ECOLOGICAL PERSPECTIVES OF

THE NORTH SEA C. CRANGON FISHERY

An inventory of its effects on the marine ecosystem

Bachelor Thesis of

Anne Doeksen
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BSc Natural Resources Management
Wageningen University

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Supervisors:

Paul van Zwieten, Wageningen University (Fisheries and aquaculture)
Esther Luiten (North Sea Foundation)

CONTENT

GENERAL INTRODUCTION

Context of the study and motivation

Crangon crangon L., more commonly known as the brown shrimp, is a species of substantial commercial value to North Sea fisheries. The North Sea C. crangon fishery is a multinational fleet of around 653 vessels which operate along the coasts of the Denmark, Germany, The Netherlands, Belgium and the UK where the species is sufficiently abundant to support commercial exploitation. A particular productive fishing zone is the Wadden Sea. The Wadden Sea stretches out along the coast of The Netherlands, Germany and Denmark and is a listed European Marine Protected Area (MPA), a provision that falls under the Bird and Habitat Directive (BHD) of the European Union. Anthropogenic activity taking place in this area is authorized only on the condition that sufficient evidence can be delivered which demonstrates that the activities are not detrimental to the marine ecosystem.

The C. crangon fishery is one of the few economic activities still taking place in the Wadden Sea under this provision and, in the Netherlands, is next up for an evaluation in 2007, on the basis of which will be determined whether the fishery may continue its practices in its present form or whether it must terminate its activities in the Wadden Sea. Considering that the C. crangon fishery is a bottom-trawling fishery using small mesh-sizes, it is to be expected that this fishery exerts considerable pressures on the marine ecosystem by ways of bottom-disturbance and by-catches. These issues will likely form the matter of concern in the up-coming evaluation.

Anticipating this event the Dutch shrimp sector and two Dutch conservation groups; The North Sea Foundation and The Wadden Association have initiated a project in which the possibility is explored to advance towards sustainable fishing practices and environmental certification of the fishery. This private arrangement would exist alongside the EU Bird and Habitat Directive and complement the command and control policies of the EU with self-regulatory market-mechanisms, advocated and supported by the sector itself. This initiative responds to the increasing market demand for environmentally sound products and is argued to path the way for an irreversible, cooperative and transparent process, of attaining more sustainable production.

The North Sea C. crangon fishery includes Belgian, Dutch, German, Danish and UK fishermen who fish under each others flags and within one another's territorial waters. The sector is dominated by two major Dutch wholesalers; Klaas Puul and Heijploeg. These interdependencies make it desirable not only from an environmental perspective but also from a sectoral perspective to broaden the scope of the project beyond the Dutch Wadden Sea fishery alone. Given this, the initiators of the project have sought collaboration with stakeholders throughout the sector in order to see if there is sufficient capacity and willingness to progress towards a certified shrimp fishery. Furthermore a recognised eco-label has been selected for which the fishery will be pre-assessed. This eco-label is provided by the Marine Stewardship Council (MSC). MSC is 'an independent, global, non-profit organisation whose role is to recognise, via a certification programme, well-managed fisheries and to harness consumer preference for seafood products bearing the MSC label of approval'. It provides the environmental standards and criteria which the fishery should meet in order for it to acquire an MSC label. The fishery is assessed according to MSC standards by one of the accredited Certification bodies listed by MSC. The project has embraced a Dutch Certification Body by the name of SGS.

SGS is momentarily in the process of making a pre-assessment of the Brown shrimp fishery after which will become clear whether or not the fishery is able to receive a MSC label and, if not, on which criteria it fails. This assessment employs a unique stakeholder approach; the certifier consults all involved stakeholders in the assessment phase and stakeholders are encouraged to set in motion a multi-stakeholder dialogue. This phase aims to align the objectives of the individual stakeholders so as to come to a consistent, clear and operational definition of sustainability.

Accordingly, the Wadden Association and the North Sea Foundation together with their fellow environmental ngo's are required to provide their own definition of a sustainable shrimp fishery and to determine whether or not, and under which conditions, they deem the fishery fit, now and in future, for acquiring an eco-label. In order to give their opinion in this matter and to formulate such a definition an understanding is required of the fishery and the way it interacts with and affects the marine environment in which it operates. Such an assessment will form the basis on which an ngo statement can be founded. The need for such an assessment has given the impulse to conducting this study and has defined its scope and matter.

Study objectives

By analysing the available literature an attempt is made to map out the effects of the North Sea *C. crangon* fishery on the marine ecosystem, thereby highlighting the mayor bottlenecks in this fishery. This inventory illustrates how fishing practices and methods relate to these effects so that it becomes evident where and with what measures could be intervened to effectively mitigate the pressures exerted on the marine ecosystem. This inventory is based on a critical analysis of the available fisheries data and literature dealing with this topic. Information sources will be discussed in terms of accessibility, completeness, quality and consistency so that the inventory may be valued for what it is truly worth and so that it may become evident where efforts need to be made to achieve a more comprehensive and more instructive impact assessment.

Thus the three main objectives of this study are; (1) to make an inventory of effects of the North Sea *C. crangon* fishery on the marine ecosystem, highlighting the bottlenecks; (2) to suggest in which areas intervention would be appropriate and what measures could be considered; (3) To illuminate knowledge gaps and data deficiency and propose how we can improve impact assessment

Approach and navigation

There are many ways of looking at effects of fisheries on the marine ecosystem. Coming from the social-technical sciences, and with only a limited education in fisheries and fish biology, choosing an appropriate approach and knowing how and where to look required a brief plunge into the fisheries literature and some instructive conversations with my supervisor, an acquired marine biologist and fisheries manager. A brief review of this is given in the second part of this introduction for those who are interested.

I have limited my study to assessing (a) the direct effects of pressures exerted by this fishery through extractions, discarding and bottom disturbance on marine populations and habitats, and (b) the flow effects that follow from these effects on populations, and (c) the way this has changed the benthic species community. This has nevertheless proven to be sufficiently demanding and time-consuming.

The paper is organised into three parts:

Part one, which consists of only one chapter (chapter 1), deals with the status and developments of the North Sea C. crangon fishery and describes the characteristics and composition of the fleet and the magnitude and scale of its operations. This illuminates by which mechanisms the fishery may put pressure on the marine environment and the scale and intensity at which this takes place.

Part two (chapter 2-5) deals with the direct and indirect effects that result from C. crangon extractions and discarding practices. Chapter 2 discusses by-catches and discarding in North Sea C. crangon fisheries in quantitative and qualitative terms and discusses discard mortality. Such figures are an indication of the kind and magnitude of fishing mortality being inflicted by this fishery. In the following three chapters (3-5) an attempt is made to determine what the implications of these mortalities are for populations. In chapter 3 the effects of C. crangon extractions and juvenile discard mortalities on the population of the target species is assessed. Chapter 4 assesses the population effects of discard mortalities on non-target species. Chapter 5 discusses the flow effects on population that follow from the direct effects through all sorts of species interdependencies.

Part three (chapter 6-9) deals with the direct and indirect effects that result from mechanical disturbance of the sea-bed and the associate benthic species. Chapter 6 discusses spatial and temporal variability in environmental conditions and fishing effort and the implications of this for impact assessment. Chapter 7 discusses trawl-bottom interactions and mechanical disturbance of benthic habitats. Consequently the effect that habitat disturbance has on populations of the associate species are assessed. Chapter 8 discusses how trawling inflicts direct mortality on benthic species (excluding the already discussed discard mortality) and the effects of this on benthic populations. In chapter 9 the effects of shrimp trawling are observed within a larger time frame at a community level. Changes in community structure and composition are discussed.

The paper has become a lengthy piece of writing, rich with detail. Those of you that have tired eyes, or little appetite and time for this may find the paragraph of reflections and insights, which you will find at the end of each chapter, useful. This summarizes the main points of the chapter, mentions insights that have been obtained concerning intervention and management measures, and suggests which (research) efforts need to be made to achieve a better assessment.

APPROACHES TO ASSESSING ECOSYSTEM EFFECTS OF FISHING

Posing the right questions

Extracting means affecting; by extracting marine resources we are ultimately taking a position in the marine ecosystem and rearranging the energy flows in this system. The reason we want to understand how and to what extent our extractions are affecting the marine ecosystem is to determine whether intervention and the implementation of management measures is called for. This requires us to pose three core questions;

I. How have the components and emergent properties of the marine ecosystem been altered?
II. What do these changes mean for the state of the marine ecosystem as a whole?
III. When do changes matter?

Interestingly, these questions are similar to the questions a doctor may ask himself before prescribing a patient medicine. Asking ourselves the first question (I) allows us to identify changes that result from pressures exerted by the fishery. The components (e.g. populations, habitats) and emergent properties (ecosystem functions and structure) of the marine ecosystem form the object of our observations. The second question (II) concerns artificial concepts such as ecosystem health, integrity and stress. Such concepts are in fact tools that allow us to define and evaluate the state of the ecosystem and attach meaning to the observed changes to the components and properties of an ecosystem. Such concepts are described by a suitable set of predefined parameters, or more specifically an appropriate set of measurable and quantifiable ecosystem components and properties. In order to perform our diagnosis we need to calibrate these parameters, e.g. what are the symptoms of a stressed system? and; how do we define different levels of stress? The last question (III) relates to how we value system changes and the level of change we are willing to accept. This implies setting criteria and benchmarks, on the basis of which we can make a qualitative judgement and on the basis of which can be determined whether intervention is required.

A fundamental problem in answering each of these three questions is that any change takes place, and therefore must be evaluated, against a background of natural dynamics and change. Evaluating the state of the system and determining which role we play in this thereby becomes a considerable challenge. Nevertheless, continuous efforts are being made to develop operational concepts and define appropriate parameters that guide our observations and can be employed in impact assessment and fisheries management.

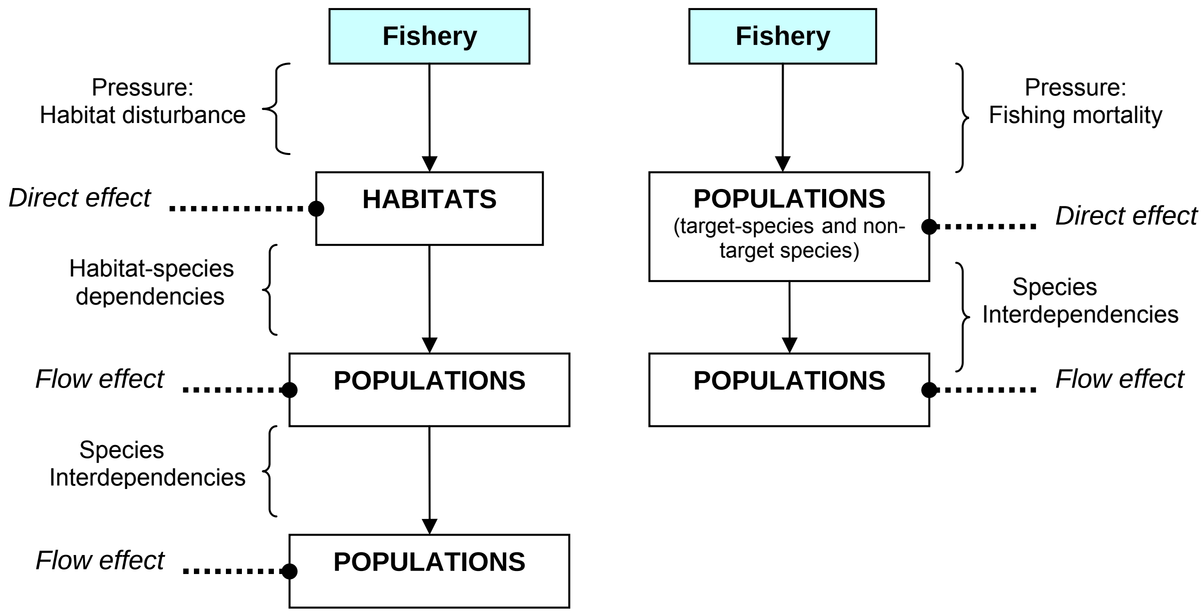
It is not my ambition to venture into such terrain within this study, as this is far beyond the scope of this paper. This study concerns the first of the above stated questions. In answering this question the focus of our lens shifts in order to account for fisheries induced changes taking place on a population level as well as changes taking place at community level. The way that effects are approached will roughly follow the lines in which the popular literature in marine sciences and fisheries management has developed; looking first at effects of fishing on the population of the target species (traditional single species stock assessment) and, from there on, moving our observations to a higher level of sophistication by including direct as well as indirect effects on non-target species. This is an attempt to capture and understand wider ecosystem effects of fishing, and how changes influence ecosystem structure and functioning.

Ways of looking at effects: adjusting the view and focus of the lens

For analytical purpose effects are classified depending on the level on which, and the mechanisms through which the effect takes place. Hall (1999) has made an excellent synthesis of the literature that deals with effects of fishing on the marine ecosystem. I have borrowed from the major lines in his work, applying a similar definitions and classifications. His synthesis is in accordance with the line along which the research agenda in this field has developed.

The first distinction that is generally made in the literature dealing with ecosystem effects is between direct and indirect effects. This is determined by the mechanism through which an effect takes place. Hall

(1999) defines direct effects as: ..” (1) fishing mortality on species populations, either by catching them (and either landing or discarding them) or killing them during the fishing process without actually retaining them in the gear, and/or exposing or damaging them and making them vulnerable to scavengers and other predators, (2) Increasing food available to other species in the system by discarding unwanted fish, fish offal and benthos, (3) disturbing and/or destroying habitats by the action of some fishing gears. “Indirect effects, according to Hall are ..” the knock-on effects that follow from direct effects”. Thus, whilst direct effects result from direct interrelationships between the fishery and species, indirect effects or flow effect are the result of species interdependencies and species-habitat dependencies.



Direct effects on populations of target and non-target species – Single stock assessment

The classic research agenda in the field of fisheries management employs a rather narrow approach and focuses on the direct population effects of fishing of the target species. This was originally done to optimize catches and to maximize profits to the fishery. The emphasis in this agenda is put on understanding population dynamics and predicting how fishing mortality will affect population biomass, size- and age structure and fecundity. This involves conducting single stock assessment. The scope of this research agenda can of course be extended by including the direct population effects on non-commercial fish and invertebrate species (e.g. population effects of discard mortality). In this study direct population effects on target species and non-target species are dealt with in chapter 3, 4 and 8.

Flow effects on populations – multi-species stock assessment

Species do not exist in a vacuum but are imbedded in a community through all sorts of biological interactions: they eat each other and may compete for food and space. This implies that the population dynamics of different species are inevitably linked and that extracting from one population may have detrimental effects on other populations. In embracing such concepts the focus thus shifts to a higher community level and sheds light on the flow effects of fishing mortality. This is a step closer towards a more comprehensive, holistic, ecosystem approach to fisheries effects. Flow effects of this kind are dealt with in chapter 5.

Direct effects on habitats and flow effects on populations of associate species

The research agenda has been extended by taking account of the effects of fishing on the marine habitat. Habitat has been defined by Peters and Cross 1992 as “the structural component of the environment that attracts organisms and serves as a centre of biological activity”. This may include physical/structural, as well as the biochemical characteristics of the benthic as well as pelagic habitat. The structural components of the benthic habitat include; …” the range of sediment types, bed forms (e.g. sand waves, and ripples, flat mud) as well as co-occurring biological structures (e.g. shell burrows, sponges, seagrass, macro-algae) (Auster and Langton, 1998).

