0.56
41F5							11796						11,796	0.51
41F6								3745					3,745	0.16

42F3					491								491	0.02
43F4							2443						2,443	0.11
43F5							5184						5,184	0.22
44F0												823	823	0.04
44F3							2631						2,631	0.11
45F0											2500		2,500	0.11
45F1											3703		3,703	0.16
46F1											3703		3,703	0.16
46F3			13831										13,831	0.60
48E6				13672	20568	25884	4423						64,547	2.79
48E7					8753		775						9,528	0.41
49E7					29918	2136							32,054	1.38
Total	199,157	270,816	178,277	232,497	310,849	198,893	217,929	203,076	97,418	147,069	131,691	128,088	2,315,760	100
%	8.60	11.69	7.70	10.04	13.42	8.59	9.41	8.77	4.21	6.35	5.69	5.53	100.0	

Table 13. Total landings (kg) by month, by ICES rectangle for Grimsby in 1997

1997	1	2	3	4	5	6	7	8	9	10	11	12	Total	%
33F1							5893						5893	0.52
33F2	13593	16076			8883	8322	9537					1068	57479	5.05
33F3	44365	24632										763	69760	6.12
34F2	16423	2419		3304		20446	8110						50702	4.45
34F3	17768	6390	11952	5381				3507				1752	46750	4.10
35F2	2918				15145	2431	9071		7999	2431			39995	3.51
35F3	30615	11007	6695		3418	5855				4951			62541	5.49
35F4			953										953	0.08
36F1					8140						1311		9451	0.83
36F2	26375	5140	7149	15876	16698	20718	6601		4366		5722	8880	117525	10.32
36F3		4218	3643	6019	20246	1864	5975	10256	8588	6196	7697	3770	78472	6.89
36F4				2381									2381	0.21
36F5											4372		4372	0.38
37F0								1142	688		1395	2678	5903	0.52
37F1	13494	6001			4748		4157	1142	7461		8003	2377	47383	4.16
37F2	4195		690		6370	1531	20214	2790	26321	22463	5969	6377	96920	8.51
37F3		7142	18018		22786	2696	8368	7979		1806	7346	2699	78840	6.92
37F4				11922	5517	11189			4352				32980	2.90
37F5				1970									1970	0.17
37F6							605				10491		11096	0.97
37F7	14781												14781	1.30
37F8					787								787	0.07
38F0									1841	714	998		3553	0.31
38F1									6776	1963	12894		21633	1.90
38F2			1370		1774					3305			6449	0.57
38F3		12671	2258							2428	2034		19391	1.70
38F4									540				540	0.05
38F5	8371	17587							2380			1957	30295	2.66
38F6			9313		9843								19156	1.68
38F7				10115									10115	0.89
39F1							634						634	0.06
39F2			2589			19383				18077			40049	3.52
39F3			1281						6491		8869		16641	1.46
39F4					7083			5838	2109			2381	17411	1.53
39F5				1847									1847	0.16
40F1	2002												2002	0.18
40F2										8621		1849	10470	0.92
40F3						10376						2145	12521	1.10
40F4							3913						3913	0.34
41F5							2235						2235	0.20
42F0										2583			2583	0.23
42F2									6136	5992			12128	1.06
43F2								26924	8103	1279			36306	3.19
45F3							5154						5154	0.45
48E6					14242	9957							24199	2.12
48E7											2860		2860	0.25
Total	194,900	113,283	65,911	58,815	145,680	114,768	90,467	59,578	94,151	82,809	79,961	38,696	1,139,019	100.00
%	17.11	9.95	5.79	5.16	12.79	10.08	7.94	5.23	8.27	7.27	7.02	3.40	100.00	

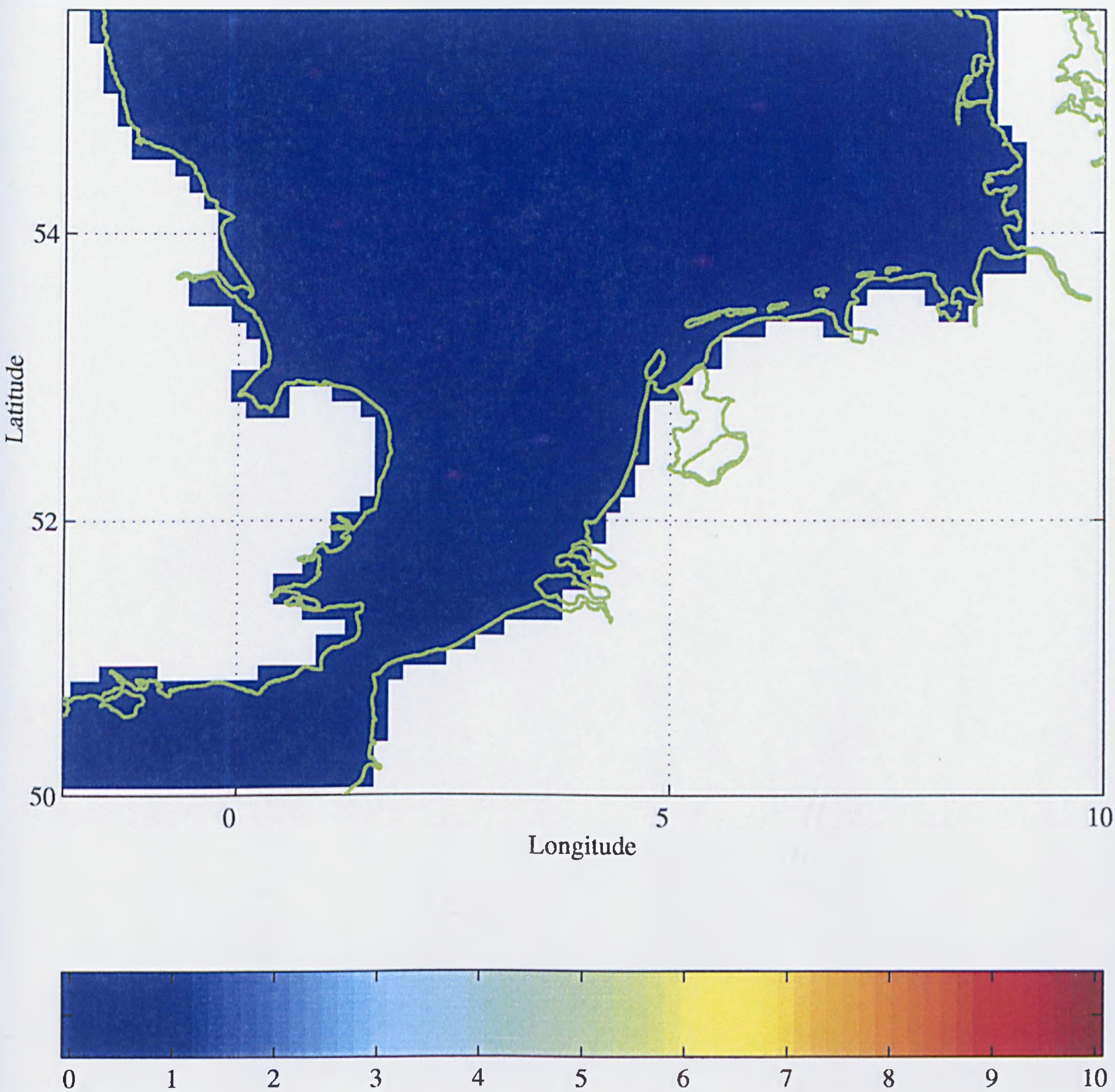
Table 14. Landings (kg) by month, by ICES rectangle for Grimsby in 1998

1998														
36F3	1	2	3	4	5	6	7	8	9	10	11	12	Total	%
31F1												15	15	0.00
32F3		7369											7,369	0.65
33F1							3026						3,026	0.27
33F2	11312	10259	2629		3130	25399	16079			8311	12696	13480	103,295	9.05
33F3		11801	231		1575								13,607	1.19
34F1						6320	4620						10,940	0.96
34F2		2075				11415							13,490	1.18
34F3	12267			1393	2595	1483						2485	20,223	1.77
34F4												1894	1,894	0.17
35F0				732									732	0.06
35F1						1732							1,732	0.15
35F2		4127				5668			9456	1937	1346	5586	28,120	2.46
35F3		8241	1415			4711					12894	20577	47,838	4.19
35F4	978					571							1,549	0.14
36F1				1782						2381			4,163	0.36
36F2	24802	10155	9516	11832	20421	24083	8478		2254	3298		8908	123,747	10.84
36F3	8773	15915	6472	7016	17207	5040	7038	14056	3180		14569	21543	120,809	10.59
36F4	5361	5483	12336	13719	7987	4509				11397	4181		64,973	5.69
36F5	5642	10347	4007								2281		22,277	1.95
37F0		91											91	0.01
37F1		164	204					1572	3479	5229			10,648	0.93
37F2		596				674	12318	9105	7003	22224	1655	2091	55,666	4.88
37F3	13753	16338		8263		34781	33494	12769	4689	3712	11696	2506	142,001	12.44
37F4		242	14381	1286		11736			13088	5657	9305	26140	81,835	7.17
37F5			5122		9822						2184	3715	20,843	1.83
38F1									1194	1252			2,446	0.21
38F2		6384		1827		21142	7194	2443					38,990	3.42
38F3		16441				7347	28976	3723			3755	142	60,384	5.29
38F4				3135						3139	4904	9748	20,926	1.83
38F5		8287									3032	8598	19,917	1.75
38F6												4585	4,585	0.40
39F1							47						47	0.00
39F2								3191		7879		142	11,212	0.98
39F3							12348	11449	10711				34,508	3.02
39F4	14531	9228		6611									30,370	2.66
40F0					350							-	350	0.03
40F2										3644	2405		6,049	0.53
43F0					233								233	0.02
47E9			1544										1,544	0.14
48E6					5889								5,889	0.52
48E7					2235								2,235	0.20
49E7					562								562	0.05
Total	97,419	143,54 3	57,857	57,596	72,006	166,61 1	133,61 8	58,308	55,054	80,060	86,903	132,155	1,141,130	100.00
%	8.54	12.58	5.07	5.05	6.31	14.60	11.71	5.11	4.82	7.02	7.62	11.58	100.00	