Mobile bottom-fishing gear may reduce habitat complexity by: (1) directly removing epifauna or damaging epifauna leading to mortality, (2) smoothing sedimentary bed forms and reducing bottom roughness, and (3) removing taxa which produce structure (i.e. taxa which reduce produce borrows and pits). Depending on the spatial scale, frequency and intensity at which this disturbance takes place, but also depending on the rate an mechanisms by which a habitat recovers, the physical and biochemical properties of a benthic habitat may be fundamentally and irreversibly changed. (Auster and Langton, 1998). Fishing may also alter the conditions of the pelagic habitat. The definition of the pelagic habitat may be based on features such as temperature, light intensity turbidity, oxygen concentration, currents, frontal boundaries, and a host of other oceanographic parameters and patterns.

Disturbance of the habitat conditions matter as species occurrence and abundance in a specific area depends largely on the particularities of the habitat. Through such dependencies chronic changes to the habitat will have flow effects on populations of the associate species. This can affect entire species assemblages at once.

Habitat disturbance and effects on populations of associate species is dealt with in chapter 7

Effects on the emergent properties of an ecosystem

From here we may take the analysis a step further, moving closer towards a holistic ecosystem approach, by expanding the view of our lens to observe the way fishing may have an affect on the emergent properties of an ecosystem. At this level we ask ourselves if and how the harvesting of one or a suite of species changes not only the structure and abundance of the individual affected populations but also to the structure and function of the community and ecosystem as a whole (Hall 1999). This requires analysis at a community or system level. Community composition and structure and ecosystem function will be discussed in the following two paragraphs.

Effects on community composition and structure

Changes in occurrence and abundance of single species and populations will change community structure and composition to varying degrees and in different ways. In order to identify effects of fishing on the marine community one has to wonder which emergent properties of marine communities have changed over time. This does not necessarily lead to a uniform approach or technique. Never the less community level analysis seems to focus its observations on the following community properties;

(1) *Community diversity* – can be measured in different ways. The most common way is using the number of species within an ecosystem (species richness) as an indicator or using an index that combines both species richness with the distribution of relative abundance among species (equitability/evenness). When employing the latter a community of high evenness and low dominance is considered more divers than a community with the same number of species but with low evenness and high dominance (Jennings). Taxonomic diversity is an entirely different way of approaching diversity and employs a taxonomic based diversity index. This index takes account of the relatedness of species in a community and their abundance. The idea is that a community containing distantly related species is more divers than a community containing closely related species. In exploring fishing effects, including these indices into diversity measures seems to provide more robust and sensitive indices of community changes.

(2) *Community structure* – Changes in community structure is demonstrated by changes in mean max. size, mean age and length at maturity, mean growth rate, but also the trophic structure of a community, all of which are closely related to the life histories of fish species. Shifts in community structure reflect the differential effects of fishing on species with contrasting life histories. Phylogenetic analysis (Jennings et

al, 2001) showed that species that decrease in abundance relative to their nearest evolutionary relatives naturally matured latter at a greater size, grew more slowly towards greater maximum size and had lower rates of potential population increase. In most fished communities there seems to be a decline in relative abundance of species with slow life histories, as these are less resistant to the pressures of fishing and are usually more desirable targets of fisheries and therefore more heavily fished. These combined effects of mortality and life history are also evident in trends in trophic structure (Jennings et al. 2001). In general species with faster life stories feed at lower trophic levels ad have higher production to biomass ratios. Due to the fact that fishing usually targets species in higher trophic levels, this may affect the trophic structure of a community drastically.

(3)*Community size structure* – Size structure of fish communities has been shown to follow regular patterns (Jennings et al. 2001). 'The biomass and numbers of individuals in size classes (pooled across all species) is relatively stable' (hall). 'This stability occurs even though the richness and relative abundance of species in a series of samples is highly variable'. Therefore, and because fishing is usually size-selective, observing changes in size structure is a useful tool when trying to detect effects of fishing on a marine community and the state that it is in.

Community effects are dealt with in chapter 9.

Effects on ecosystem function

An ecosystem is not a neatly defined entity with definite boundaries. Depending on the matter, scope and ambitions of the research the virtual boundaries of an 'ecosystem' may be redrawn. Nevertheless any ecosystem, irrelevant to how we define this, interacts with its wider environment and provides particular services or regulatory functions. Ecological functions can be defined as involving ".ecological and evolutionary processes, including gene flow and nutrient cycling" (Noss 1990). This is the study of how components such as energy and types of species in the ecosystem change over time. It differs from the study of structure, which investigates how the components of ecosystems change over space. The relationship between components of an ecosystem and ecosystem functions is not fully understood and this matter is situated at the forefront of scientific research. There is for instance strong evidence that a relationship exists between species diversity and ecosystem function, with species being classified according to their functional role in regulatory system processes. However research into these areas is in its infancy. Before this is better understood it will be precarious or at least difficult to say through which mechanisms and in which ways fishing activities may interfere with ecosystem functions. Therefore the effects of fishing on ecosystem functions will not be addressed in this paper.

PART I

THE NORTH SEA C.CRANGON FISHERY

Chapter 1

THE NORTH SEA C. CRANGON FISHERY

In order to advance towards understanding interrelationships between the marine environment and the fishery, a thorough investigation of the fishery itself is required. Such an inventory should answer the where, when, what, how and how much questions. Fishing methods and gears, fleet size and composition, spatial and temporal effort distribution and patterns, and the direction in which the fishery is developing, are fundamental matters into which we must gain insight, and without which any attempt to identify and asses the impacts of the fishery on the marine ecosystem and give management advice, will be flawed.

This chapter not only serves to bring these fishery aspects to our attention and to describe them for this fishery, but also to identify, as far as possible, the major bottlenecks which thwart our attempts to do so. This may be understood in terms of data deficiency, which I understand to reflect the extent of our failure to record, process, compile, collate, translate and access insightful fisheries data in order to produce sound fisheries statistics and databases. This failure may occur any where along the information chain, from fisher to policy maker.

1.1 North Sea *C. crangon* fisheries

Commercial fishing of *C. crangon* in the North Sea occurs along the coast of Germany, the Netherlands, Denmark, Belgium and east England where *C. crangon* densities are sufficiently high enough to support a profitable industry (see figure 1.1) Generally, this is the zone that falls within the 20m isobath (Lancaster, J).

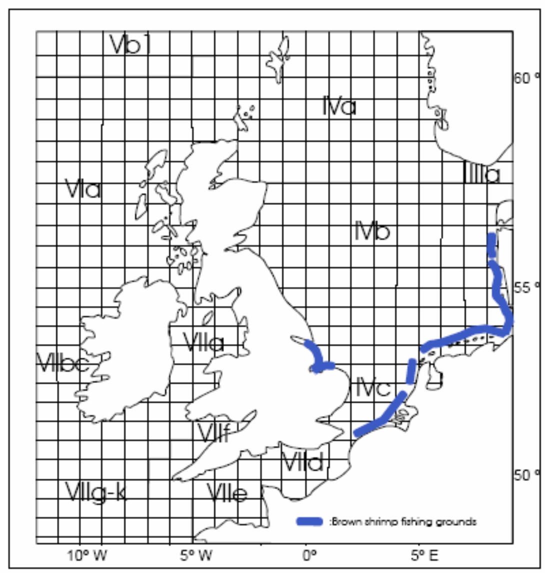


Fig 1.1 The North Sea (IVa, b, c area) and the major *C. crangon* fishing grounds (Source: Polet 2003)

Along the east coast of England, fishing for *C. crangon* is concentrated in The Wash Estuary. Particularly rich fishing grounds are encountered in the southern, eastern and western Wadden Sea [see appendix 1], and the adjacent German and Dutch Wadden coast, above the Frisian Islands. Fishing grounds extend southward to include the entire Dutch coast, the Scheldt Estuary (Eastern Scheldt and Western Scheldt), the Voordelta and the Northern reaches of the Belgian coast down to Nieuwpoort. North of the German Wadden coast, *C. crangon* fishing occurs along the Danish coast up as far as Thyborøn [see appendix 2-4 for maps].

The North Sea Crangon fishery currently supports a fleet of around 643 vessels, with 247 and 225 vessels coming from the German and Dutch fleets respectively (Polet, 2003). The UK contributes to this grand sum with a total of 98 vessels (2003), the Danes with 32 vessels (2005) and the Belgians with 51 vessels (2003). In France, 133 vessels (2003) target shrimp but only 3 of these operate in the North Sea. Therefore this fleet will not be considered in this study.

The vessels of these five countries operate throughout each other's national waters and exhibit various temporal and spatial fishing patterns. Most traditional vessels will target solely *C. crangon,* whilst other vessels target a wider range of species (flatfish and *C. crangon*) and target *C. crangon* only in peak season or whenever shrimp fishing proves more lucrative. Alternatively, vessels might turn to shrimp trawling when quotas for other regulated target species have been exhausted.

In addition to a continuous increase in the numbers of larger vessels in the shrimp fishery, there seems to be a tendency for the so-called "Eurocutters" from the flatfish fishery to move into the *C. crangon* fleet. These are larger, more powerful vessels, targeting flat-fish as a main species, built to operate within the

12 mile zone, with dimension and engine power close to the upper limit of 221 kW (300hp) allowed in this zone.

1.1.1 Data collection and provision in the North Sea *C. crangon* fishery

Logbook requirements have been in place since 1983 (EEC 2807/83) for all vessels with an overall length of 10 or more metres. Logbooks are kept on a per trip basis. In these logbooks fishers are required to keep information on the vessel, the gear used and details of the fishing operations such as; date and port of departure and arrival, effort data (days-at-sea or fishing hours), geographical position (in ICES-squares, see appendix 4) and quantities caught and retained on board. Vessels of more than 10 metres in overall length must submit a landings declaration to the authorities at the place of landing. Logbooks and landings declarations are handed over or dispatched to the Authorities of the Member States. Logbook requirements have been revised several times since 1983 (EEC 38801/91 and EEC 018/93) but the basic requirements have remained more or less the same.

This data can be used in fisheries management to keep track of vessel effort levels accounting for changes in gear and vessel capacity. When collected and compiled at a fleet level, logbook data can give a fair understanding of spatial and temporal effort- and catch patterns and trends, which may be put to various managerial purposes. It seems however that the accessibility and quality of this data and the efforts that have been made to collect and compile logbook data are not entirely uniform across the five countries.

Vessels of >15 metres overall length are also required to keep a satellite-system (vms or blackbox) onboard. These systems give a continuous and very accurate specification of a vessel's geographical position and movement. This data is used by the national inspection services (e.g. AID) to observe whether ships are operating in legal waters. Such data would provide much better spatial effort data than the logbooks which work with ICES units of 60X60 km. however this data is not accessible.

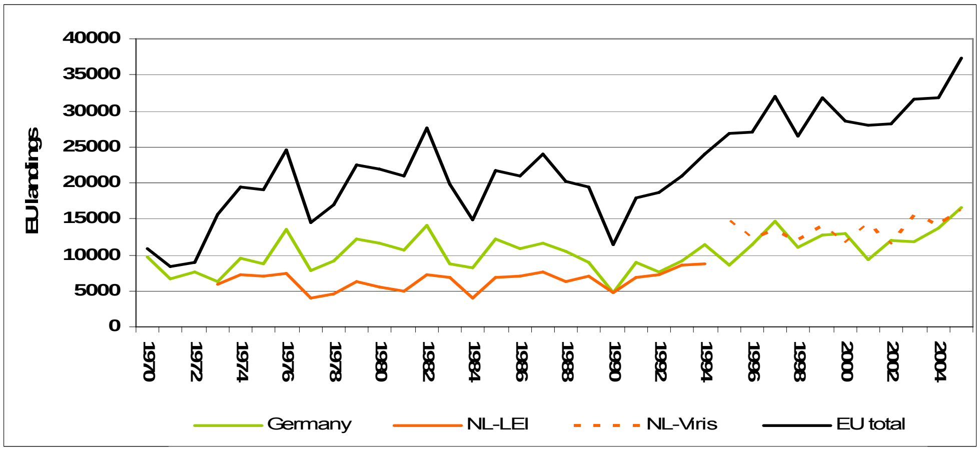
1.1.2 North Sea C. crangon landings

Observing landings data will bring to light trends in the fishery which may give an indication of the status of both the fishery and the stocks on which it depends. In addition, landings data may be usefully employed in stock assessment, when combined with effort data.

All EU vessels are required to report their landings, thus landings statistics are reasonably complete. A systematic error may occur in the data due to the black landings.

Landings have increased significantly over the past years and continue to grow. The combined effort of the Dutch, German, Danish and British fleets brought landings to a historical high of over 37 000 tonnes in 2006 (ICES 2006). The German and Dutch fleets accounted for 87 % of the landings, with around 16,000 tonnes each. The Danes accounted for 11%, with the remainder coming from British vessels (ICES 2006). Belgian data has not been updated this year but has remained below the 1000 tones since the mid-eighties (ICES 2005).

Compared to 2002, mainly Dutch, Danish and Belgian landings have increased, whereas British landings have more than halved. Compared to the average mean annual landings of the previous period of 14 years (1992-2005), Danish and Dutch landings for 2005 have been considerably higher (63% and 26% respectively). German landings equal the average landings over this period whilst British landings in 2003 are considerably below average (45%). Belgian landings in 2003 were close to the average (9% higher).



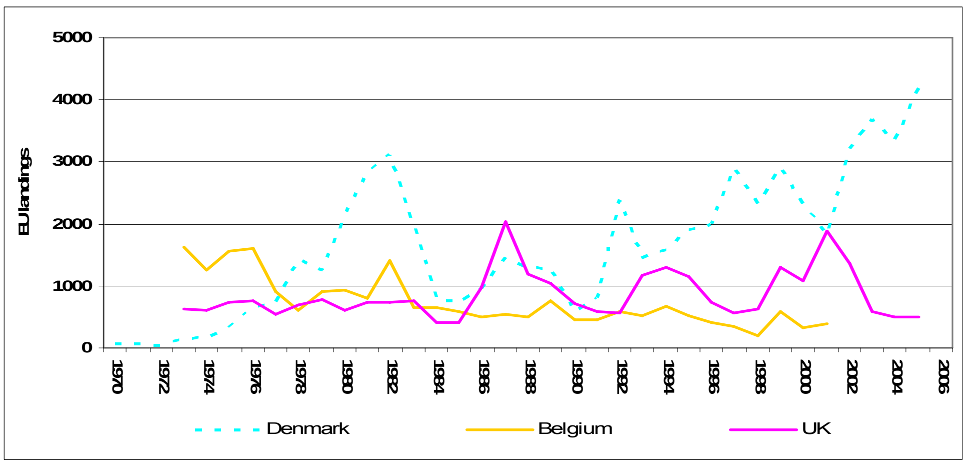


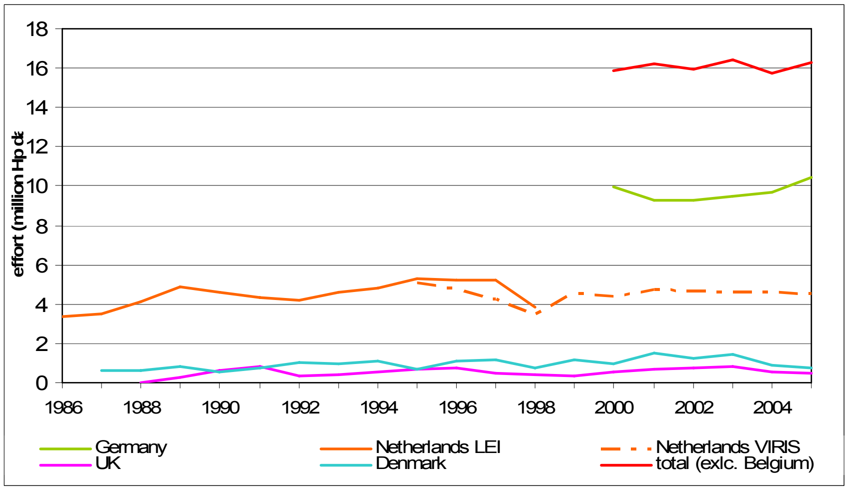
Fig 1.2 and 1.3. Total landings per national fleet (data: WGCRAN 2006)

Unlike most commercial EU fisheries, fishing for *C. crangon* is not regulated by EU-imposed effort or output limitations (TAC and quota). Nevertheless, this has not prevented the sector negotiating and imposing effort and output limitations by their own device. In 1992, in order to avoid over-saturation of the market and ensure price stability Danish, German, and Dutch shrimp fishers agreed on effort limitations, implementing a restriction on the numbers of fishing days per week (SGS rapport 2006). Moreover, during the period of the 1st of January 1998 till the 30th of January 2000, the sector (including the two dominating shrimp processors) consolidated a self imposed landings restriction. This limited weekly landings per vessel to ~ 1 t (December 1999) and to 6t (October 1998) and served to guarantee high prices. As a result, the average price for one kilo of *C. crangon* in Germany in 1999 was 3.20 Euro/kg as compared to a normal level of about 2.30 Euro/kg (SGS-rapport 2006). The price-quantity relationship is unique for *C. crangon* fisheries and is attributed to the fact that the market in *C. crangon* is dominated entirely by one or two major Dutch-owned purchasers (Klaas Puul and Heijploeg). This agreement was condemned by the Netherlands Competition Authority as violating the EU Competition Act, and was therefore abolished in 2000. This has led to an increase in landings and a proclaimed growth in effort over the last years, the latter of which is only supported by Danish and German effort data. There is now talk of bringing all *C. crangon* fishers under one international PO. This would once more open the door to negotiating effort or landings restrictions, as a PO has the entitlement (according to EC law) to establish and enforce such restrictions in order to benefit the sector and stocks.

1.1.3 Trends in effort and landings

Logbooks provide different forms of effort data (days at sea, hours fished, gears, engine power etc.). However, the way in which logbook effort data is used and compiled by the different countries to produce effort statistics differs. This results in different effort units, making comparison and aggregation difficult.

Moreover, systematic effort registration in logbooks has only been obligatory since 2000, and has seemingly not been implemented in all countries, making effort time-trends patchy and incomplete. Effort data prior to 2000 has been derived from alternative sources. Attempts by ICES to standardize effort over the North Sea fleet has delivered a data set that suggests an overall increase in effort, expressed in horse-power-days, in the North Sea *C. crangon* fleet, with particular contribution coming from the Danish and German fleet. The Belgian reporting system records the actual hours spent fishing and these cannot be directly compared to any of these measures.



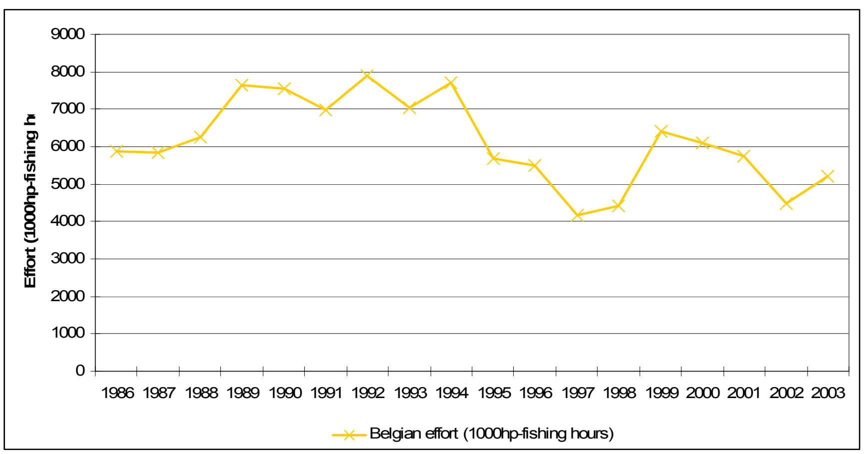


Fig 1.4 and 1.5 above: Effort of national fleets in Hp-days, under: Belgian effort in10^3hp-fishing hours (data source: WGCRAN 2006)

When combining effort time-series with landings time-series, we get LpUE data. The LpUE trends of the countries will be discussed individually in the following paragraphs. Fluctuations in LpUE seem to be typical to this fishery.

The LpUEs of the Netherlands, Germany and Denmark have risen over the past four years. For Denmark and Germany this seems to be a trend. For the Netherlands this is not certain. Although the LpUE of the UK has declined in the past years this does not seem to be a continuous trend when taking into consideration the fluctuations over the twenty years. Belgium, although experiencing a small increase in 2003, seems to be on a negative trend.

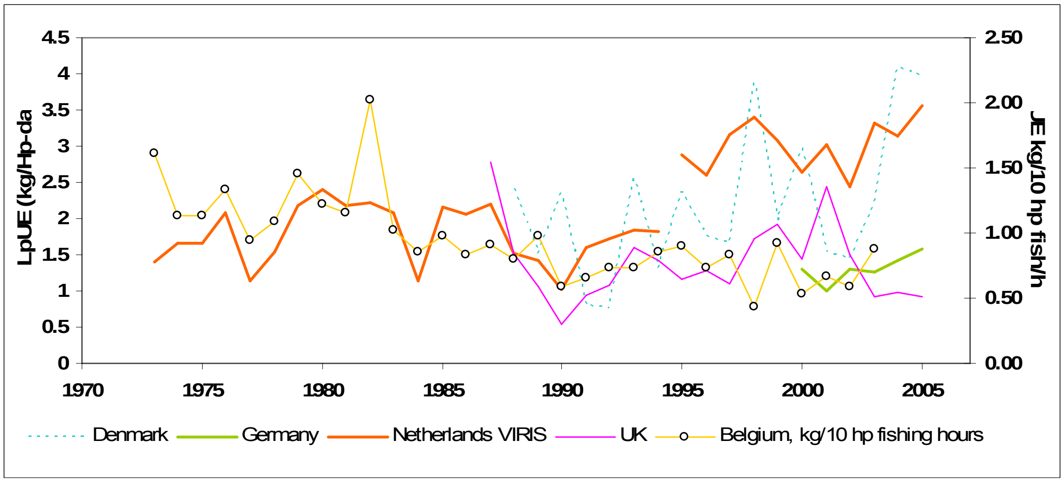


Fig 1.6. Landings per unit effort per fleet in kg/Hp-days (data source: WGCRAN 2006)

In general, observing these trends does not lead to a direct concern in relation to stock densities. Instead, the LpUE data of Germany, Denmark and the Netherlands may even lead us to believe *C. crangon* abundance is increasing or else the fishing has become more efficient due to changes in gear or vessel. Something is also happening in British and Belgian waters, which may have biological or fisheries related explanations. This will be commented on below.

1.1.4 C. *crangon* fishing: vessel, method and gear

The vessel

Traditionally, shrimp trawlers are rather small vessels, suited to operate in an inshore fishery. However, these shrimp trawlers are gradually, in some countries more than in others, being replaced by larger vessels that can operate further offshore, can withstand rougher weather conditions, can make longer multiple-day trips and can continue to fish throughout the winter season.

The *C. crangon* fleet is composed of a range of vessels, with most vessels ranging between the 14 and 20m [See figure 1.7D] and with an engine power of between 150 and 221 kW [see fig. 1.7A] (van Marlen et al. 1998).

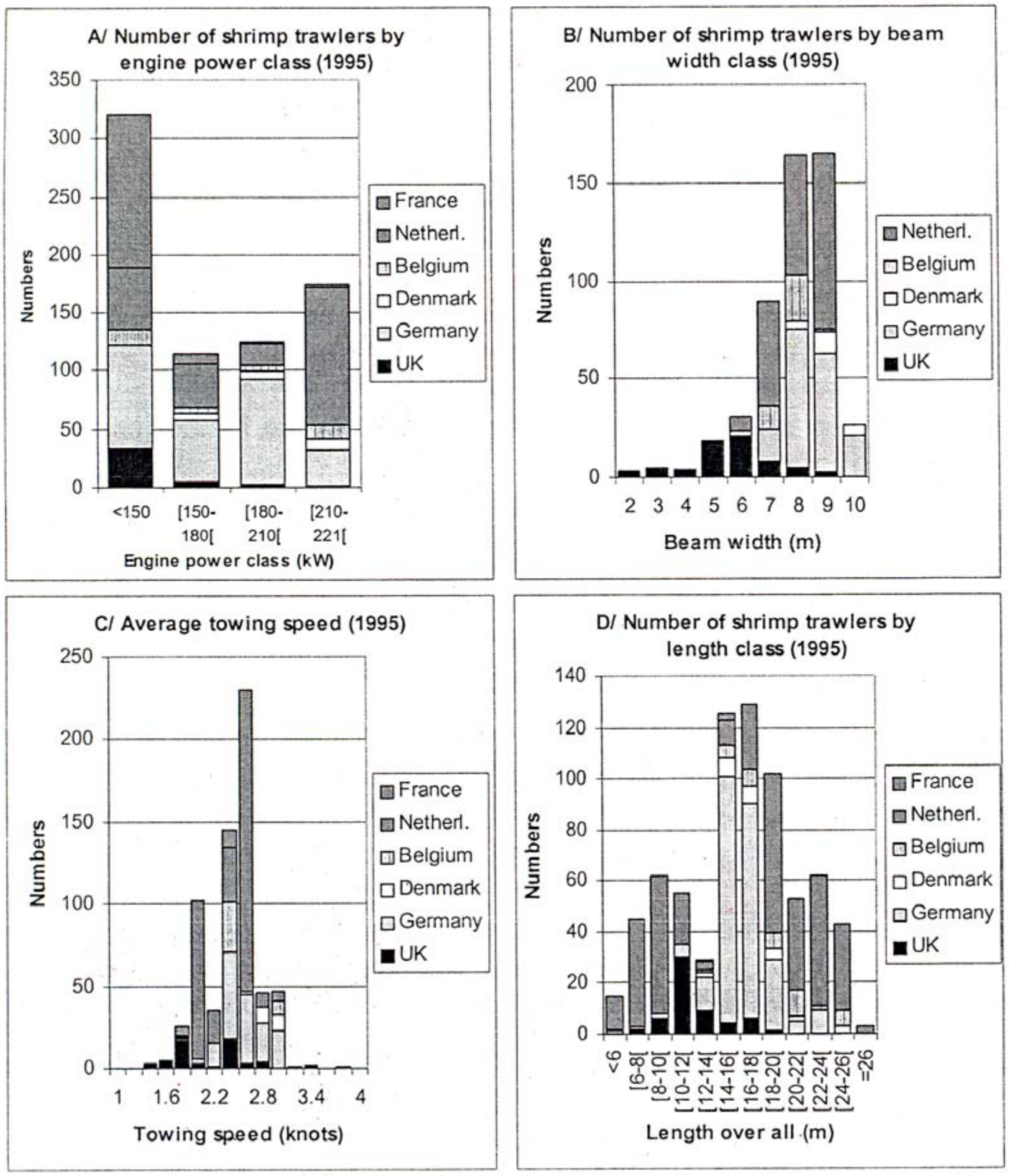


Fig 1.7 National fleet data 1995 (North Sea fleet + France) (source: SGS Rapport 2006)

Fishing gear and method

The fishing gear and method that is employed in the *C. crangon* fishery seems to be more or less standardized throughout the North Sea *C. crangon* fishery. A beam trawl is a demersal fishing gear that is used to target shrimps as well as flatfish. In his work (2003), Polet described the fishing method employed: ..'The net is held open horizontally by means of a steel beam, supported on both sides by the beam trawl shoe. The construction of the net is quite basic consisting of a top and lower panel and a cod-end where the catch accumulates. The top panel is attached to the head line, which is rigged to the beam trawl shoes. The lower panel is attached to the bobbin-rope, which assures bottom contact'... Tickler chains are never used when targeting shrimp.

The design of the net is quite similar throughout the fleet, with mesh size decreasing towards the cod-end. The minimum legal mesh-size imposed by the EU is 20mm but Polet (2003), in his work, reported that standard cod-end mesh-size is usually 22mm. The beam length varies, depending on the vessel, between 3 and 10 meters [see fig. 1.7B] (van Marlen et al, 1998). This beam length influences efficiency quite significantly.

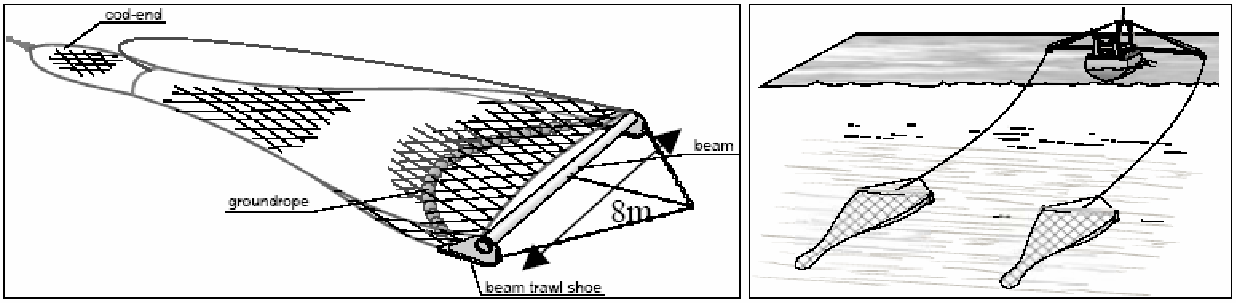


Fig 1.8. The single beam trawl (left) and a shrimp beam trawler rigged with double beam trawl (Polet 2003)

A fishing vessel targeting *C. crangon* is usually rigged with a double beam trawl, which is dragged simultaneously along the seabed on either side of the vessel by means of two outrigger beams. The double beam trawl is dragged along a sandy bottom, during which the catch will collect in the cod-end. The length of the haul will vary in duration form thirty minutes to three hours (Lavalije and Dankers, 1993), depending on the catch volume and season. When catch volumes are excessively high, or when the meshes get clogged with hydroids, the tow duration will be decreased. The average haul length is one hour.

The catch of each haul is handled on board. On the newer vessels, catch-handling equipment may be more modernized and automated. Nevertheless all vessels follow more or less the same procedure (Polet, 2003). The cod-end catch is collected into a container and sorted into separate fractions, after which the non-commercial by-catch is discarded. The catch is sorted into fractions by way of a rotating shrimp riddle or a flatbed riddle, the former of which is more commonly used on the modern vessels.

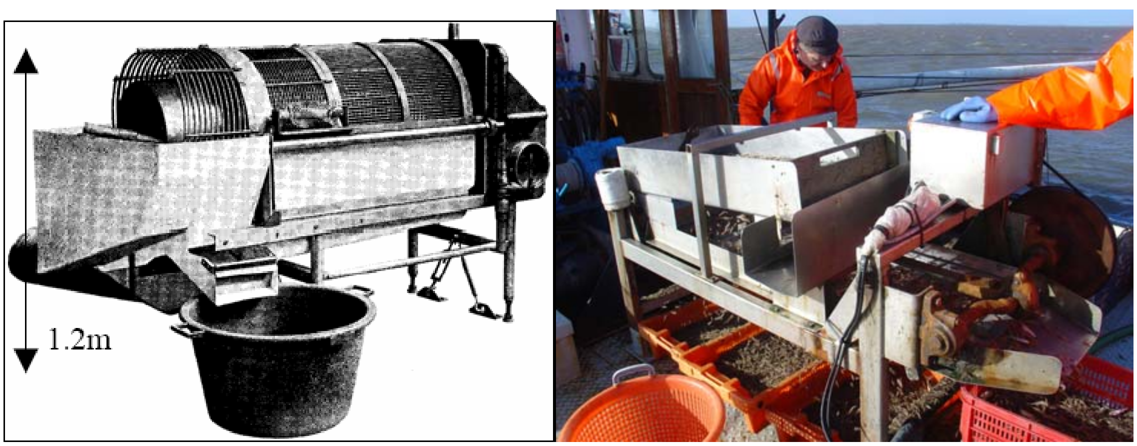


Fig 1.9. Left: Rotating shrimp riddle (source: Polet, 2003); Right: flatbed riddle (Source Catchpole 2006)

A flow of water leads the collected catch onto a conveyer belt, which leads to the rotating shrimp riddle. The catch fractions are collected in containers. The commercial shrimp fraction is boiled on board in cauldrons (Polet 2003). Marketable fish are picked out manually before and/or after the catch has gone through the sorting device. Unwanted by-catch is discarded overboard manually (surface disposal) or, aboard the modern Eurocutters, is discarded via a tube which leads straight from the rotating riddle to a subsurface opening in the hull.