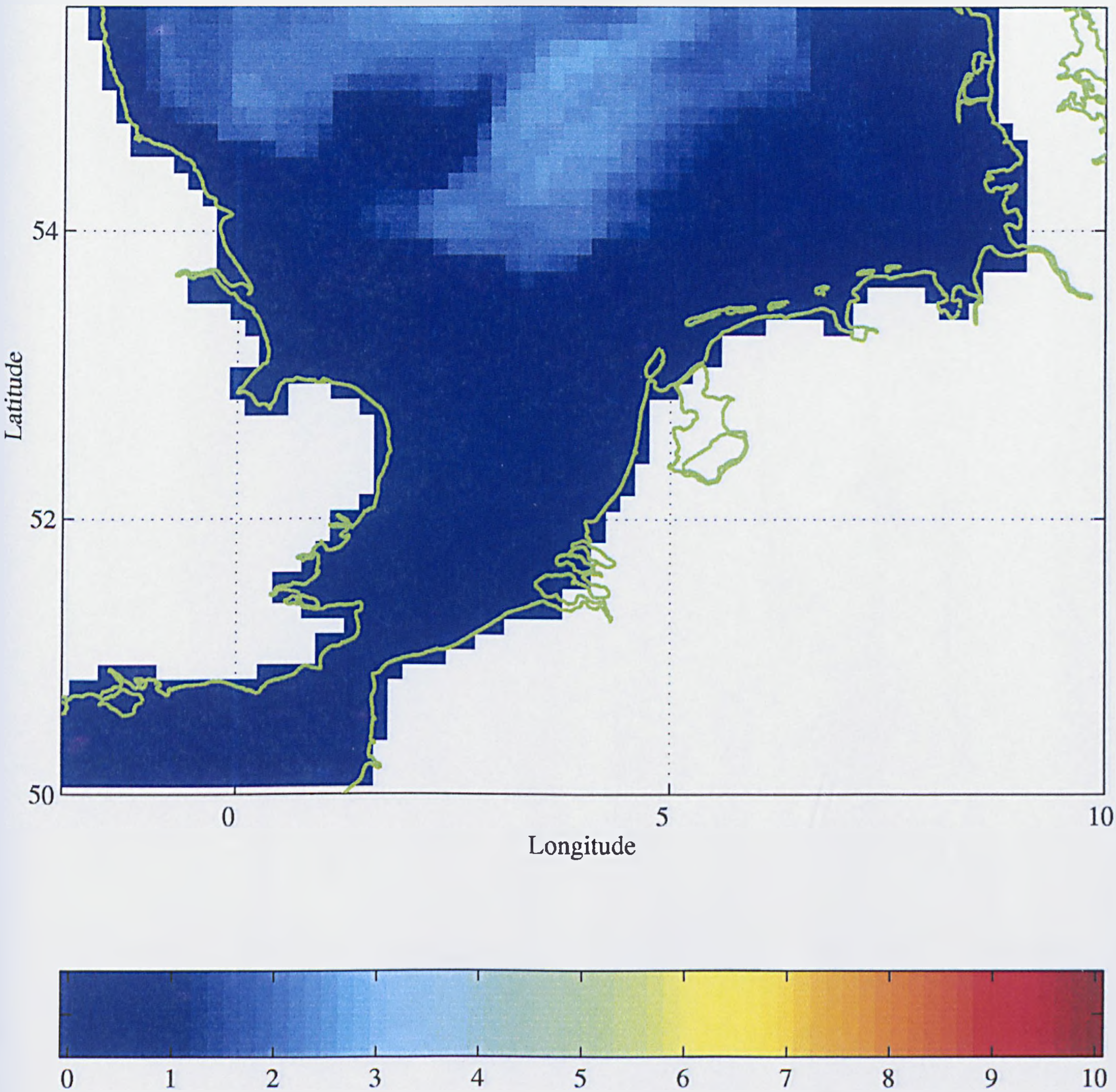
Table 15. Landings (kg) by month, by ICES rectangle for Grimsby in 1999

1999	1	2	3	4	5	6	7	8	9	10	11	12	Total	%
31F2		1849											1849	0.13
31F3			264										264	0.02
32F1			764										764	0.05
32F2												2600	2600	0.18
32F3				1111									1111	0.08
33F2	37145	14893			12651	20356		3445	4679	489		1473	95131	6.70
33F3	4366			1666	16277							3663	25972	1.83
33F4								324					324	0.02
33F5			1575										1575	0.11
34F1							4710						4710	0.33
34F2	525		1769			6144	26	1123	1976				11563	0.81
34F3	15205		3597			10343	8305	4934		240	3634		46258	3.26
35F1					33								33	0.00
35F2		15070	19208	20230	18672	56111	19777	24059	26189	12710	10054	1200	223280	15.74
35F3	13049	7633		23434		16457	4511			8939	1595		75618	5.33
36F1				9484			5780	8508	216				23988	1.69
36F2	31042	22492	14015	6505	1038		1865		17389		143	3309	97798	6.89
36F3	21510	8650	11113	8888	9086	26065	4376	30305	15981		121		136095	9.59
36F4	15583	3905	916	17063	10771			13224			8157		69619	4.91
36F5			7341							647			7988	0.56
37F0									522	996			1518	0.11
37F1						1135	1241	1030	2747			1456	7609	0.54
37F2	9960	8547		9615	8559	23626	14876	30026	14016	28198	8834		156257	11.01
37F3	12519			18437		14139	17895	13409	14724		16237	5049	112409	7.92
37F4			23520	607	6256		4689	4926		11369	6779	1461	59607	4.20
37F5				4490		7461							11951	0.84
37F6				1330									1330	0.09
37F7				1330									1330	0.09
38F0						49			590				639	0.05
38F1							829			1030			1859	0.13
38F2					1202	12415	336						13953	0.98
38F3		426			32481	4007			9297		750		46961	3.31
38F4							15450		4879	1285			21614	1.52
38F5	21434	18735						6257		327			46753	3.30
39F0						483			1704	3800			5987	0.42
39F2									3348		4535		7883	0.56
39F3		2256			4871	7501	6588			14991	9201		45408	3.20
39F4		853									11235	2356	14444	1.02
40F0									655				655	0.05
40F1								11696	6326				18022	1.27
40F2									2773				2773	0.20
41F1						583			2426				3009	0.21
43F1						49							49	0.00
43F2									1593				1593	0.11
49E7					8659								8659	0.61
Total	182338	105309	84082	124190	130556	206924	111254	153266	132030	85021	81275	22567	1418812	100.0
%	12.85	7.42	5.93	8.75	9.20	14.58	7.84	10.80	9.31	5.99	5.73	1.59	100.00	

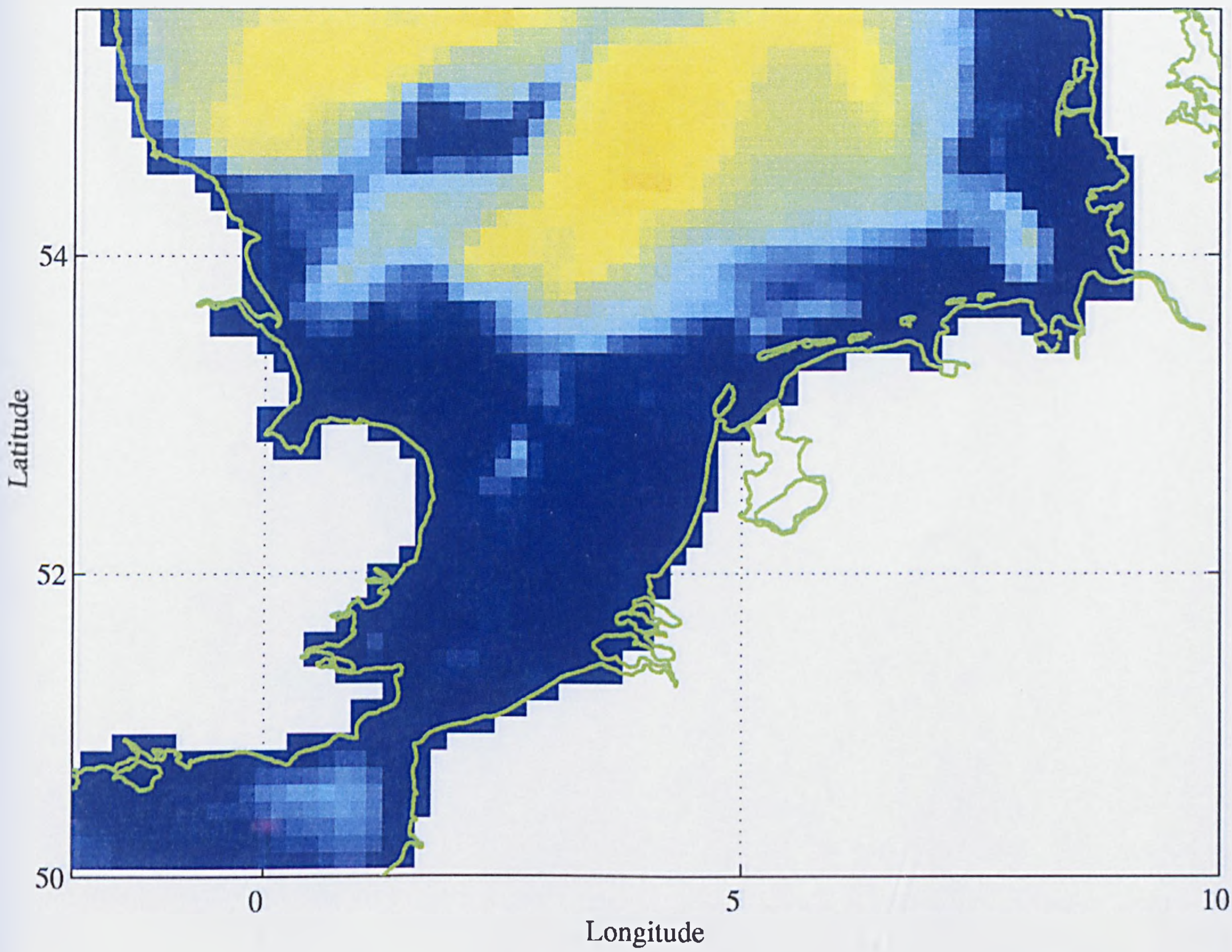
ANNEX 3

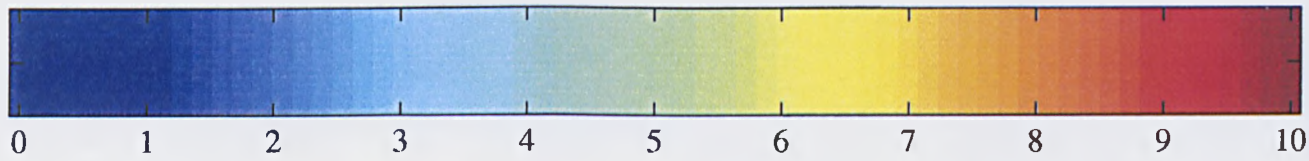


Annex 3: Figure 6-1. Model run surface to bed temperature difference for April (source: CCMS: POL)

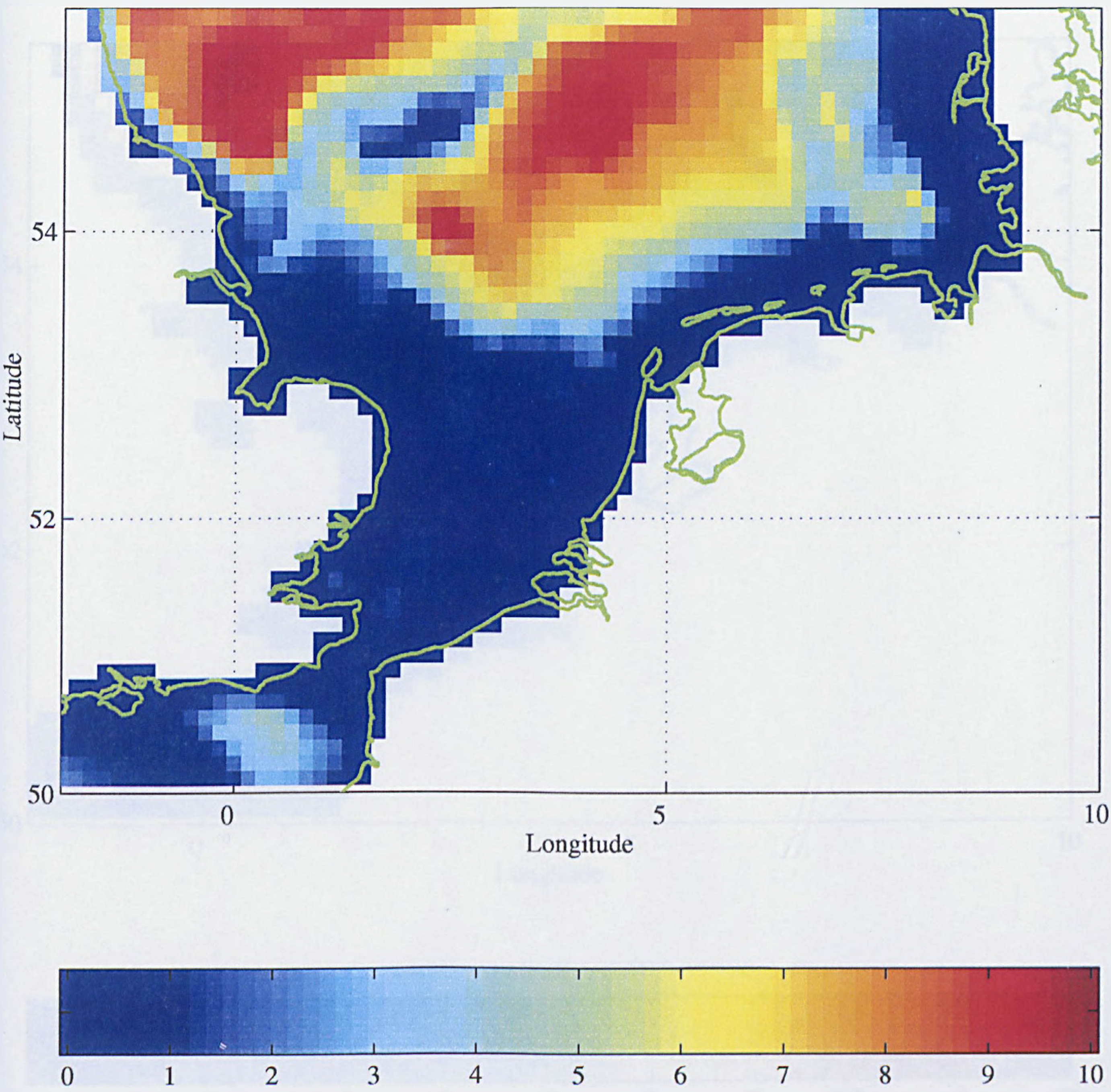


Annex 3: Figure 6-2. Model run surface to bed temperature difference for May (source: CCMS: POL)

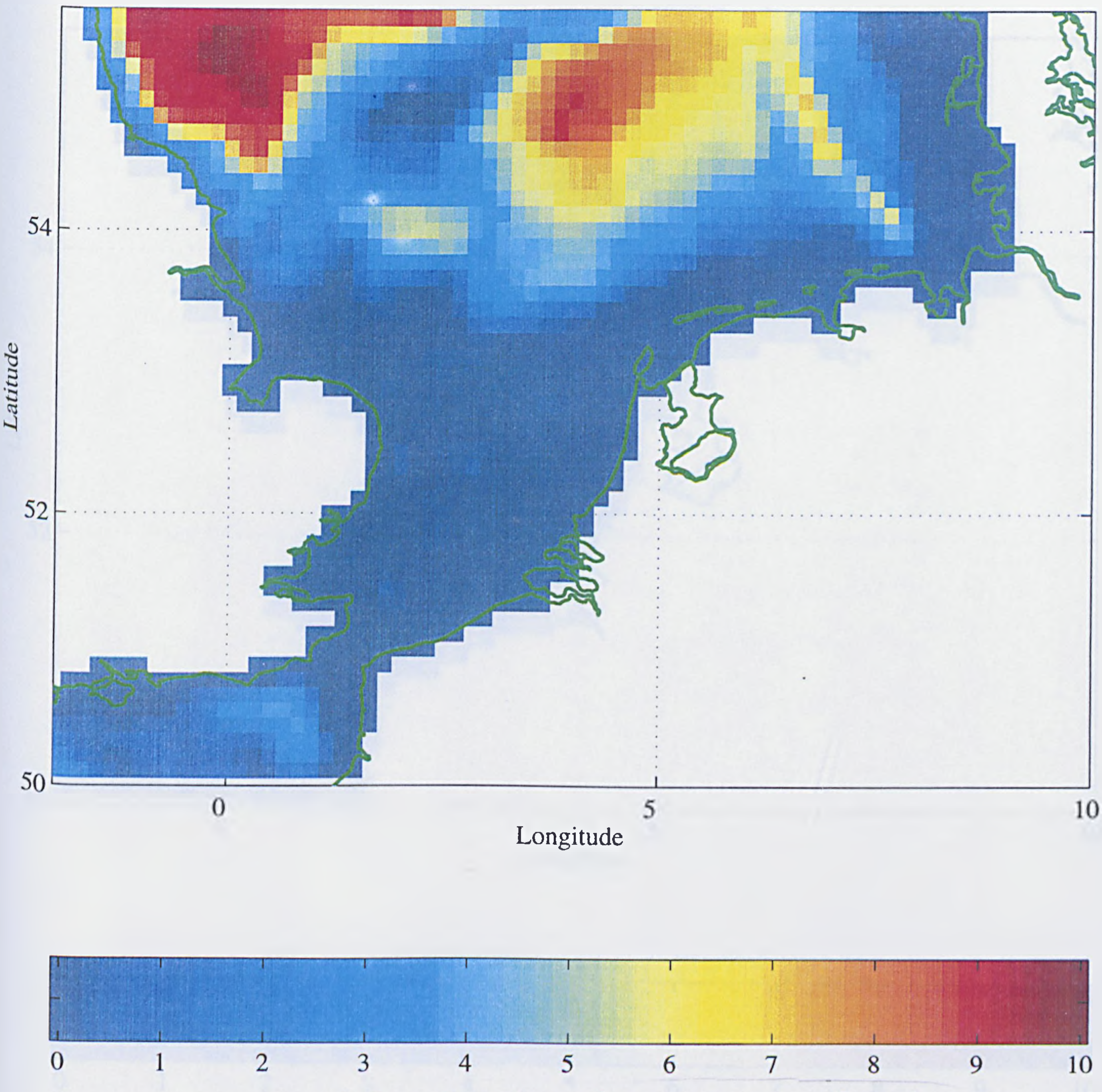




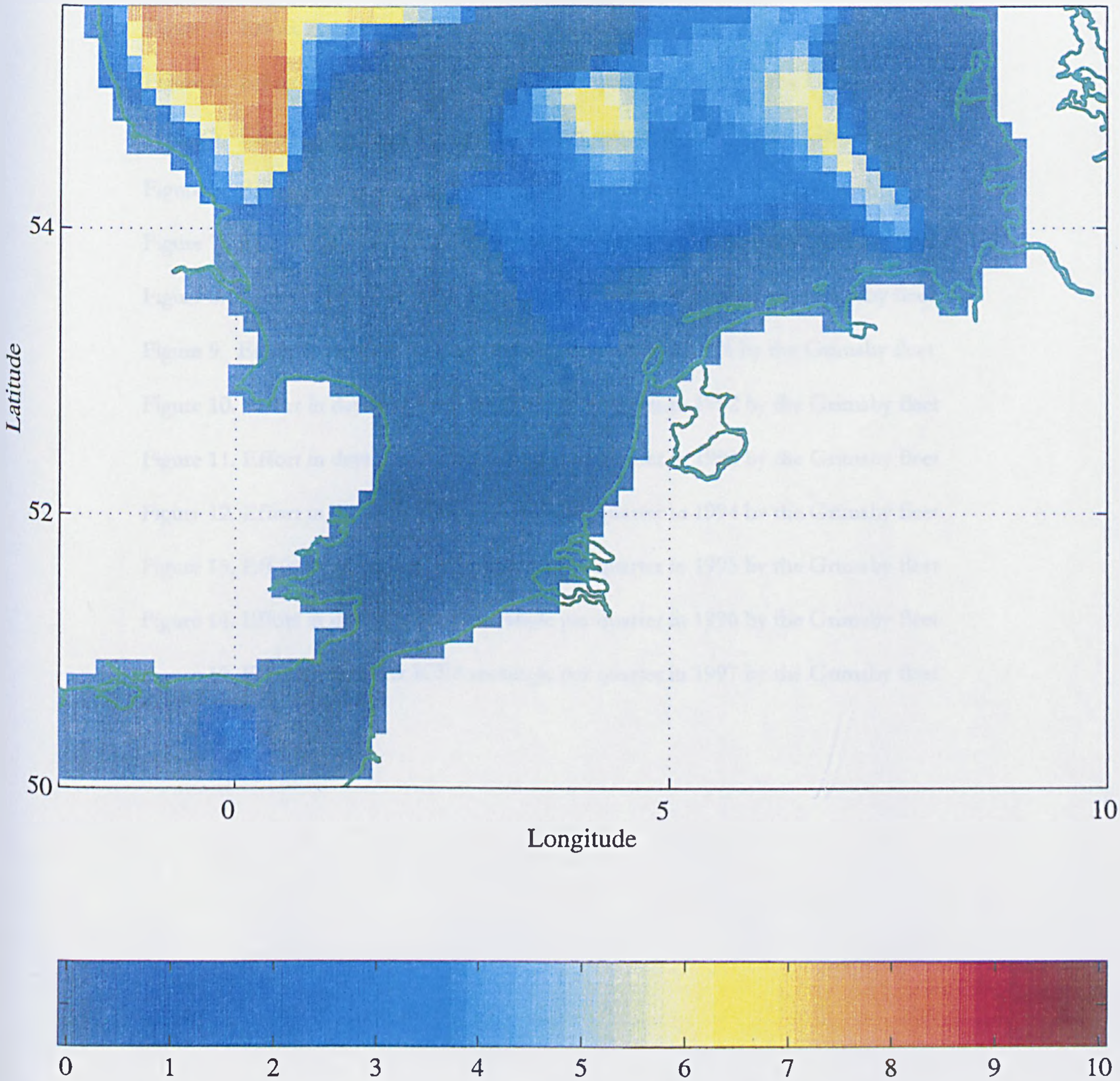
Annex 3: Figure 6-3. Model run surface to bed temperature difference for June (source: CCMS: POL)



Annex 3: Figure 6-4. Model run surface to bed temperature difference for July (source: CCMS: POL)