Selective devices

A significant amount of by-catch in the *C. crangon* fishery, owing to its small mesh-size and typical areas of operation, has led the EU to draw up legislation concerning selective devices for this fishery. In January 2000, legislation was enacted by the EU requiring all *C. crangon* fishers to use selective gear (such as veil nets and sorting grids) that reduce the incidental by-catch of juvenile commercial species. This legislation came into force in 2003. The implementation and enforcement of this provision is left up to the individual member states. As a result, differences are assumed to exist between the fleets, as to the actual use of such devices. Tom Catchpole (participant, WGCRAN meeting, 2006) is investigating this area. Prior to this regulation, sieve nets (a selective device) were already employed on a voluntary basis, depending on the area and season, and motivated by economic reasons. As the only exception, Danish law already has required the use of sieve nets by its national shrimp fishers before this EU law came into force, Danish C. crangon fishers therefore use sieve nets all year round.

1.2 Dutch *C. crangon* fisheries

1.2.1 Logbooks and data storage and accessibility of Dutch fleet

Only recently logbook data have been made available to RIVO (Rijks Institute voor Visserij onderzoek-national research institute for fisheries) by the Dutch inspection service (AID). Data have been processed from 1990 and onwards. This national data set is referred to as VIRIS (Visserij Registratie en Informatie system- Fishery registration and information system). Prior to this effort and landings data were obtained through various sampling programmes and from alternative sources by RIVO (1973-1995) and LEI (Landbouw Economisch Institute- Research institute for agriculture and economics).

1.2.2 Dutch fishing waters and ports

The main Dutch ports where *C. crangon* is currently landed are: Harlingen and lauwersoog (for the Wadden Sea, and coastal waters above the islands), Goederede, Colijnsplaat and Breskens (for the Schelde and Voordelta fishery), and Wieringen (for the Coast of Holland fishery) (Temming et al. 2000). A number of foreign shrimp vessels land in Dutch ports and these landings are recorded. In 2005 vessels landing *C. crangon* into Dutch ports (1t per year, per vessel) included; 14 Belgian vessels, 1 Danish, 7 German, 1 UK, and 198 Dutch vessels (Tulp, 2006). It may be assumed that these vessels also operate in Dutch waters. Fishing in Dutch waters occurs in the Dutch part of the Wadden Sea, The Scheldt estuary and Voordelta and in the deeper waters along the Dutch coast.

1.2.3 Spatial effort distribution and trends

Despite logbook requirements, no consistent spatial effort statistics are provided for the Dutch fleet. Alternatively landings data specified per port can be used to derive spatial effort patterns and long-term spatial effort trends (Temming et al. 2000), as there seems to be a strong correlation between the geographical location of the port and the geographical location of the fishing grounds. Using this approach spatial fishing patterns could be derived for the period 1973-1995 for the Dutch fleet landing in Dutch ports [fig 1.10]

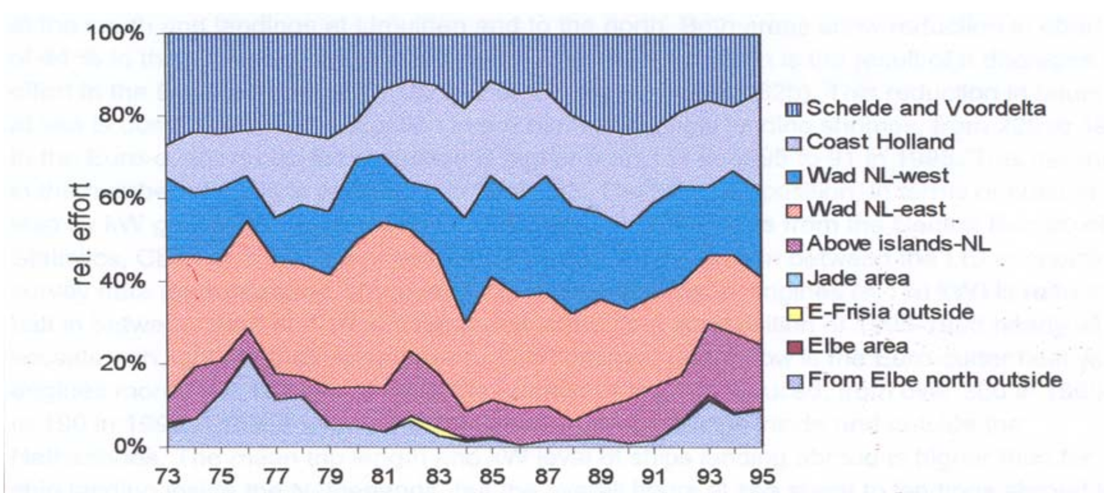


Fig 1.10 Relative effort distribution of Dutch landings at Dutch harbours over 9 geographical areas (source: Temming et al., 2000)

It becomes obvious from this figure, however, that the Dutch fleet operates throughout the waters of the Dutch and German coast and the Wadden Sea.

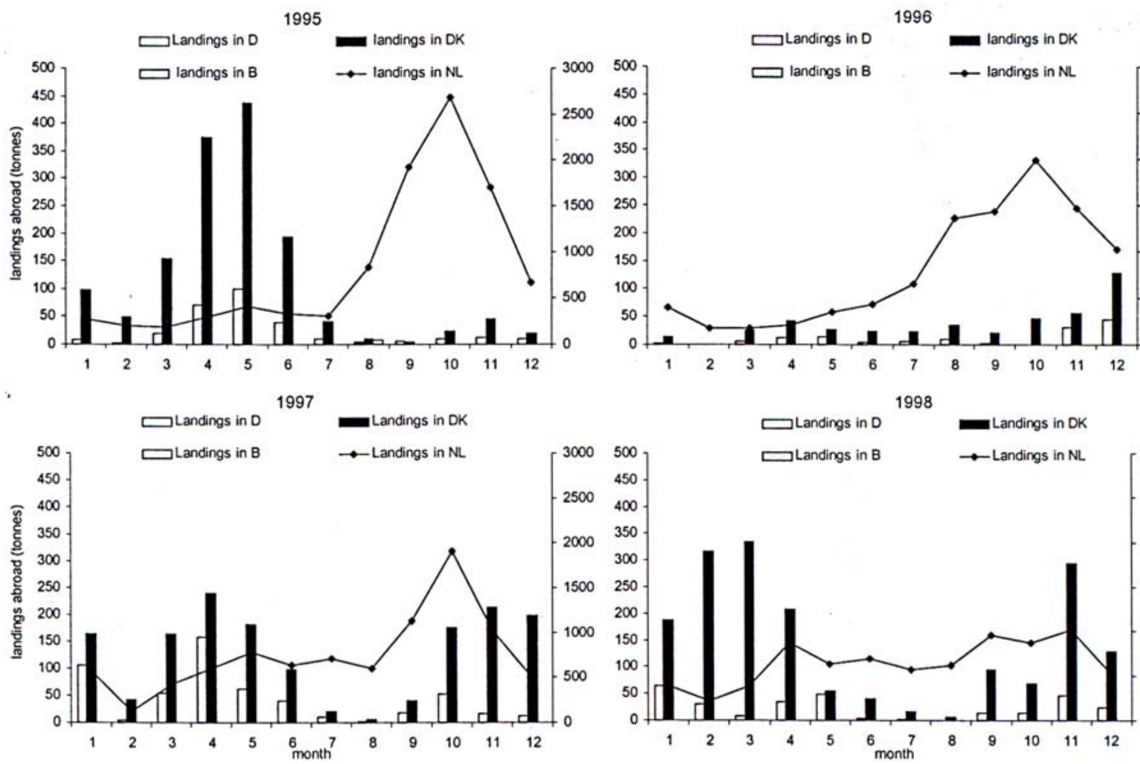


Fig 1.11 Landings pattern for the Dutch shrimp fleet. Landings are divided in harbours abroad (left axis) and landings within the Netherlands (right axis) (source: Temming et al., 2000)

From the logbook data from 1995 to 1998, a better indication of the activities of the Dutch fleet in foreign waters could be derived. This data illustrates that landings in Danish ports by Dutch vessels are quite impressive with landings in Danish ports almost equalling landings in Dutch ports in the first four months of the year (Temming et al., 2000). This would indicate a reasonable share of winter season fishing taking place in Danish waters.

1.2.4 Spatial -seasonal fishing patterns

Dutch effort is reasonably smoothed out over the year with a small peak in autumn (September to November) and slightly smaller peak in spring (March to May). A relatively significant contribution is made by the winter fishery accounting for of around 29% (2003) of the total annual Dutch effort.

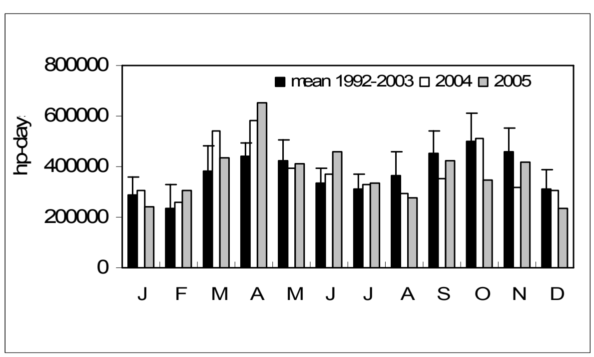


Fig. 1.12 Seasonal effort of Dutch fleet (Source: WGCRAN 2006)

Observation of the seasonal landings data results in a similar seasonal fishing pattern. This seasonal pattern is consistent with *C. crangon* densities, showing a gradual increase in densities nearing the autumn months, with these reaching a maximum between August and October.

Seasonal fishing patterns have a strong spatial element due to spatial variation in seasonal shrimp abundance. Seasonal fishing patterns were obtained using seasonal landings-per-port data of the period 1973-1995 [fig 1.13].

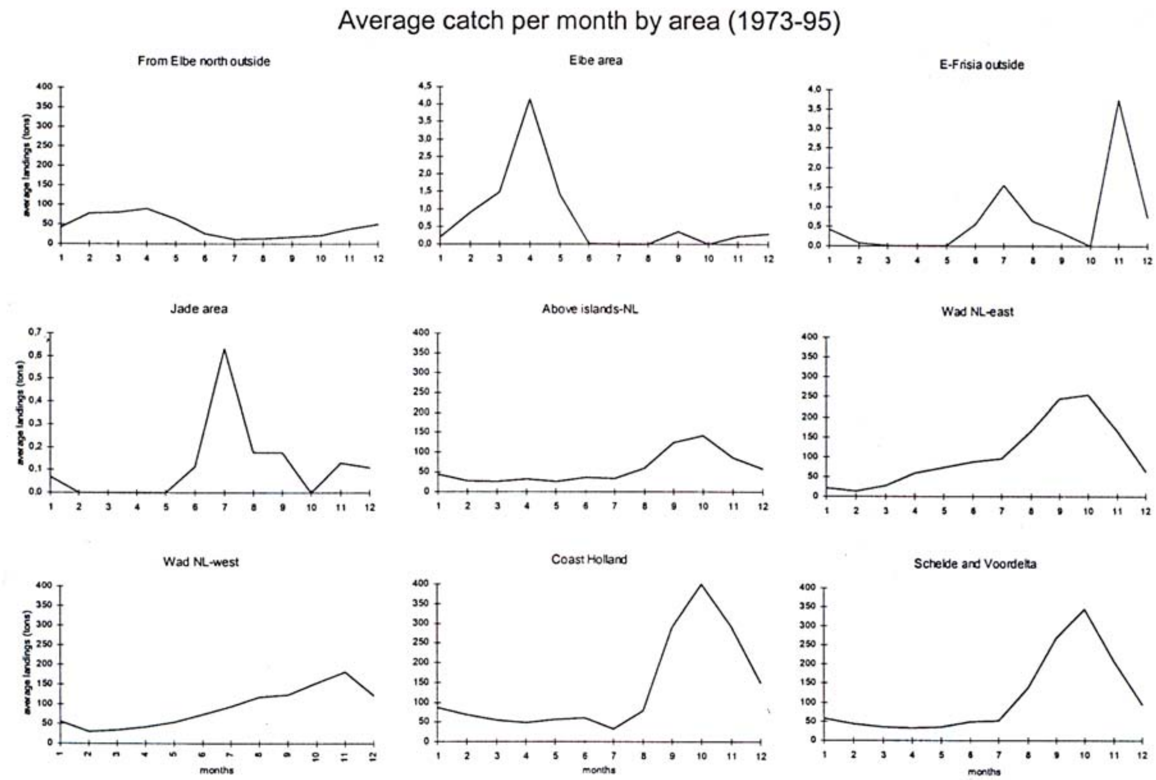


Fig.1.13 Seasonal landings pattern from catches originated from the different geographical regions (source: Temming et al., 2000) See appendices for map of regions.

A strong seasonal fishery exists in the southern waters, with the majority of the landings occurring between August and January. In the Dutch Wadden Sea directly above the islands the seasonal pattern is less pronounced. In the most northern waters (north and outside of the Elbe) catches are high during spring. In the Jade area and in East Frisia, they were hardly any catches in the winter and spring months

1.2.5 Fleet composition and characteristics and trends

After a decline in 1998, the number of vessels in the Dutch fleet has returned to its mid-nineties level again and in 2003 comprised 225 licensed vessels. The Dutch fleet is composed of two segments, referred to as “GK”, which stands for “Garnalen Klein” (small shrimps) and “GV”, standing for “Garnalen Vis” (shrimps and fish). The GV vessels are larger and equipped with more engine power, as compared to the average vessel in the GK-class, and target flatfish during summer. Some GV vessels never target shrimp (Temming et. al., 2000). The GK-licensed boats (89 in 1999) have a special permit to fish in the Dutch Wadden Sea and the Ems-Dollard Estuary. Only 90 of these permits are available. The GV-licensed boats (139 in 1999) operate outside of the Wadden Sea.

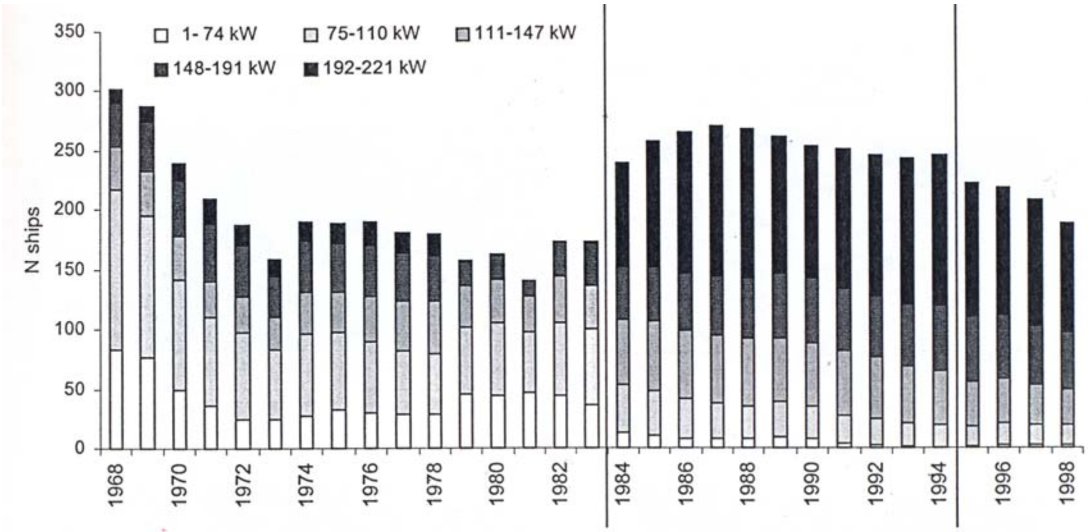


Fig. 1.14. Fleet composition over time (Source: Temming et al., 2000)

Since 1984, a strong increase has been noted in the number of 261-300 Hp (192-221 kW) vessels, or, more specifically, Eurocutters. This increase is attributed to a decline in the catch or insufficient quota of other commercial target species of the fleet, such as Cod and Plaice (Temming et al, 2000 referring to Salz and de Wilde, 1990).The dominant group in the fleet is now the Eurocutter fleet with engines of more than 192 kW (Temming et al., 2000). In 1998 the average Dutch shrimp vessel was 21 m, with an engine power of 184 kW. The Dutch fleet is relatively modernized compared to the rest of the North Sea *C. crangon* fleet. The width of a single beam trawl is usually 8-9m (van Marlen et al. 1998).