Annex 3: Figure 6-5. Model run surface to bed temperature difference for August (source: CCMS: POL)



Annex 3: Figure 6-6. Model run surface to bed temperature difference for September (source: CCMS: POL)

ANNEX 4

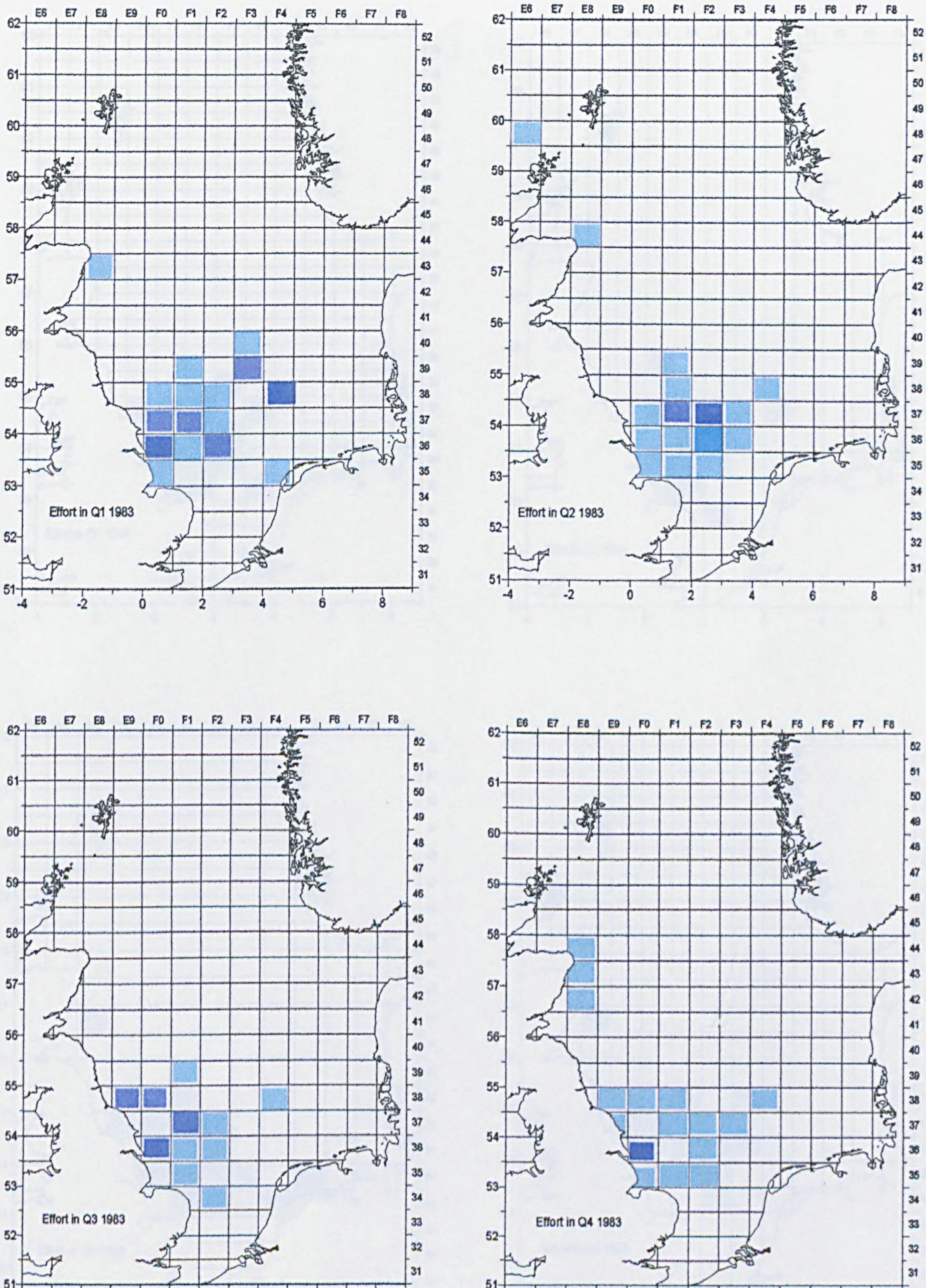


Figure 1. Effort in days per ICES rectangle per quarter in 1983 by the Grimsby fleet

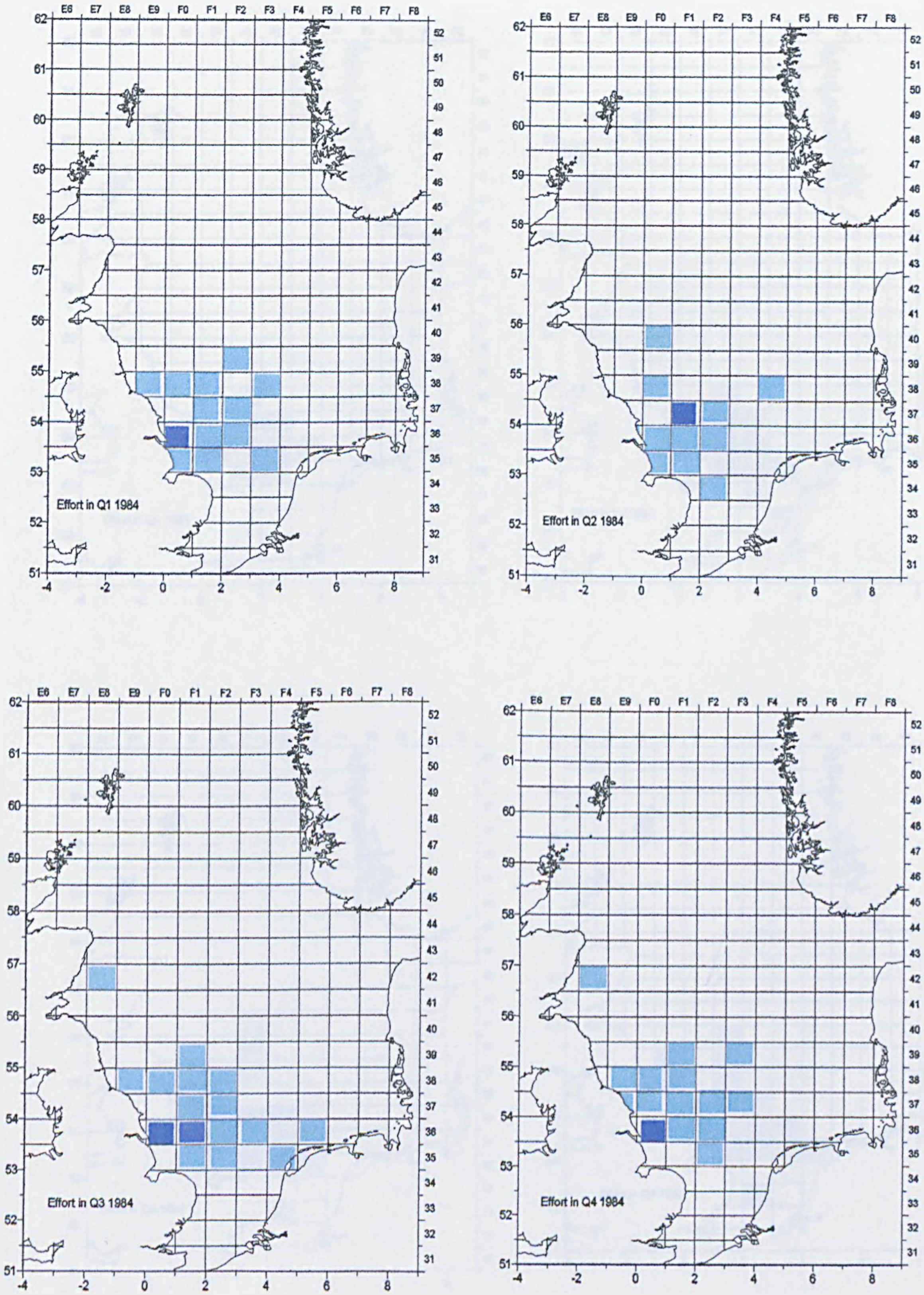


Figure 2. Effort in days per I ES rectangle per quarter in 1984 by the Grims y fleet

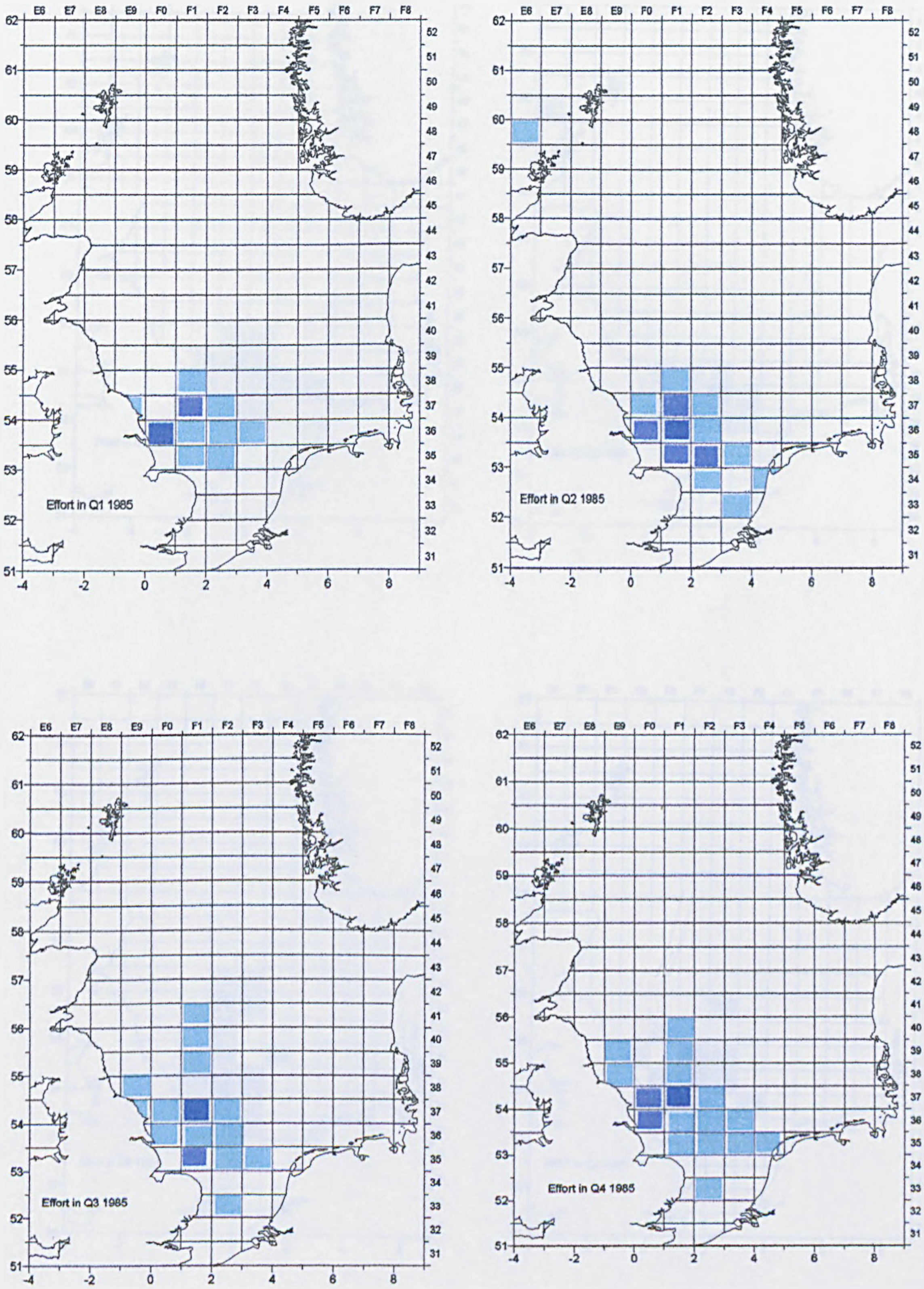


Figure 3. Effort in days per I ES rectangle per quarter in 1985 by the Grims y fleet

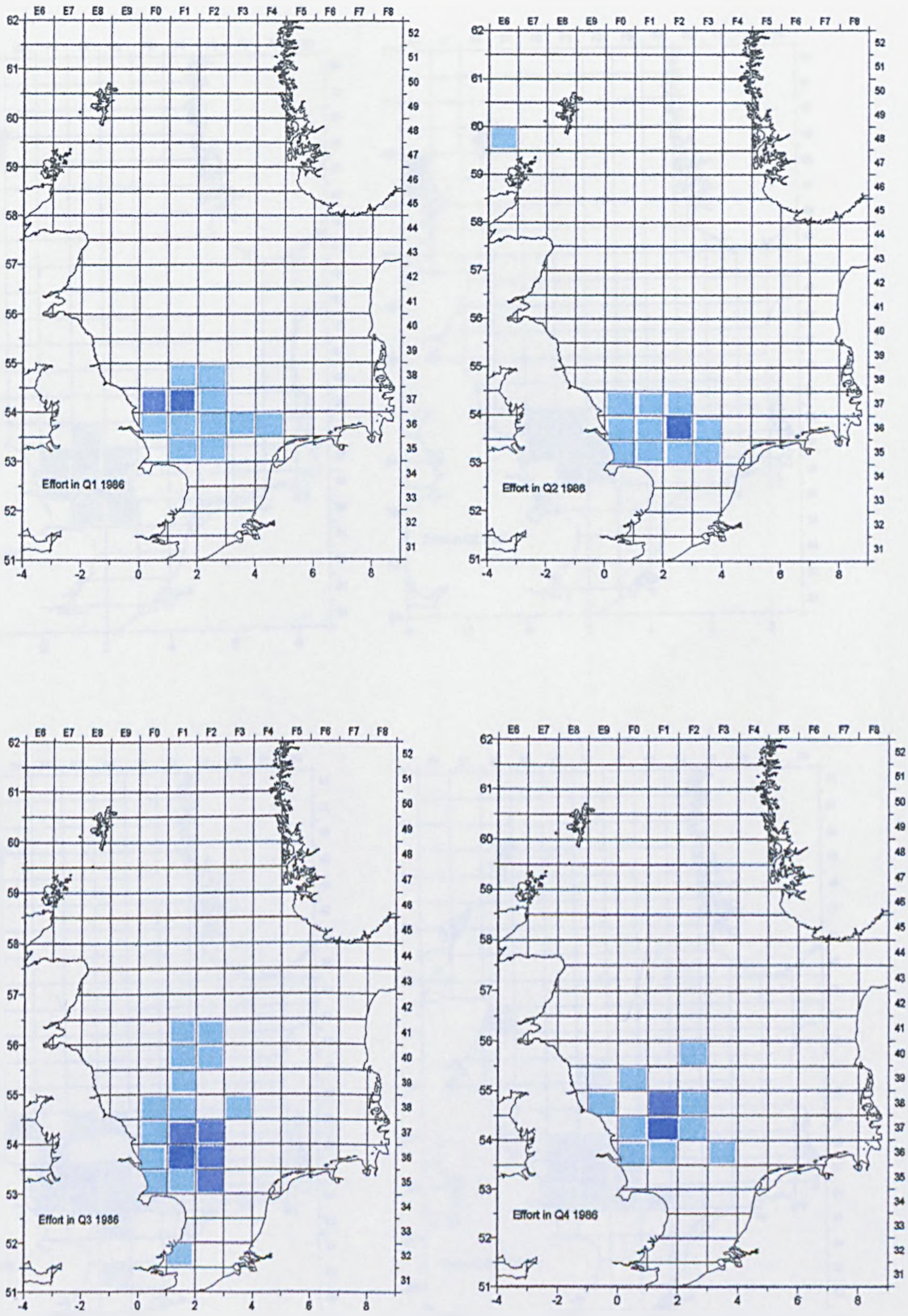


Figure 4. Effort in days per I ES rectangle per quarter in 1986 by the Grims y fleet

Figure 5. Effort in days per ICES rectangle per quarter in 1987 by the Grims y fleet

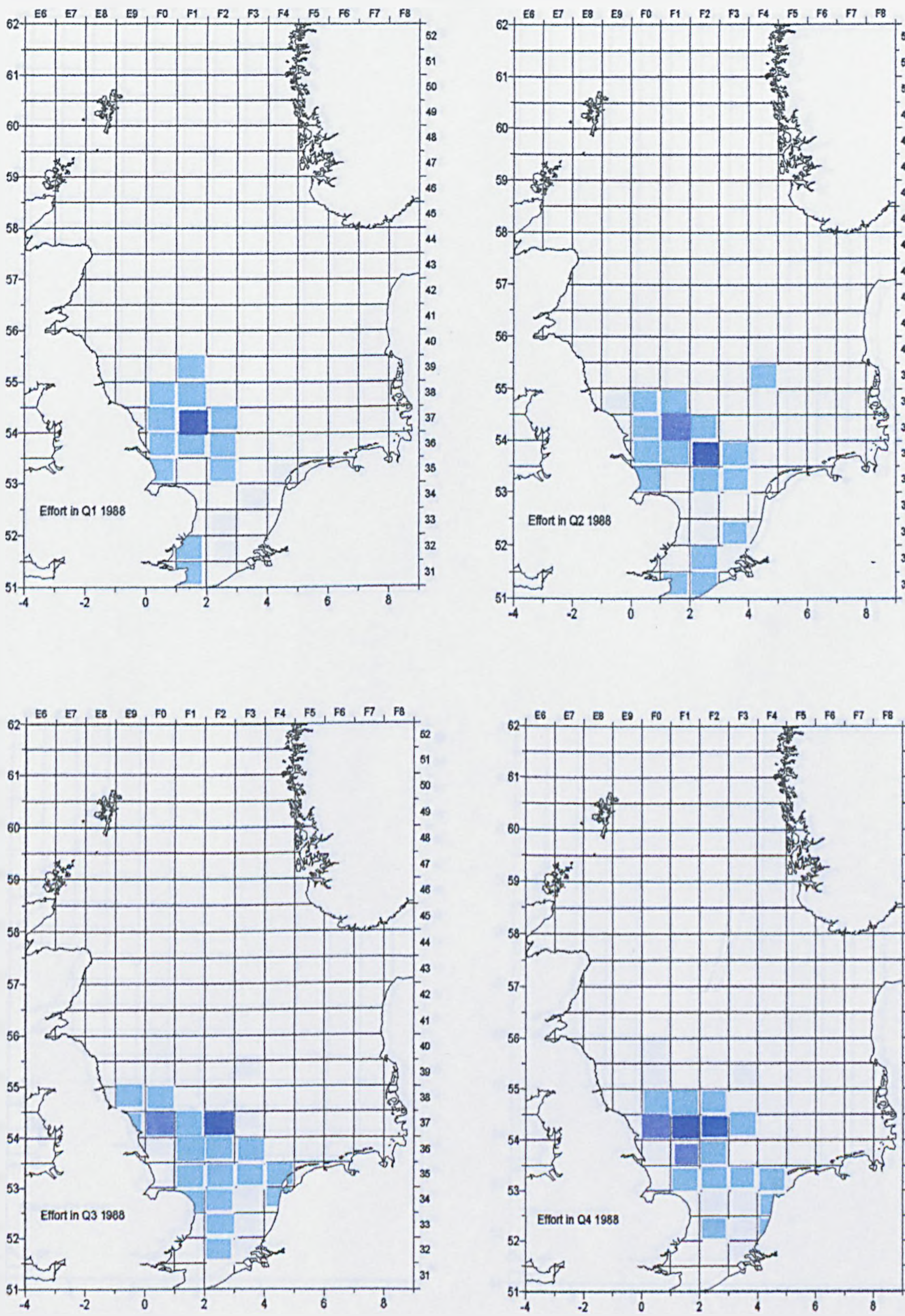


Figure 6. Effort in days per ICES rectangle per quarter in 1988 by the Grims y fleet