Thus, although the total number of vessels has not increased, the average power of the vessels in the Dutch fleet has. This may have led to an increase in effort or in catch efficiency.

1.2.6 Trends in landings and effort

The period preceding 1995 shows relative stable annual landings of around 6000-7000 tonnes. The period following this year shows a notable increase to14, 000 tonnes, with total Dutch landings in 2005 reaching a historical high of 16,142 tonnes.

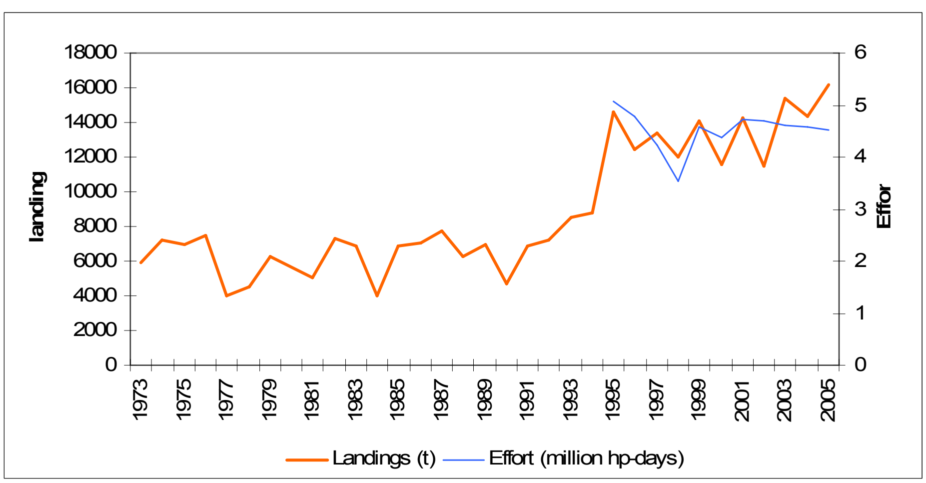


Fig. 1.15. Dutch Effort and landings data 1973-2006 (data source: WGCRAN 2006)

Total effort in 2005 was 4.5 million hp-days. Total effort by the Dutch fleet has increased slightly since 1986. The hp value per vessel increased in the late nineties, but, at an hp of around 270, has remained constant in the period since 2000. Since 1995 the number of vessels has stabilised around 200-225.

Growth in effort over the last decades is most probably a result of an increased number of boats since 1984 and not due to more fishing days per boat (Temming et al., 2000). The effort level, as shown in the figure below, has, over the last five years, remained more or less stable, despite annual fluctuations. The LpUE over the last five years also has a stable character, with an increase in 2005 as a result of the high landings in this year. The increase could be the result of high *C. crangon* abundance which can have the tendency to fluctuate remarkably between years.

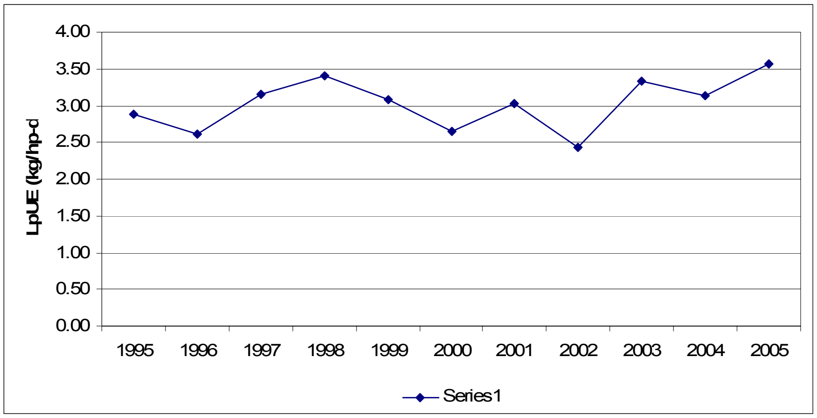


Fig. 1.16. Dutch LpUE in kg/hp-days (data source: WGCRAN 2006)

The study conducted by Temming et al. (2000) experimented with LpUE statistics by using different approximations of effort. Consequently they obtained different results in LpUEs and trends, as can be seen below.

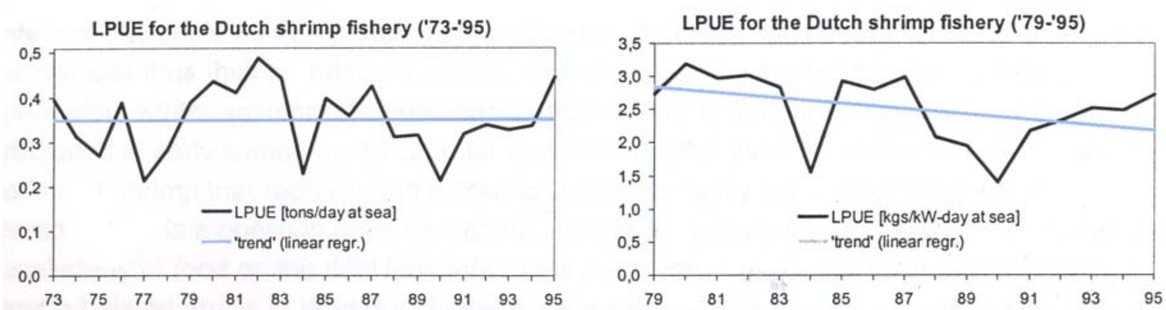


Fig. 1.17. LpUE for Dutch shrimp fishery. Left: effort measured as days-at-sea; Right: effort measured as kW days-at-sea. (source:Temming et al.2000)

This indicates that, depending on the way effort is approximated, different trends may be observed, leading to very different conclusions concerning the condition of the C. crangon stocks; If we measure effort as kW days-at-sea, we may conclude that stocks are dwindling either due to the fishery or because of biological reasons. This is relevant if we want to properly evaluate the status of the fishery and illustrates that care must be taken when reading on LpUE data-series.

1.3 German *C. crangon* fisheries

1.3.1 Logbooks and data storage and accessibility of the German fleet

Since 2000 the EU log sheet system has been mandatory for German fishing fleet. Prior to 2000, Landings were recorded to the state fisheries authority, where data was stored as landings per month. Effort data was not recorded systematically and difficult to find. Thus, prior to 2000 only landings data can be presented.

1.3.2 German waters and ports

The German fleet operates from the 27 ports scattered along the entire German Coast, occasionally using Dutch or Danish ports to land their catches. Only German vessels are allowed to exploit German territorial waters within the 3- mile zone (Berghahn and Vorberg ,1998). The maximum engine power of 300 Hp (221kW) in this zone is, similar to the 12-mile zone. Between the 3-mile and the 12 mile limit, several EU states, notably the Netherlands and Denmark, are permitted to fish. Within the base line[1] the upper engine power permitted is 250 hp (184 kW).

1.3.3 Spatial effort distribution and trends

From the data derived from the log-books, spatial fishing patterns may be discerned for the German fleet. The German trawler fleet primarily operates in the Wadden Sea. Similar to the Danish fleet, most landings originate from the squares closest to the coast (36F8-41F8 and 36F6-26F7) [see appendix 6]. There is an indication that an increasingly higher share of the catch is being taken from deeper waters of the neighbouring column of squares (37F7-41F7) throughout the year. This corresponds to the observed trend of increasing *C. crangon* abundances in deeper, cooler waters in summertime, as opposed to a steady decrease of *C. crangon* abundances in shallower waters (WGCRAN 2006). A recent development, remarked upon in the WGCRAN report 2006, is that the German Brown shrimp landings did not originate from the entire coast, but tended to originate from the Inner German Bight, i.e. the Jade-Weser and Elbe estuaries and north towards the peninsula of Eiderstedt. Further north in the area of the North Frisian Islands, and west near the East Frisian Islands, catches were very low. According to the WGCRAN group, this is the reason that the fishing activities of the fleet concentrated in the south-east of the German Bight.

A small number of these cutters operate from Dutch ports (4 in 1998) and Danish Ports (3 in 1998). This may be taken to indicate that German vessels also operate in foreign waters, albeit on a very low level.

1.3.4 Spatial -seasonal fishing patterns

High levels of effort are observed during the months of April to November, with a small depression in June/July and low winter effort levels (10 % of total German effort in 2003) (WGCRAN 2006). Seasonal landings data support these findings. This trend reflects shrimp densities encountered in German waters which show a gradual increase nearing the autumn months with maximum densities encountered between August and October and with corresponding peak catches. Moreover the German fleet is composed of smaller vessels unfit to partake in the offshore winter fishery. This tendency is also stimulated by the state benefits that are granted to vessels for non-active days in harbour (pers. note Neudecker 2006). A development remarked upon in the WGCRAN report (2006) is the extension of the autumn fishery towards November/December in 2005, with exceptionally high landings in these months.

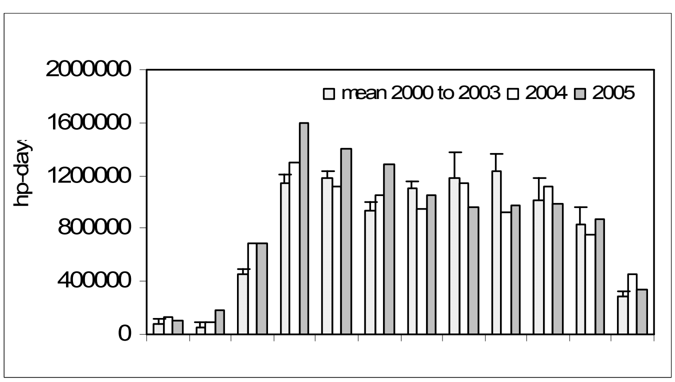
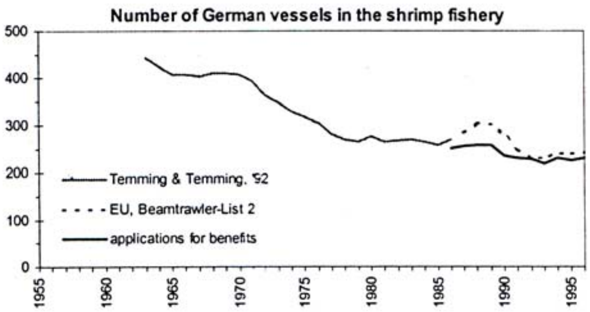


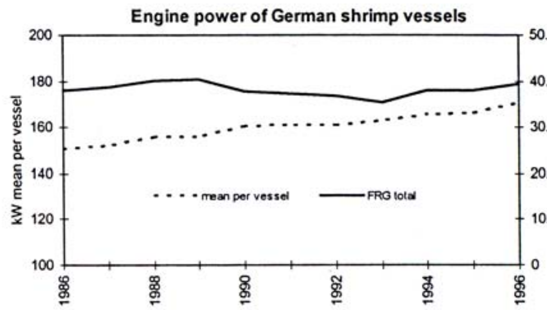
Fig. 1.18. Seasonal effort of German fleet (Source: WGCRAN 2006)

[1] The baseline is used as a reference line from which the other limits are measured. It runs along the coast of the respective country basically parallel to the low water mark.

1.3.5 Fleet composition and characteristics and trends

While in the period from 1963 to1996 the number of vessels in the German fleet decreased to roughly half the 1963 size (from ~ 440 to 210), the average vessel size and engine power has increased resulting in a relatively constant aggregate engine power of German fleet. , as can be seen in figure below (Temming et al., 2000).





The German fleet, targeting shrimp either seasonally or on a permanent basis, consisted of 247 cutters in 1998. No changes to this total have been reported since (WGCRAN 2005). 204 of these vessels targeted shrimp as a main species (van Marlen et al., 1998). Most of the vessels are rather old, with vessels having an average age of 24 years. Renewal is at a low level. Most of the vessels have a length of between 14 and 20 metres and an engine power of 150-221 kW. The beam employed is between 8 and 9 m wide (van Marlen et al.,1998). The majority of the trawlers use selective trawl devices (Berghahn and Vorberg,1998). Besides these 247 cutters, 44 small vessels of an average total length of 7.8m target shrimp as an alternative activity (fishers will have other non-fishing related occupations throughout most of the year) (van Marlen et al.,1998). These vessels operate exclusively within the German baseline areas, in the estuaries and on the Wadden Sea as they are not fit for venturing into deeper, rougher seas. With an average of 60 fishing days a year each and using one or two small (3-4.5m) beam trawls, their contribution to the German *C. crangon* catches is negligible (van Marlen et al., 1998).

1.3.6 Trends in landings and effort

Landings reached a record high of 16,485 tonnes in 2005. Landings were argued to be lower than they could potentially have been, according to the ICES WGCRAN (2006), as self-imposed landings-limitation of the international PO affected about half of the German fleet.

Fout! Ongeldige koppeling.

Fig. 1.19 German landings and effort (data source: WGCRAN 2006)

Despite the decline in vessel numbers from the 1952 level of 578, shrimp fishing effort has increased. According to estimations by ICES using German input data, effort has increased by 60% since 1986. Effort per vessel increased from 1986 until 1996, due to a slight increase in the number of days spent at sea per single vessel (Temming et al., 2000), which, according to the WGCRAN (2005), is the result of the extension of the fishing season. Traditionally fishing for *C. crangon* took place in the period that *C. crangon* are highly abundant in the Wadden Sea, coming to a complete standstill in the winter months when the shrimp migrate to their winter quarters outside the Wadden Sea. Nowadays however, the larger vessels will continue to fish for shrimps during the winter outside the Wadden Sea (Berghahn and Vorberg, 1998). Nevertheless, total days at sea of the entire fleet have remained more or less stable during the period 1986 to1996 as a result of the decline in the number of vessels. The increase in effort (expressed as kW days-at-sea) observed in the period 1986 to1996 must therefore be the result of the increased average engine capacity over the same period (Temming et al., 2000).

LpUE trends have been analysed by Temming et al. (2000) for the period 1986 to 1996, and by WGCRAN (2006) in the period 2000 to 2005. As can be seen in the figures below, the observed trend will depend on the way that effort has been measured. LpUE show a slight declining trend when approximated as kgs/kw-day-at-sea, as opposed to a stable LpUE when approximated as tonnes/day-at-sea. A declining trend could indicate that *C. crangon* abundances are dwindling as result of either the fishery or other biological factors.

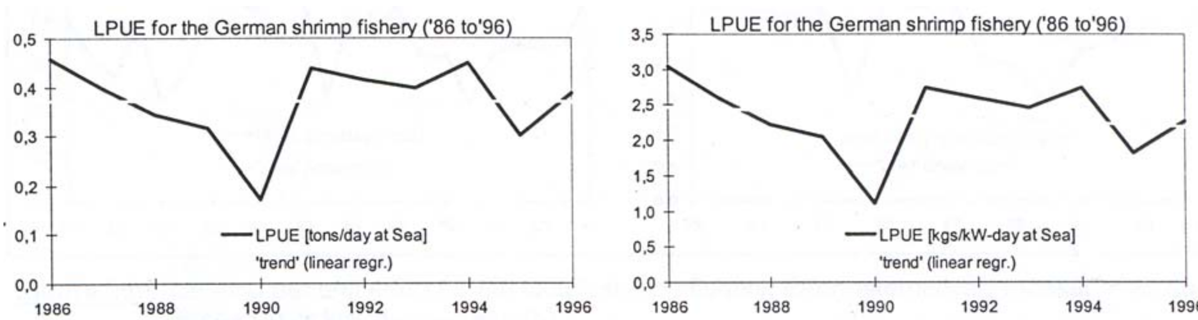


Fig. 1.20. LpUE for German shrimp fishery. Left: effort measured as day-at-sea; Right: effort measured as kW day-at-sea.

Fout! Ongeldige koppeling.

Fig.1.21. German LpUE in kg/hp-days (data source: WGCRAN 2006)

The LpUE of the last five years (kg/hp-day-at sea), however, show a steady increase. This might mark the onset of a new, positive trend in LpUE. It is, however, certainly too early to make such bold statements.

1.4 Danish *C. crangon* fisheries

1.4.1 Logbooks and data availability of Danish fleet

Data on landings and effort of Danish vessels are recorded in the logbooks on a per trip basis. The position references of fishing activities of the Danish fleet is specific to fishing in the northern regions, as spatial data of fishing activities of the Danish fleet in other national waters is not recorded. The spatial fishing pattern remains on a very low resolution as landings are referenced to ICES areas or the statistical ICES rectangles fished in the course of a voyage.

1.4.2 Danish waters and ports

The main Danish ports from which *C. crangon* vessels operate are Havneby and Esjberg, both close to the Wadden Sea and with landings of >1,100 tonnes in 2004 (Per Sand Kristensen), and Hvide Sande, located on the west coast of Jutland with landings of around 100 tonnes in 2004. Minor landings (< 7 tonnes) are reported from the most northern harbours of Thorsminde and Thyborøn.

Shrimp fishing in Danish coastal waters is restricted to all areas beyond the shrimp line (SL), which was enforced in 1977. The SL runs between the Danish Wadden Sea islands from the peninsula of Skallingen to Rømø, basically closing off the entire Danish Wadden Sea.

A relatively large number of Dutch and German vessels, and a smaller number of British and Belgian vessels, operate and land catches in Danish waters. In 2005 this amounted to 4,557 tonnes, compared to Danish landings originating from Danish waters for the same period of 4,191 tonnes (WGCRAN 2006). Belgian and UK vessels only account for 0.5% or less of the total landings in Danish ports (WGCRAN 2006).

1.4.3 Spatial effort distribution and trends

Fishing in the first and the second quarters takes place north of Horns Reef. In the 3rd and 4th quarters fishing takes place further down south and westwards (Kristensen and Wellendorph, 1995). Seasonal spatial effort patterns derived from the logbook effort data support this [see appendix 6] (WGCRAN 2005).

This figure is a compilation of both German and Danish data; therefore Danish fishing patterns may not be abstracted from this.

Over the years 2002 to 2003, a trend towards more landings from ICES areas further offshore in the North Sea along the Jutland West Coast is observed. Another change that seems to have taken place in the years of 2002 and 2003 is that in the second and third quarters relatively higher landings were recorded in the ICES squares north of Horns Reef. This is in line with the general trend observed in North Sea *C. crangon* fisheries of a South-North shift and a shift to deeper waters of higher shrimp densities in summer (WGCRAN 2005/2006).

1.4.4 Spatial-seasonal fishing patterns

In contrast to the other fleets, the main shrimp season in Denmark is spring, which corresponds to peak *C. crangon* densities encountered at this time. Annual Danish effort and landings show a depression during the summer and winter months (WGCRAN 2006). The contribution of winter effort to the fisheries was 25 % in 2003, which is higher than the mean share of 19% during the years 1992 to 2001.

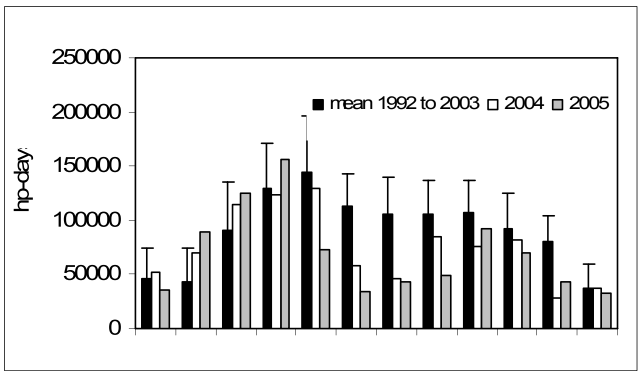


Fig. 1.22 Seasonal effort of Danish fleet (Source: WGCRAN 2006)

1.4.5 Fleet composition and characteristics and trends

22 vessels operated in the Danish fleet in 2003, with an average age of 27 years and an average engine power of 200kW (Polet, 2003). This total increased to 28 and 32 in 2004 and 2005 respectively. This change is due to 4 vessels leaving and 8 vessels joining the fleet (WGCRAN 2006). Most of the vessels have an LOA between 14m and 18m (Polet, 2003). The width of the beam is 9m or 10 m. In Denmark the use of a sieve net is mandatory in the *C. crangon* fishery in order to reduce by-catch.

1.4.6 Trends in landings and effort

Similar to the Dutch and German fleets, the Danish fleet reached their highest ever recorded landings in 2005, with landings amounting to 4,191 tonnes. This is 77% higher than the average Danish landings of the preceding 12-year period. Despite an increase in vessels, the total fleet effort decreased from an average of 1,100,000 fishing hours in the previous 12 years to 842,249 fishing hours in 2005. In the same period LpUE rose from an average of 2.14 in the previous 12 years to 4.98 in 2005. Something significant is apparently occurring that is resulting in such a remarkable increase in LpUE. However, this is not explained.

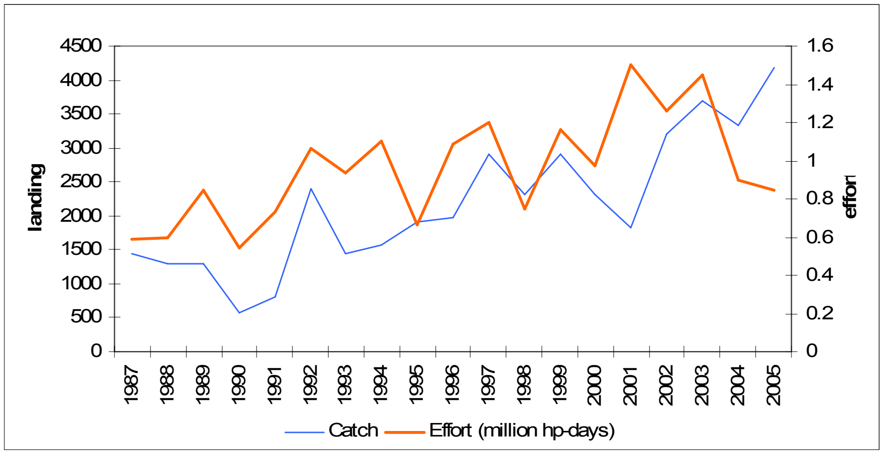


Fig.1.23. Danish Landings and effort (data source: WGCRAN 2006)

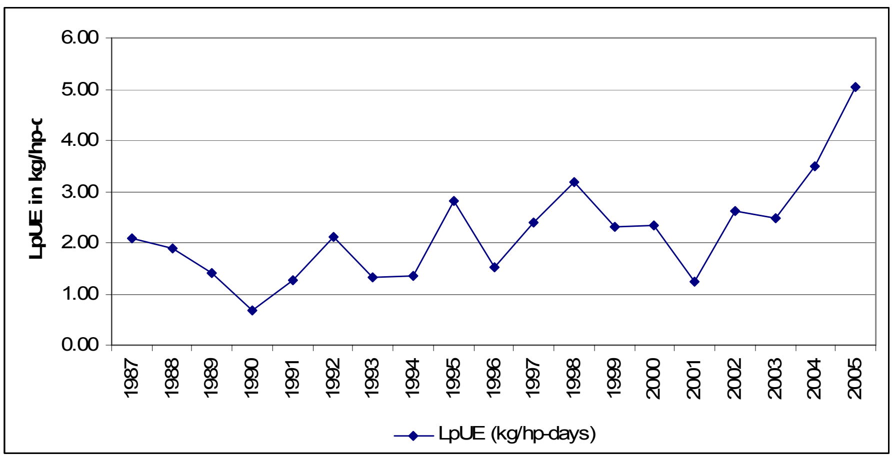


Fig.1.24. Danish LpUE in kg/hp-days (data source: WGCRAN 2006)

1.5 Belgian *C. crangon* fisheries

1.5.1 Logbooks and data availability of Belgian fleet

Data on Belgian landings is considered to be of poor value (van Marlen et al., 1998). No data has been derived from the logbooks on spatial fishing patterns. The inventory of Polet (2003), however, gives some insight into the spatial fishing patterns of the Belgian fleet.

1.5.2 Belgian fishing waters and ports

Fishing in Belgian waters occurs in a narrow strip along the coast of western reaches of Belgium, concentrating on the “Stroombank”, “Oostendebank”, “Wenduinebank” ,”Wandelaar” and “Vlakte van Raan”, which fall within the 6-mile zone. The major Belgian C. crangon fishing ports are Zeebrugge, Nieuwpoort and Oostende.

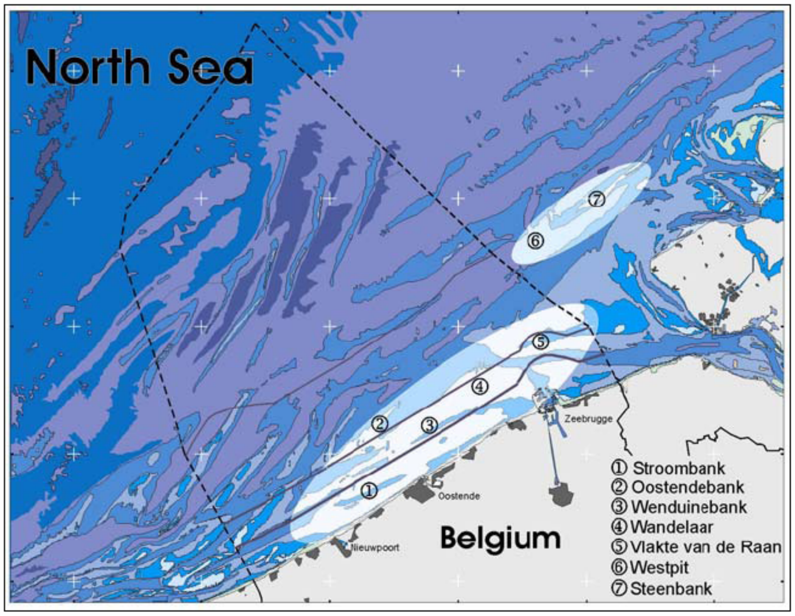


Fig. 1.25 The South Eastern part of the North Sea with the shrimp grounds highlighted and the banks most visited by the Belgian fishermen indicated. (Source: Polet, 2003)

1.5.3 Spatial effort distribution and trends

The Belgian fleet mainly operates close to the Belgian coast within the 12-mile zone [see fig 1.25]. The main shrimp fishing grounds for the Belgian shrimp trawler fleet are highlighted in this figure. The so-called Scheldt trawlers also fish for *C. crangon* in the Westerscheldt estuary, as well as in the Southern most part of the Dutch coastal waters. Vessels operating from Belgium's most southern port, Nieuwpoort, occasionally fish within the French 12-mile zone.

As a result of a declining abundance of shrimp in the western part of the Belgian coastal waters, and because a large number of Belgian shrimp trawlers are now owned by Dutch companies and therefore operate from the northerly Dutch ports, fishing effort tends to be forced towards deeper and more northern shrimp grounds. This is reflected by an apparent shift in shrimp-directed fishing effort to the north (WGCRAN 2005).

1.5.4 Spatial-seasonal effort distribution

The main shrimp season falls in the months of August, September and October. Peak effort and landings coincide with peak densities of *C. crangon* in Belgian waters in autumn, in contrast to remarkably low densities in spring.

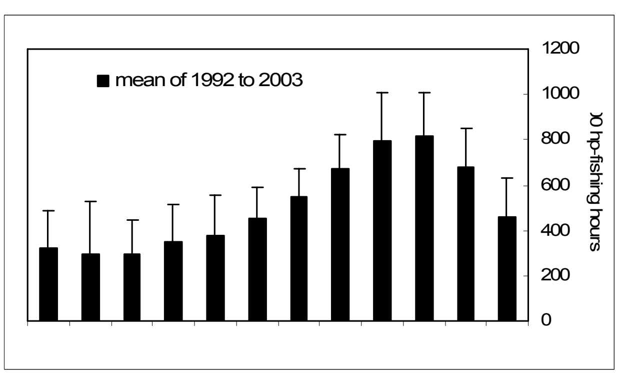


Fig.1.26 Seasonal effort of Belgian fleet (Source: WGCRAN 2006)

In accordance with the winter migration of *C. crangon* populations into deeper waters a part of the Belgian fleet follows these movements in winter, exploiting the deeper shrimp grounds further off the coast, particularly the “Steenbank” and the “Westspit”.

1.5.5 Fleet composition and characteristics and trends

The Belgian fleet has decreased in size over the years and is down from 52 vessels in 1995 to 37 in 2001. It is a very heterogeneous fleet in terms of fishing activities and only a limited number of the vessels target *C. crangon* all year round. The Belgian shrimp trawlers are multi-purpose vessels. Their fishing activities are seasonal and based on catch opportunities for shrimp, Cod and Sole. H. Polet (2003) classifies the Belgian fleet into three categories: he classified 16 of the 37 vessels as genuine shrimp trawlers, having shrimp as their main target species for at least 8 months of the year; 14 vessels were classified as seasonal shrimp trawlers, targeting shrimp from August to November in the main shrimp fishing season and 7 vessels were classified as a-typical, having a rather low shrimp directed fishing effort and without a clear fishing pattern’. These a-typical vessels target *C. crangon* under particular circumstances: when their quota of their main target species have been exhausted or when their vessels prove too small to pursue quota stocks into distant fishing grounds. Independent of the class, all vessels in the fleet were attracted to the *C. crangon* fishery in the main shrimp season of August to October. The catch opportunities along the Belgian coast, for the other target species vary yearly in terms of magnitude, time span and period, and depending on the conditions. This makes predicting fleet and vessel activity near to impossible. In general, when Sole is abundant on the Belgian coast in spring during the Sole spawning season, most vessels will target this species. Similarly, if in winter catch opportunities are high on the Belgian coast for Cod, the fleet will target Cod.

The Belgian shrimp trawler is rather small, its overall length being less than 22 m, with keel depth of 2.3 m, and engine power less than 221kW with and an average of 220hp (1993-95). These vessels are typically designed to operate in an inshore fishery. Although most of the vessels of the Belgian fleet are reasonable old, newer and more powerful Eurocutters, which can venture further offshore, have started to enter the fishery since 1995. This seems to follow the modernisation observed in the Dutch fleet. Considering some of these Belgian vessels are Dutch flag ships, this trend is not surprising.