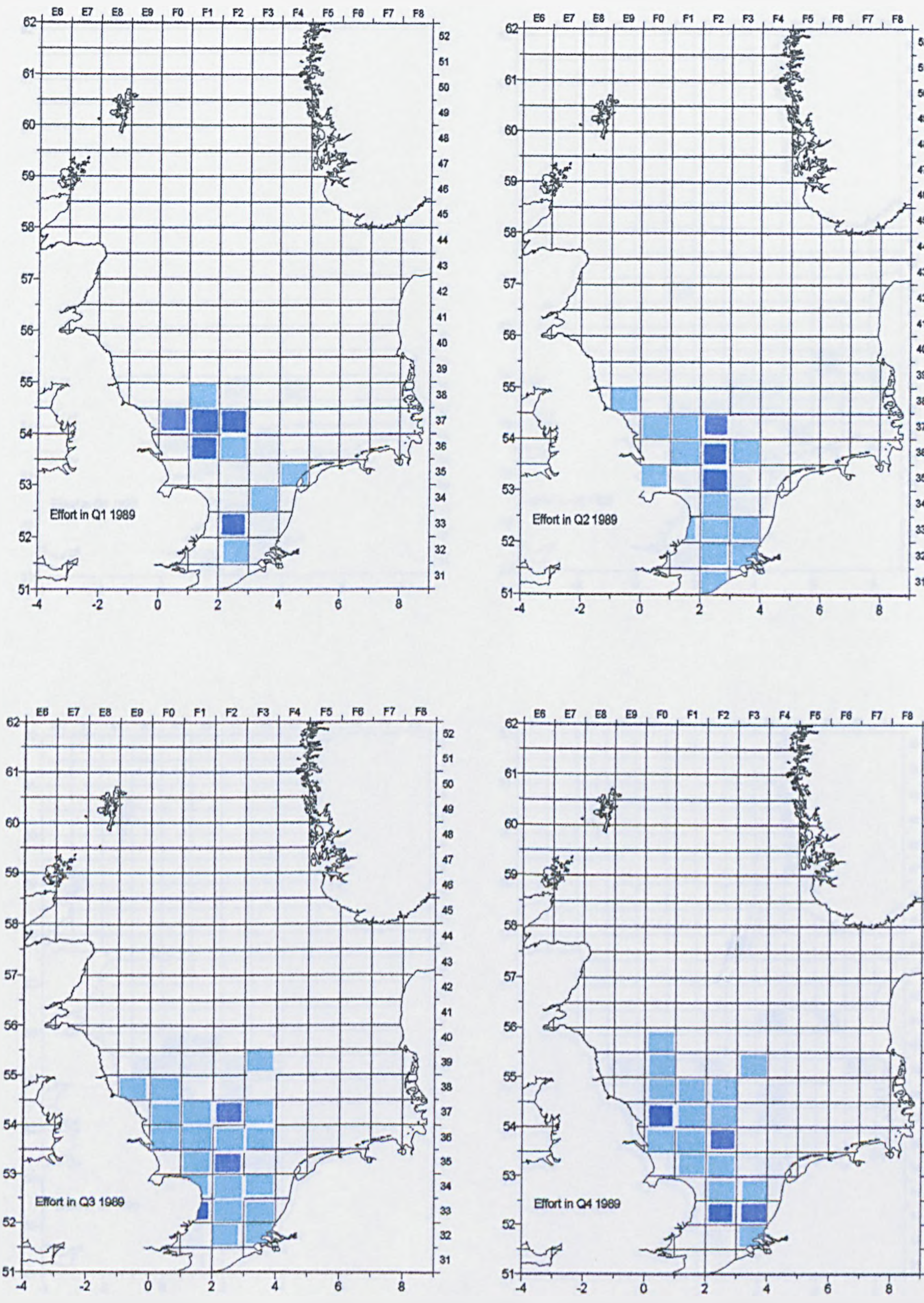


Figure 7. Effort in days per I ES rectangle per quarter in 1989 by the Grims y fleet

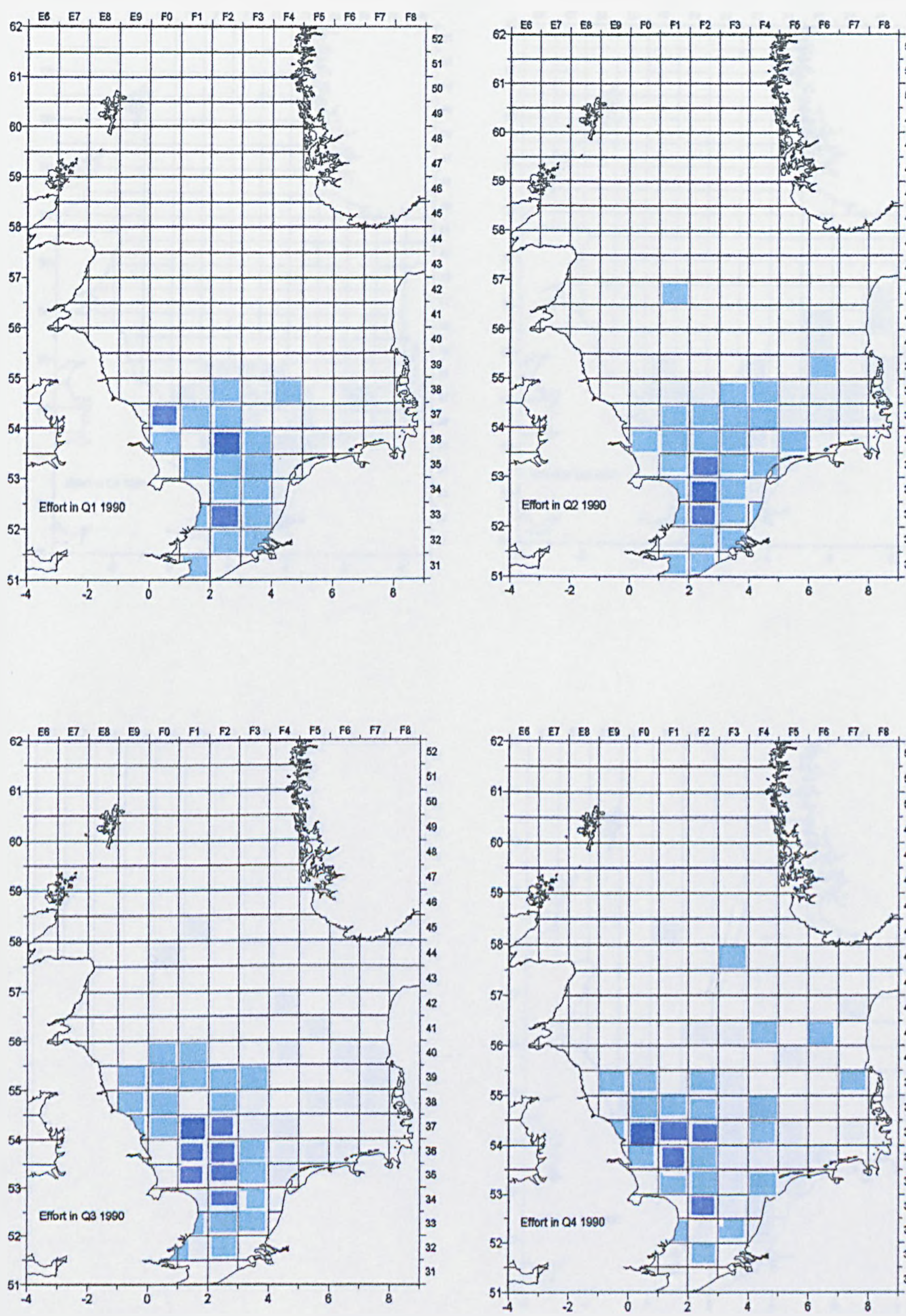


Figure 8. Effort in days per I ES rectangle per quarter in 1990 by the Grims y fleet

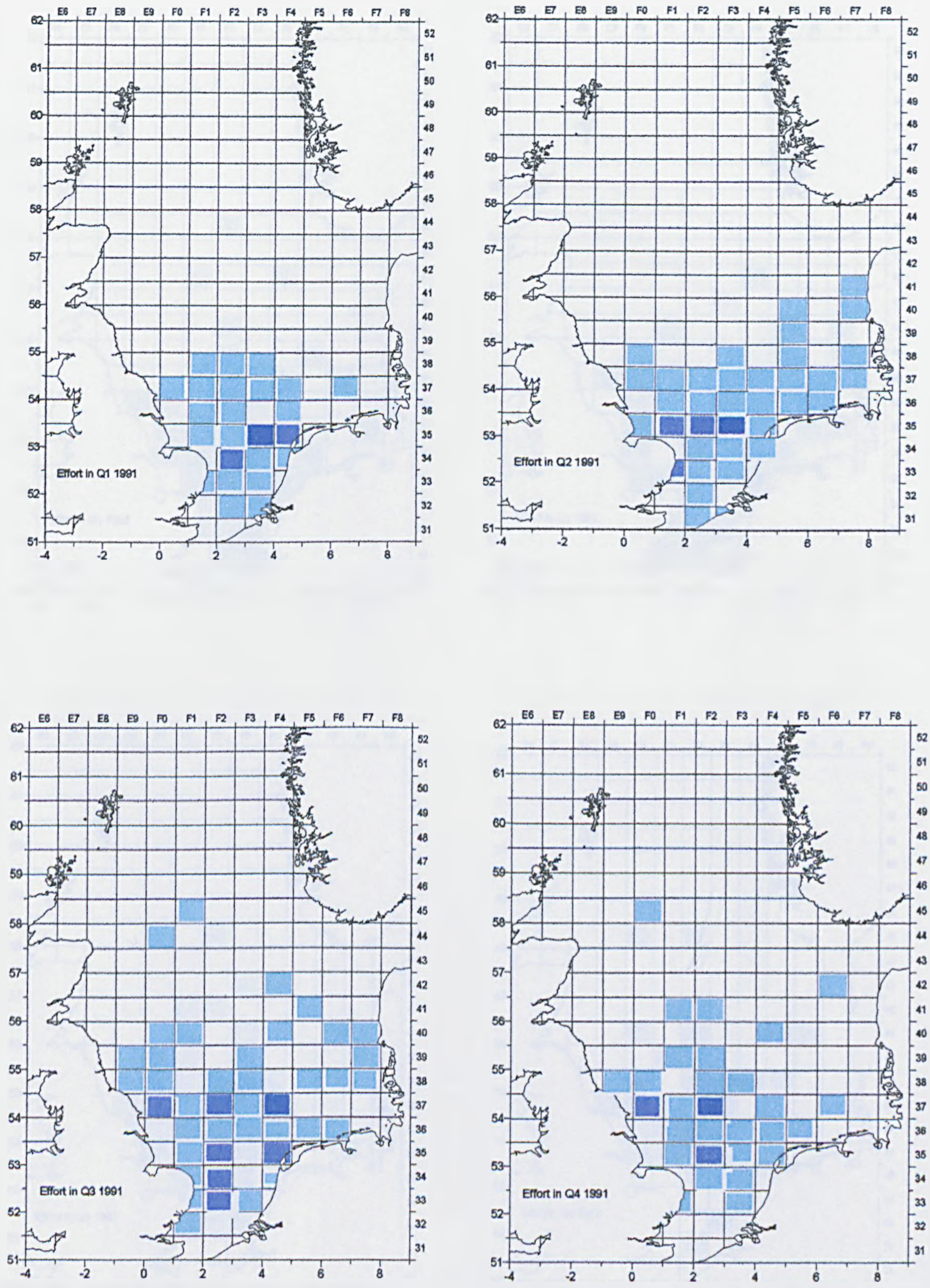


Figure 9. Effort in days per I ES rectangle per quarter in 1991 by the Grims y fleet