The width of beam trawls used in the Belgian shrimp fishery lies within 7 to 8 m (VAN MARLEN ET AL. 1998). According to Polet (2003), one quarter of the vessels used a sieve net, for a short period of the year, when large amounts of jellyfish appeared in the catches

The average haul observed in Polet’s (2003) study was 1.5 hours. This haul can be extended to 3 hours in winter when catch volume is low. Similarly, when catch volumes are exceptionally high or when nets get clogged with hydroids, the haul duration will be downsized, sometimes to less than 30 minutes. In Belgium, the fleet is particularly active during the night as shrimp catch-ability is higher then due to increased activity and exposure of shrimp. Accordingly, day-fishing will exploit those fishing grounds with high water turbidity as this will decrease light intensity on the sea bed and thus increase the catch-ability of shrimp. The vessels haul with an average speed of 2.75 knots and have an average beam length of 7.65m. This allows them to cover an area of $0.08km^2$ in one hour.

1.5.6 Trends in landings and effort

Both landings and effort have fallen consistently in the Belgian fleet. So has LpUE. The reason for the declining LpUE is argued to be biological, with shrimp abundance declining in the more Southern waters.

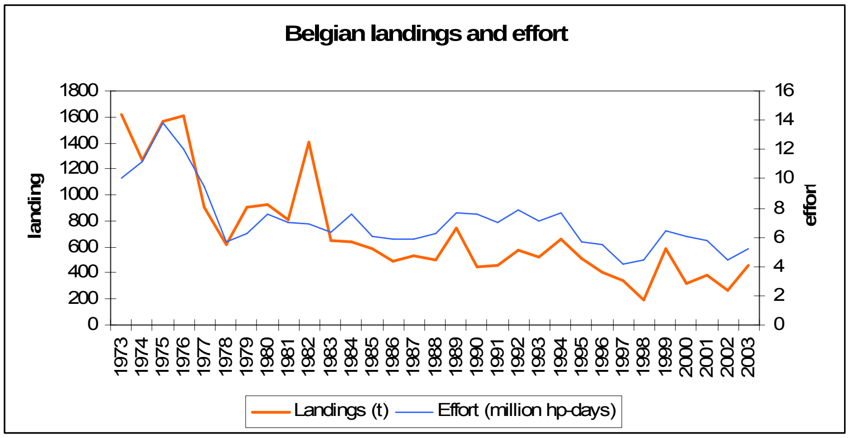


Fig. 1.27. Belgian landings and effort (data source: WGCRAN 2006)

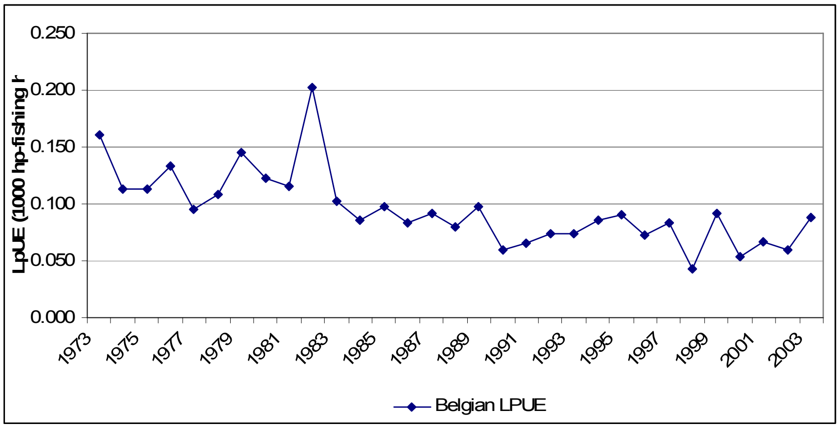


Fig. 1.28 Belgian LpUE in kg/hp-days (data source: WGCRAN 2006)

1.6 UK C. crangon fisheries

1.6.1 Logbooks and data availability of UK fleet

Vessels over 10 metres long declare landings. For vessels under the 10 meters this is not a legal requirement. Nevertheless, most landings data can be retrieved from merchants. Effort and fishing area is estimated but, given vessels are small, the operational range of the boats is limited and therefore restricted to day trips in local ICES rectangles. Activities of UK vessels in waters of other member states cannot be reconstructed, as the required data is missing (WGCRAN 2005).

1.6.2 UK fishing waters and ports

The east coast *C. crangon* fishery operates from the ports: Kings Lynn, Boston and Grimsby (Revil, A., 2000). The main UK east coast *C. crangon* grounds are located in the Wash, the Humber and north of the Norfolk coast.

1.6.3 Spatial effort distribution and trends

The Wash fishery in the North Sea is the source of usually over 90% of the recorded landings for the UK. British catches are restricted to three ICES squares 34F0-36F0, with almost no variation on this scale. 35F0 and 34F0 continue to be the most important.

1.6.4 Spatial-seasonal fishing patterns

The effort is more evenly distributed over the year, although it is highest in the autumn months of September to November. Landings are remarkably higher in these autumn months and exceptionally low in the spring. This corresponds to consistently high *C. crangon* densities encountered in the Wash fishery from August through to December. An average of 28% of the effort is directed to the winter fishery. In 2003 this share increased to 36 %.

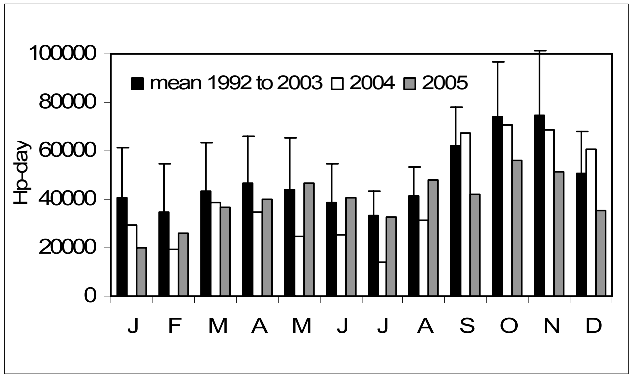


Fig. 1.29. Seasonal effort of UK fleet (Source: WGCRAN 2006)

1.6.5 Fleet composition and characteristics and trends

98 vessels fished under the UK flag in 2003, most of these vessels date back to 1980 (Polet, 2003). The average LOA of a traditional shrimp trawler is 11m with an engine power of 106 kW (Polet 2003). The beam is between the 3 and 9m but usually below 7m. Although a small 15 % of UK Shrimp fleet still employs a single beam trawl the Wash *C. crangon* fishery employs twin beam trawls. Twin beam trawling was introduced in the late 1980s when large Dutch investments came into the East Coast *C. crangon* fishery (Lancaster 1999). In the years from 1987 investment in larger boats up to 17m has become common. This allows the Wash fleet to exploit waters further off-shore during winter (Lancaster 1999). According to van Marlen et al. (1998) Crangon fishing effort of the UK east Coast fleet can vary considerably from one year to the next due to the opportunistic tendencies of this fleet. Most vessels in this fleet are multi-purpose and target *C. crangon*, as well as other fish species depending on species abundance, management strategies and market prices. A large number of the UK East Coast vessels are rather inactive and in 1995, 94% of the fishing effort in this fleet could be attributed to only 32 vessels (Revill, A 1996)

1.6.6 Landings and effort trends

According to the data of the ICES WGCRAN, annual landings have been variable, with a decreasing trend observed since 2001, which was the year of highest recorded landings (1,865 tonnes). In 2004 and 2005, annual landings have been below 500 tonnes. In line with this, effort levels in 2004 and 2005 have been lower than in previous years. This trend is attributed to low prices in the continental European market, combined with high fuel prices in the UK.

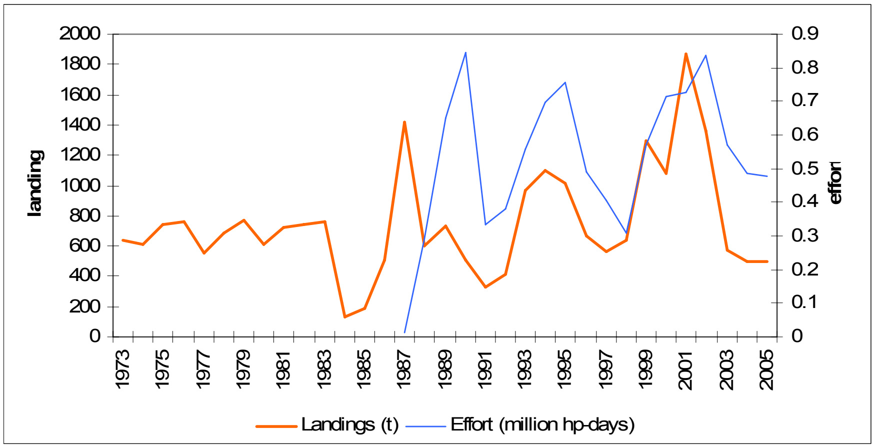


Fig.1.30. UK landings and effort (data source: WGCRAN 2006)

LPUE data show a continued low level, following a sharp decline in 2003. According to the WGCRAN group, this indicates that biological factors may also be contributing to the reduced landings in the most recent years. This trend is also consistent with the general shift observed in *C. crangon* densities in the North Sea in a north easterly direction, perhaps due to climate changes (WGCRAN 2006).

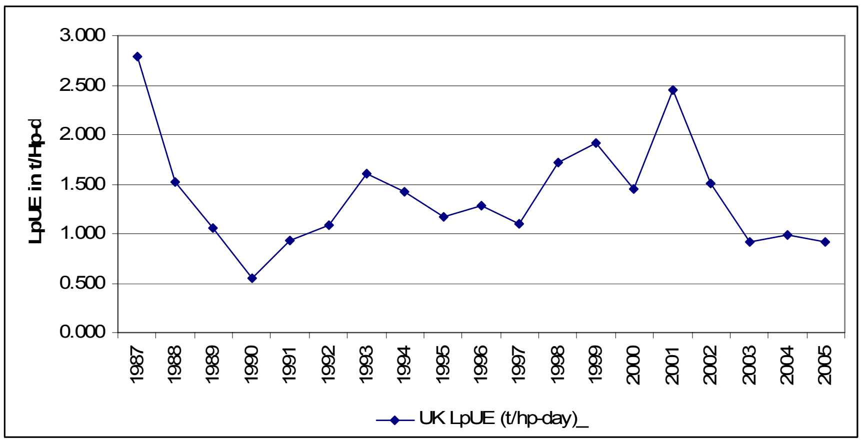


Fig.1.31. UK LpUE in kg/hp-days (data source: WGCRAN 2006)

1.7 Reflections and insights

1.7.1 Summary of the main fishery characteristics and trends

The *C. crangon* fishery is a bottom-trawling fishery, employing a beam trawl with relatively small cod-end mesh size (20mm). Both methods and gears are more or less uniform across the North Sea *C. crangon* fishery, although there are some differences in the employment of selective gears.

C. crangon abundance is known to be highly dynamic and can fluctuate enormously in between years. The observed inter-annual variation in landings and effort in North Sea *C. crangon* fisheries are therefore not surprising. The North Sea *C. crangon* fishery is, since the abolition of the sector-imposed landings and effort limitations (2000), a virtually unregulated fishery and is therefore free to expand. Nevertheless, since 2000, total effort expressed as horsepower days, has remained more or less stable, whereas landings have increased considerably in this same period achieving a record high in 2005. This is most probably explained by high *C. crangon* abundance over the last years. Landings and effort trends have not been uniform across all fleets, nor have they been so in the past. This also applies to spatial and seasonal effort patterns. As we have seen in this chapter, effort, a function of average capacity, fleet size and fishing days, is governed by a multitude of factors that shape the conditions in which fleets operate and that are all, some more than others, subject to change. These include biological factors (*C. crangon* abundance and/or abundance of alternative target species), economic factors (market price of *C. crangon*, fuel prices and income diversification), fiscal or private arrangements (income benefits, cartel arrangements), and technological developments (vessel modifications). Quite obviously, fleets do not operate under entirely uniform conditions, nor are they necessarily subject to the same changes taking place (these may be taking place at a local, regional or sectoral level). Finally, and in relation to this, similar changes will not necessarily provoke identical responses across fleets and vessels. This explains why effort distribution in both space and time, and trends in this, will vary across vessels and between fleets and regions.

Germany and the Netherlands have by far the largest *C. crangon* fisheries, in terms of landings, as well as in terms of shrimp directed effort and fleet size. Both the fleets' landings are above the 10 year average and have contributed to the recently observed increase in landings. Effort, on the other hand, has slightly decreased in the last 4 years in the Netherlands, but this does not necessarily signify any trend. It does imply that the increase in landings is the result of increasing LpUEs Germany's effort has increased significantly since 2002 but, there is no reason to believe that this signifies a trend. The enormous variability in effort is not explained, but does not seem to be the result of changes in fleet size. The increase in landings is explained by both the accumulated effect of an increase effort and the LpUE. Denmark, the UK and Belgium make only a minor contribution to the total fishery. All effort levels are down from their 2000 levels, but only in Belgium does this seem to be part of decreasing trend in effort. This long-term trend is also observed in Belgian LpUEs and consequently landings. Landings have increased significantly in Denmark, owing to phenomenally high LpUEs. UK landings have declined owing to a decline in effort as well as LpUEs. When putting these decreases into a longer time perspective, nothing remarkable seems to be happening, although we must wait to see if the declining LpUEs are chronic or just a reflection of inter-annual fluctuations.

Seasonal effort and landings distribution and patterns are rather well established for each of the countries. Fleets operate throughout the coastal waters of the participating countries, not being restricted to their own national waters. In winter the fishing concentrates in the deeper, offshore shrimping grounds, as the larger shrimp particularly congregate in these deeper waters. The winter fishery is only relevant for a select group of larger vessels, mainly belonging to the Dutch fleet. The main shrimp season continues to fall in autumn and fishing in this season is concentrated in the shallower, more inshore waters of the estuaries and tidal inlets. Denmark is an exception to this as their main shrimp season is spring.

1.7.2 Management implications; fisheries intervention and management measures

What can we learn from the status and development of the fishery that would warrant intervention?

- Firstly, we could say that the status of the fishery in terms of landings and LpUE seems to be in a stable position, with declining LpUEs observed only in the UK and in Belgium. This suggests that *C. crangon* populations are being exploited at sustainable levels, thus not warranting intervention. It cannot, however, be determined how LpUEs might react to possible effort increases. This requires stock assessment, which will be addressed in chapter 3. Declining LpUE in Belgium and the UK may not signify a regular fluctuation, as there are indications that the declining LpUEs are part of a larger trend. This will also be discussed in chapter 3.

- Although the target species populations may not be the prime concern in this fishery, it is likely that this fishery exerts additional pressures on the marine environment. The gears and methods employed in this fishery intuitively lead us to expect that this fishery may be exerting pressures on non-target species and sea-bottoms through other fisheries mechanisms, such as by-catching and sea-bottom contact made by the trawl. If such pressures are assessed as being detrimental intervention in this fishery may be warranted. These issues are topics dealt with throughout Part I and Part II.

- It is appropriate to remark here that the effort and landings limitations that were in place throughout the 90s were beneficial for the environment, by way of promoting lower total effort levels (relative to uncontrolled levels) and thus reducing total fishing-exerted pressure. Therefore, the possibility of reinstalling such well-supported effort-limiting arrangements deserves looking into, even if warranted solely from an environmental perspective. The international PO offers scope for such arrangements

1.7.3 Improving fisheries statistics

In order to conduct a better inventory of the *C. crangon* fishery, more detailed, accurate and consistent, but also accessible, fishery statistics need to be provided. This should focus on several aspects:

Logbooks can potentially provide us with accurate fisheries data on a per trip base. Despite EU regulation, these logbooks do not seem to be used consistently across all fleets. Proper implementation and enforcement is required. Secondly, this data should be compiled and stored in accessible databases. Thirdly, this data needs to be translated into a uniform language that is easily employed in fisheries management. Effort, for instance, ought to be approximated in a uniform way in all countries to allow for comparison and aggregation. The ICES Work Group on *C. crangon* invests efforts into collecting data, but completeness of their statistics depends very much on the individual efforts of the different representatives and the way in which the various countries record and compile logbook data. Finally, the quality of the data that logbooks provide should be improved, specifically in terms of spatial data. Although approximate spatial effort distribution across the seasons has been established, spatial effort data remains insufficient to determine where the main shrimping grounds are located, at which intensity these are fished, during which time of the year and how such spatial effort patterns and distributions change over time. ICES squares, the units in which spatial data is currently being recorded in logbooks, is insufficient to produce such statistics.