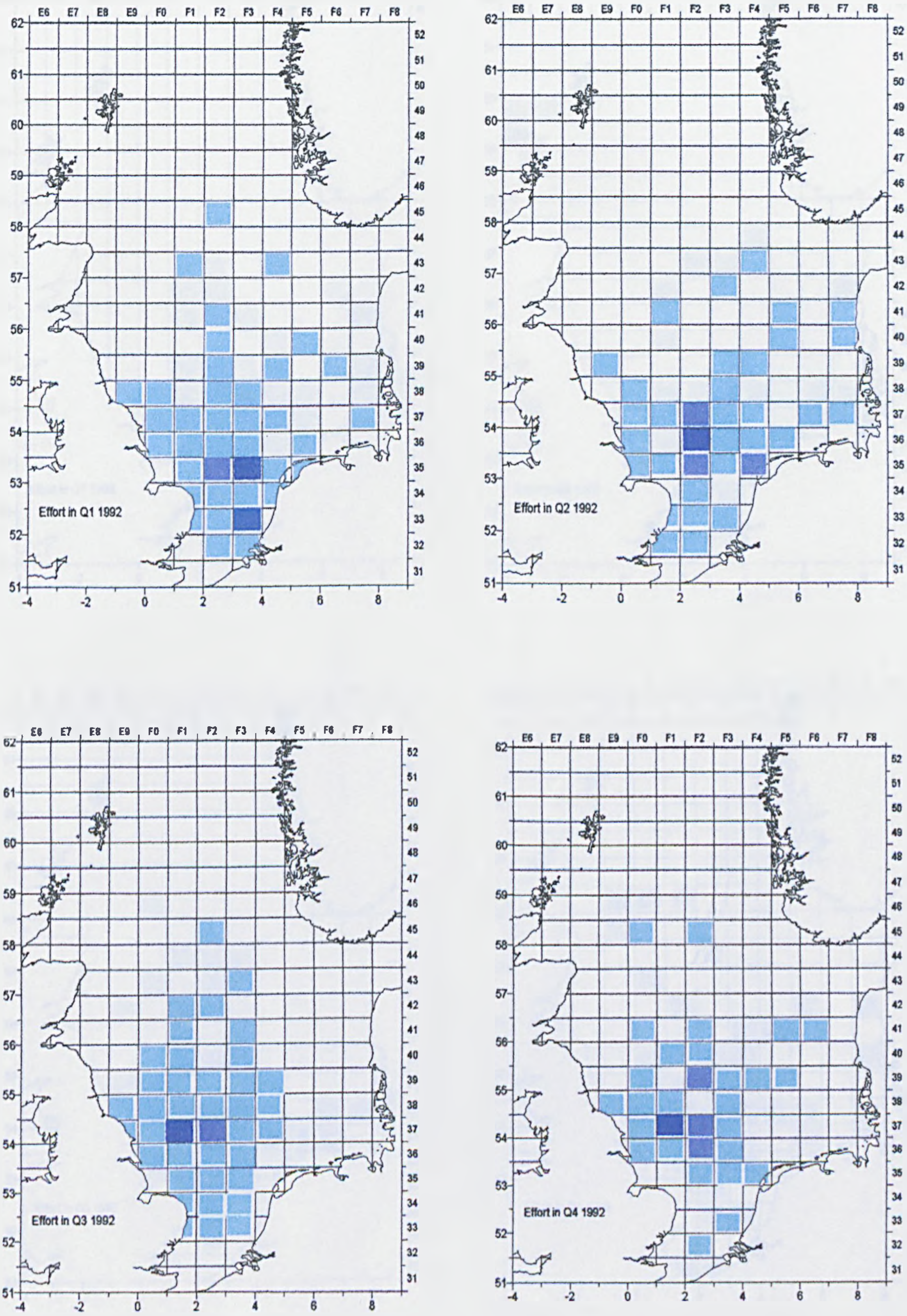


Figure 10. Effort in days per ICES rectangle per quarter in 1992 by the Grims y fleet

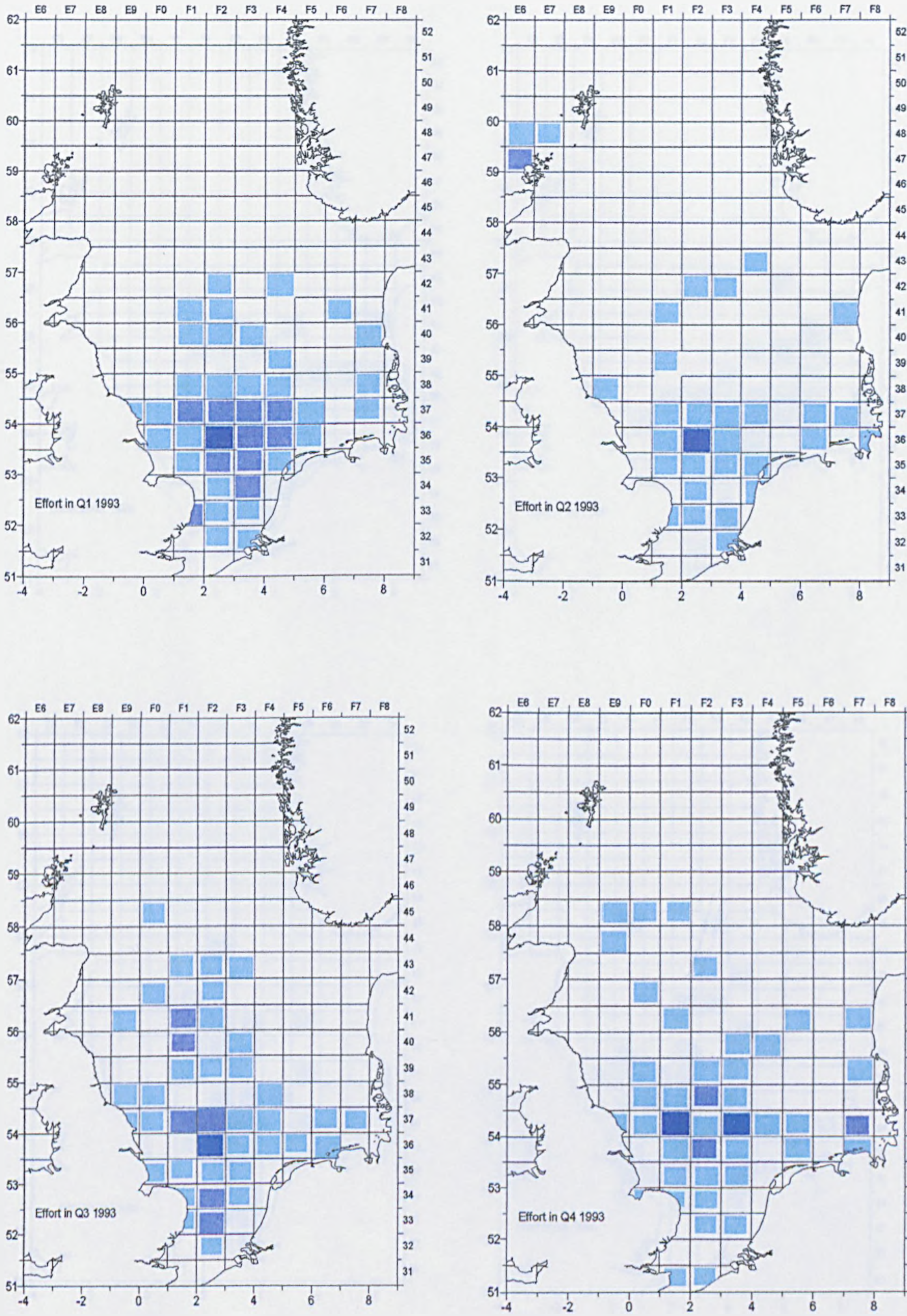


Figure 11. Effort in days per I ES rectangle per quarter in 1993 by the Grims y fleet

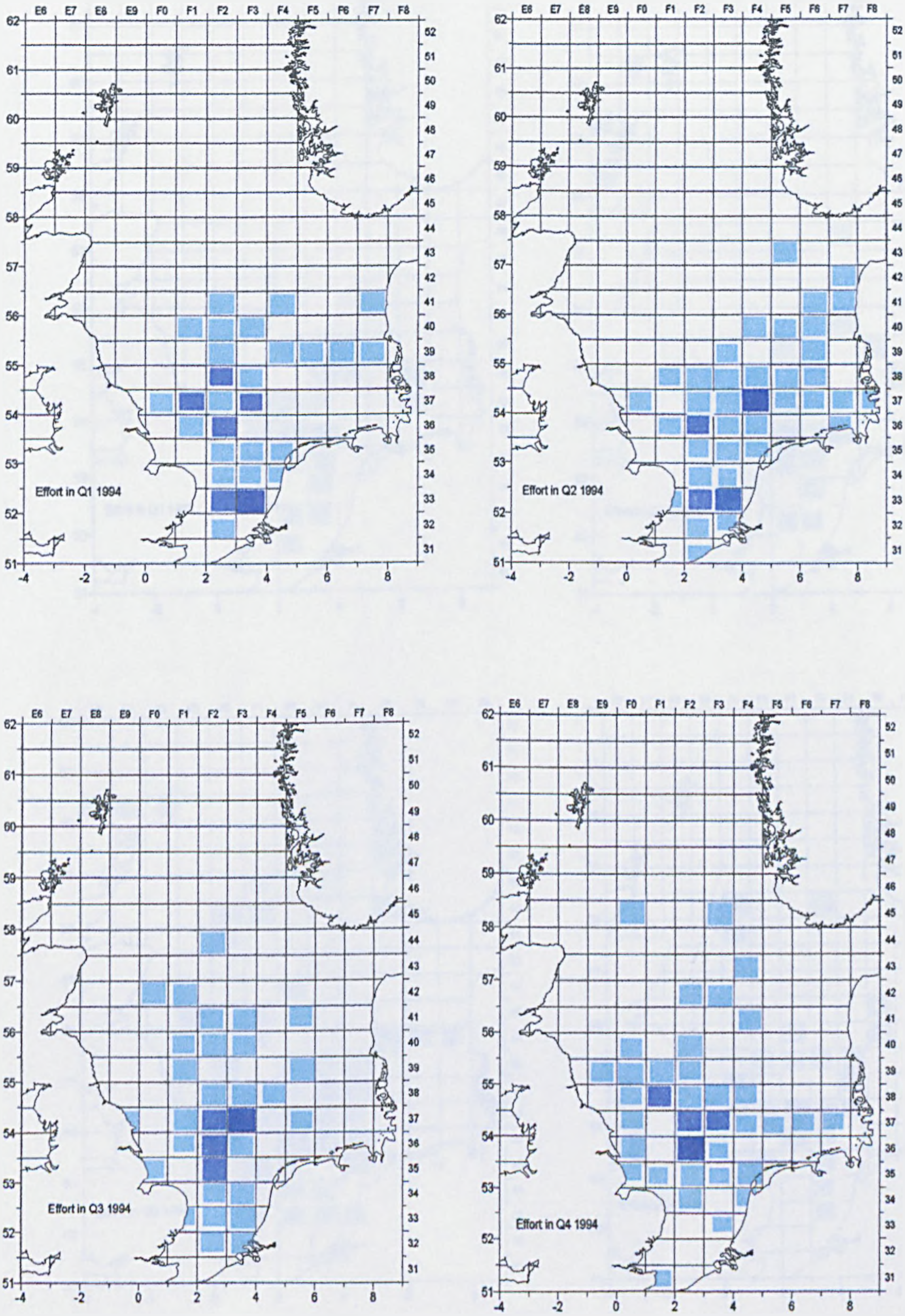


Figure 12. Effort in days per I ES rectangle per quarter in 1994 by the Grims y fleet

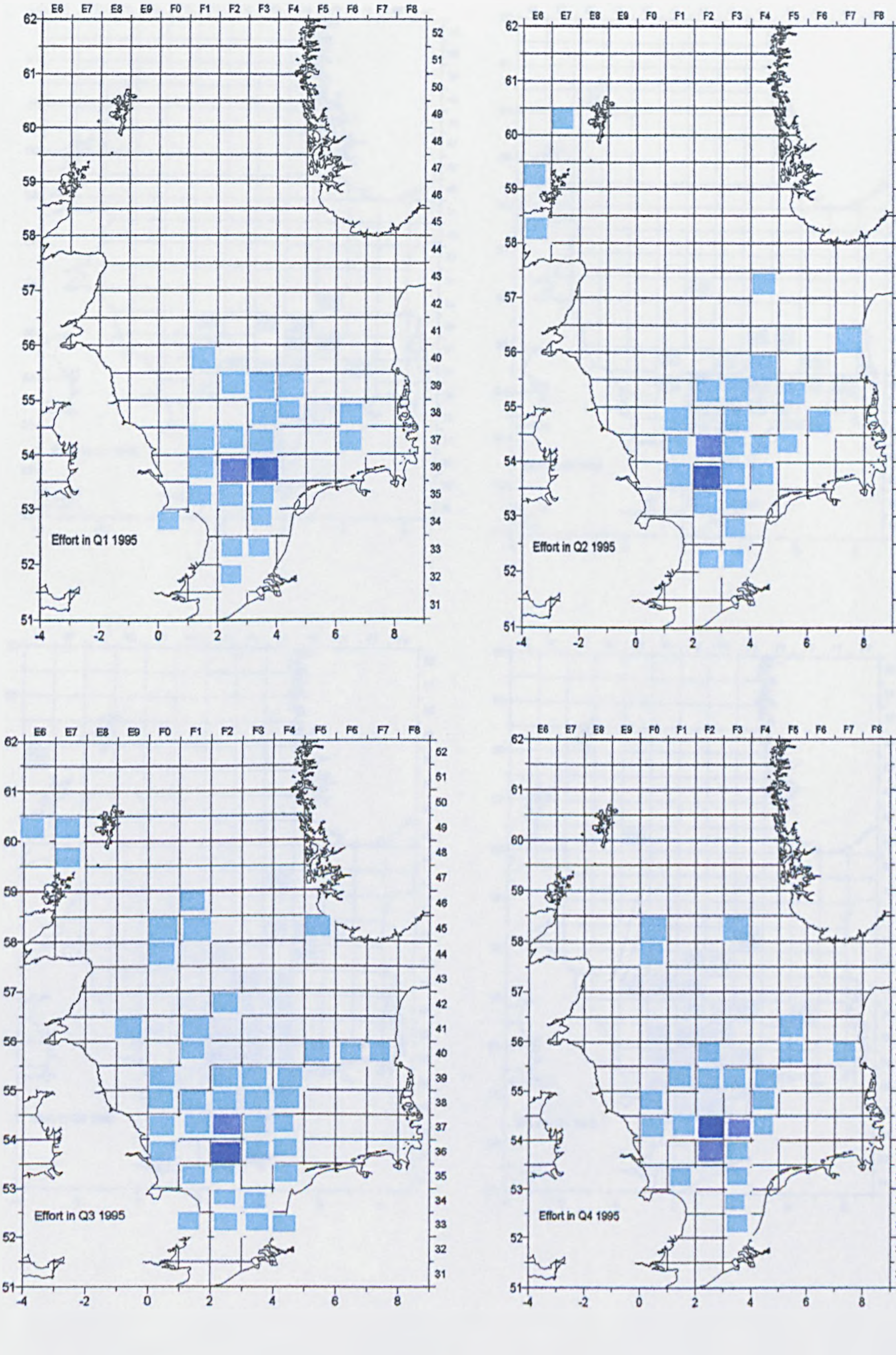


Figure 13. Effort in days per I ES rectangle per quarter in 1995 by the Grims y fleet

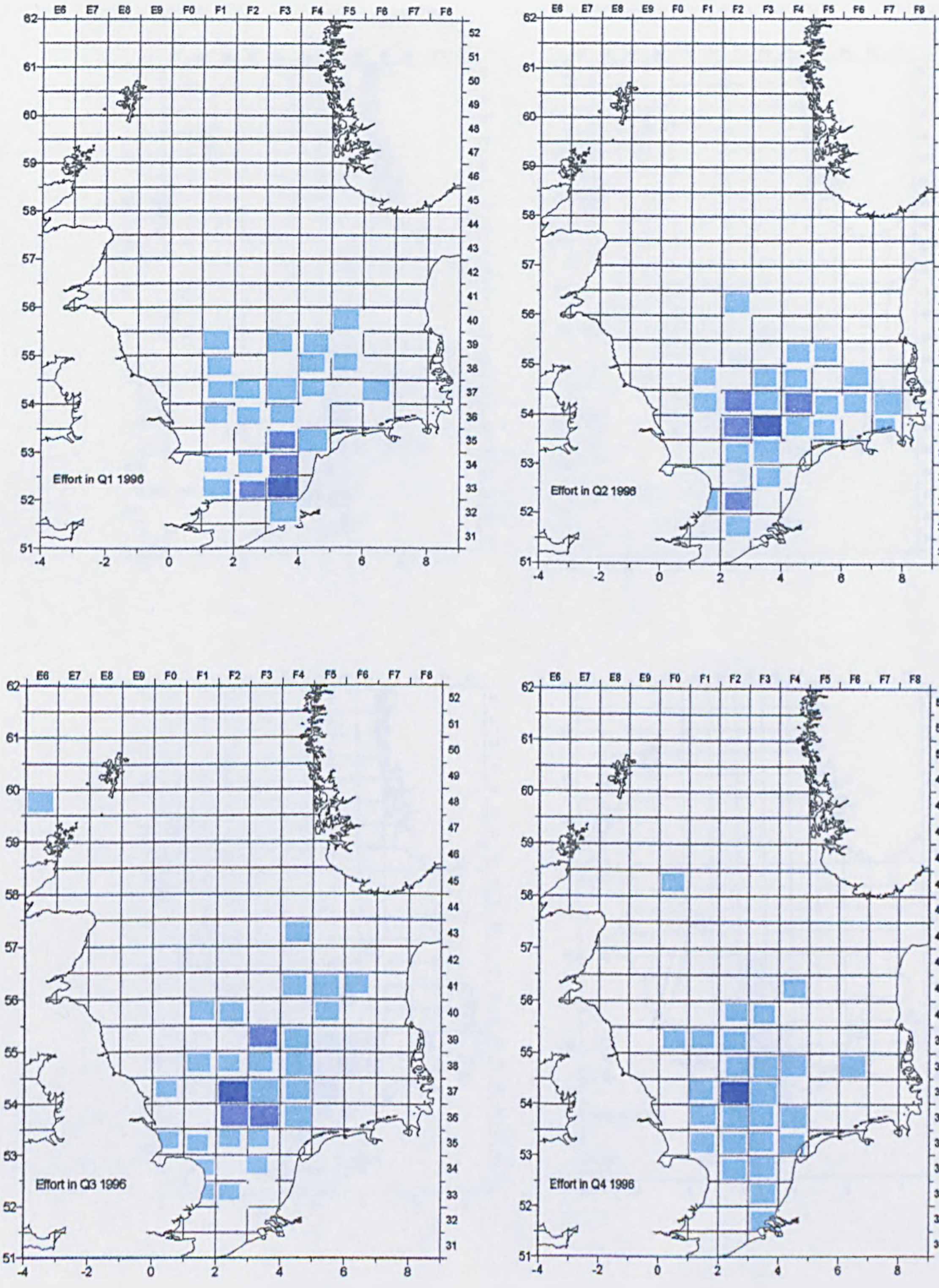


Figure 14. Effort in days per I ES rectangle per quarter in 1996 by the Grims y fleet

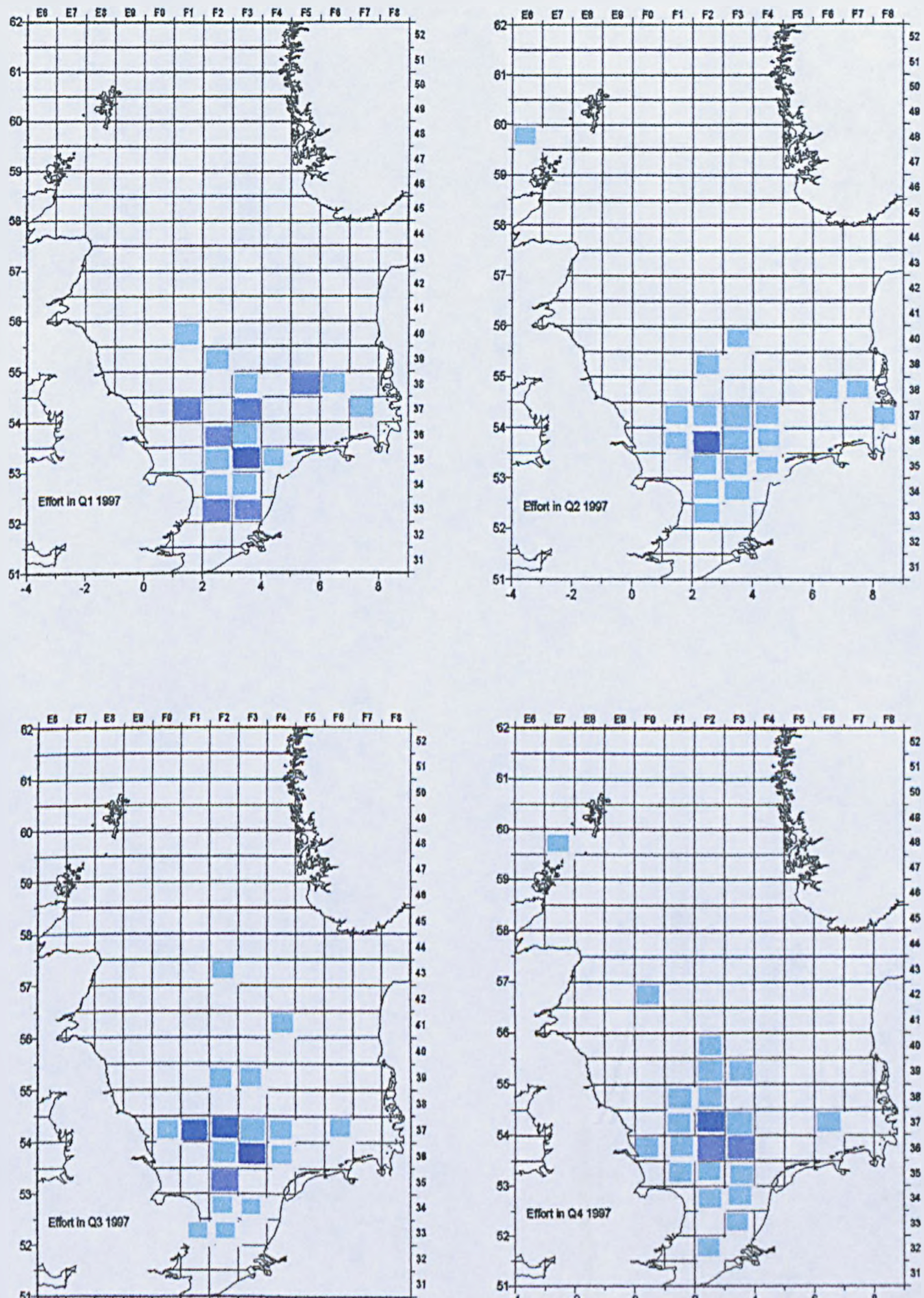


Figure 15. Effort in days per I ES rectangle per quarter in 1997 by the Grims y fleet