PART II

DIRECT AND INDIRECT EFFECTS OF
EXTRACTIONS AND DISCARDING

Chapter 2

BY-CATCHES AND DISCARDING IN C. CRANGON FISHERIES

The *C. crangon* fishery is a bottom-trawling fishery using a highly unselective gear (cod-end mesh-size of 20mm). In targeting *C. crangon* by-catch of bottom-living or bottom-feeding fish and invertebrate species is inevitable. By-catch includes all non-target species and unwanted target species. In the literature by-catch is decomposed into incidental catch and discards. The incidental catch pertains to the by-catch fraction that is retained and landed for economical proposes. Discarded catch is the fraction of the by-catch that is disposed of overboard and may include target species (commercial discards) and/or non-target species (non-target catch).

The target species for this fishery is the *C. crangon*. However, not all *C. crangon* catches are landed. The EU has imposed a minimum market-size (EC 2406) into this fishery and requires C. crangon to be graded into marketable (≥45mm) and non-marketable shrimp (<45mm). The legal minimum mesh-size is 20mm. This is smaller than the 22mm cod-end mesh-size that is required to catch 75% of the 45,2mm T.L shrimp (Polet, 2003). This implies that by using a 20mm cod-end mesh-size, as is common in C. crangon fisheries, substantial quantities of C. *crangon* are discarded. Discarding of C. crangon is dealt with in the paragraph 2.2.

More than 50 by-catch species are encountered in this fishery; these include non-commercial as well as commercial fish species and invertebrates. The commercial species may be retained and landed. This will depend on; the economic motive of the fisher; the minimum legal or commercial landing size (if and when these apply), and; if the fisher holds quota for such species, in the case of quota species. By-catches and discarding in by-catch species is addressed in paragraph 2.2 and 2.3

By-catch would not be a concern were it not for the high discard mortality rate induced through the catching, sorting and discarding processes. Discard mortality will be addressed in paragraph 2.4.

When an understanding of the quantitative and qualitative composition of the catches and discard mortalities has been achieved we may attempt to assess the impact that this fishing mortality has on the respective stocks and species community.

2.1 Gear efficiency and selectivity and resulting by-catch

By-catch is a reflection of gear efficiency. Understanding the by-catch problem therefore begins by understanding the gear-species interactions and the spatial and temporal distribution of species on the shrimp grounds. According to Harden Jones (1974) gear efficiency is influenced by species behaviour in 3 ways; (1) *availability*; is determined by migration patterns which causes fish to move from one area to another during their life, (2) *accessibility*; environmental factors may cause fish to aggregate in places which are not accessible to the gear. This will depend on gear that is used. A shrimp beam trawl for instance gives little stimulation to fish borrowed in the in seabed, moreover, only fish present in a particular water column are accessible for capture. Accessibility may fluctuate constantly, (3) *Vulnerability*; determined by fishing power or selectivity of the gear, which is subject to variability and the ability of fish to escape from a gear. This ability is a function of body size, shape and fitness and gear design. Selectivity (Wileman et al., 1996) as quoted by Polet (2003) is: the process which causes the catch of a gear to have a different composition from that of the fish population in the geographical area in which the gear is being used [see fig. 2.1 for illustrative example of a selectivity-curve]. Gears will select by species and for each species there will be a size selection. Below a typical selection curve is given for a particular fish species. It gives the probability that an animal, entering the trawl, of length TL (total length) is retained in the cod-end (black line).

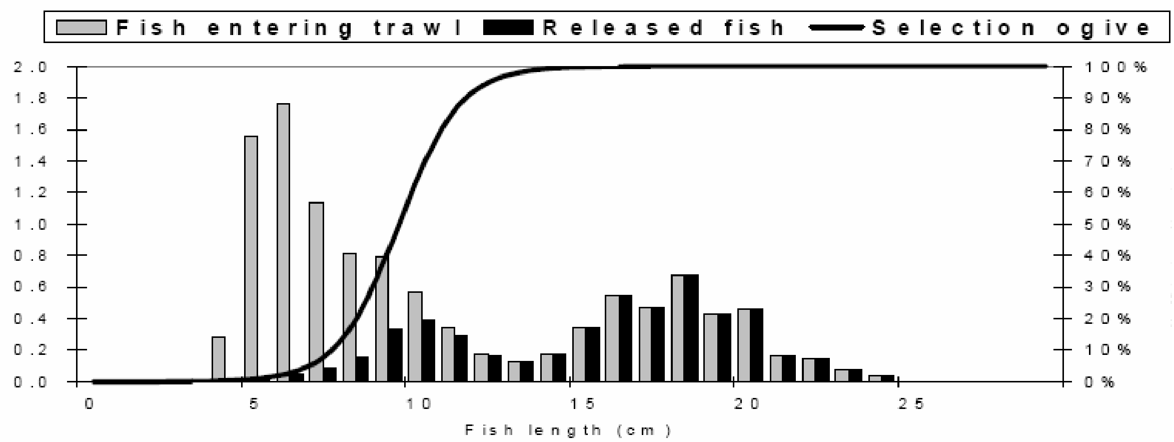


Fig. 2.1 A selectivity curve with on the left axes: no of fish per 10,000 m^2 and on the right axes no's of fish released by the (selective) gear (source: Revill, 2000)

2.1.1 Standard shrimp trawl and gear selectivity

The standard shrimp beam-trawl is a highly unselective gear. Polet (2003) studied trawl selectivity in Belgian waters for C*. crangon* and fish species (Plaice, Dab and Sole) using a commercial beam-trawl with 22mm cod-end mesh-size. Selectivity studies for C*. crangon* were done for the entire trawl, whilst selectivity studies for fish species (Cod, Whiting, Plaice, Sole, Dab) focused on the cod-end. Trawl selectivity is low for both the target species as well as for fish.

The bulk of the marketable (>45mm) shrimp ends up in cod-end (65%), the other 35% of the marketable shrimp do not end up in the commercial catch and escape underneath the ground rope (9%), through the meshes of the net (19%) or through the cod-end meshes (7%). Of all <45mm shrimp, 44% escape through the net meshes and only 23% escape through the cod-end meshes, indicating that net selectivity is more important than cod-end selectivity [see figures 2.2]. A 24% of the non-marketable shrimp (<45mm) are caught in the cod-end. Cod-end selectivity for C. *crangon* is L50[2] = 39.4mm. Cod-end selectivity proved highly variable for shrimp, this is largely explained by the clogging of the meshes with hydroids, the catch volume (higher catch volumes lead to lower selectivity), and the state of the sea (rougher sea conditions lead to higher selectivity)

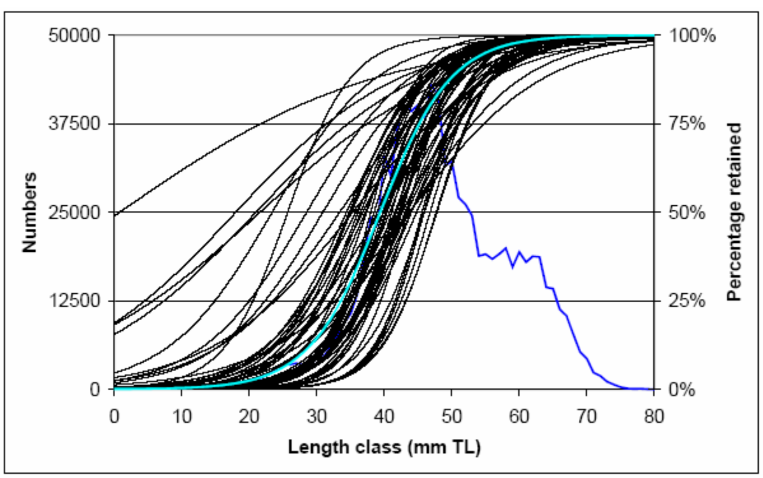


Fig 2.2 . estimated overall selectivity ogive (Bold light blue line) and 58 selection ogives of the single hauls and length distribution of the cod-end + cod-end cover catch for C. crangon (bold deep blue line) (Source Polet, 2003)

[2] L25, L50, L75 are the body lengths at which 25%, 40% and 75% of the shrimps are retained in the cod-end

Due to the small cod-end mesh-size, cod-end selectivity for fish is very poor, even for small captured juveniles (0-group). This is illustrated by the selectivity curves [see fig 2.3-2.5]. For Dab L50 = 4.5cm. For Sole L50= 7.9cm. For Plaice specimens of lengths down to 5cm were caught, but no cod-end selectivity was observed, implying that all caught place were retained. The length frequency distribution of the cod-end is given in figure 2.5.

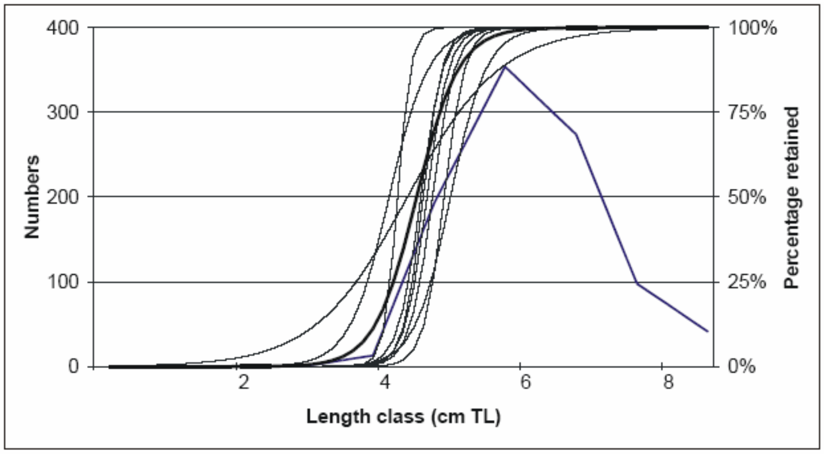


Fig 2.3 The estimated selectivity ogives for Dab together with the length frequency distribution of the cod-end + cod-end cover catch (overall selectivity ogive in bold)

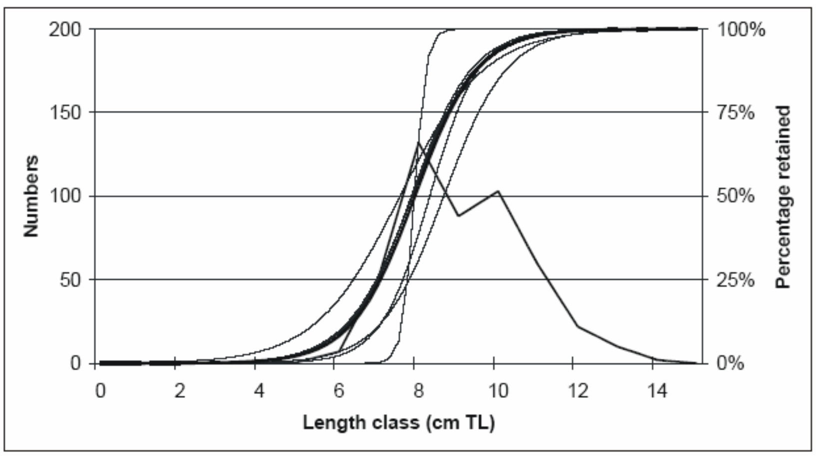


Fig 2.4 Estimated selectivity ogives for Sole together with length distribution of the cod-end + cod-end cover catch (overall selectivity ogive is drawn in bold light blue)

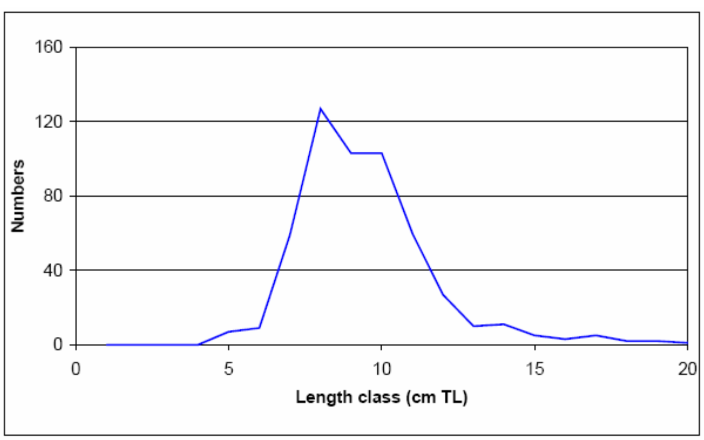
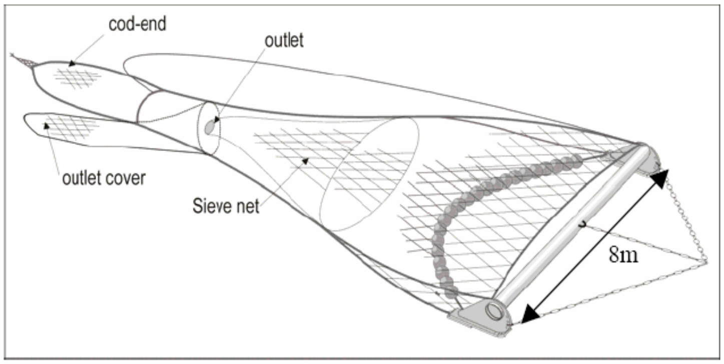


Fig 2.5 Length distribution of the cod-end catch for Plaice

In addition, the other parts of the net did almost not allow any fish to escape. Consequently the shrimp beam trawl will inevitably catch high volumes of small fish in coastal area and estuaries where juveniles prevail (Polet, 2003).

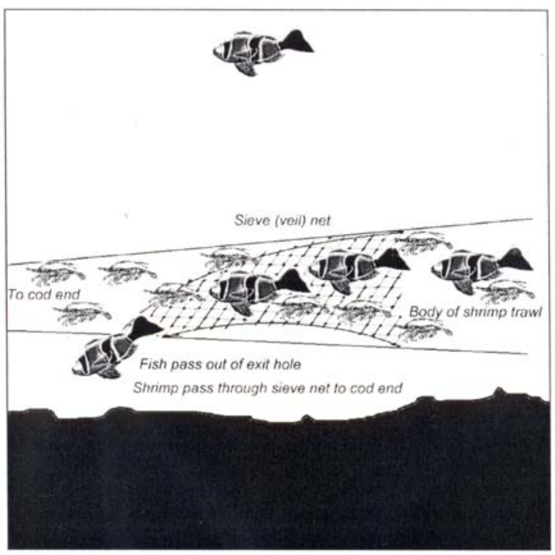
2.1.2 Sieve nets and gear selectivity

The use of selective devices, to reduce by-catches in the C*. crangon* fishery is required by EC law, however, only Denmark has gone as far as effectively implementing and enforcing this regulation by requiring the use of sieve nets by all fishermen. Sieve nets have been in use prior to EC legislation, and are still in use today, albeit on a random basis (by the other 4 countries) depending on season and area.



Use is motivated by practical reasons, e.g. to save time and labour in the sorting process when large quantities of jellyfish occur in the catches (Polet, 2003). The major draw-back of using selective devices is that a part of the commercial catch (C. crangon) is lost. In Belgian waters, when using a sieve net this usually exceeded the 10%, but under favourable conditions remained below the 15%. In case of clogging or presence of gilled fish, losses of marketable C*. crangon* could exceed 30%.

Generally speaking, sieve nets are the most accepted and commonly used selective devices in North Sea C. *crangon* fisheries, therefore we will briefly review the selective properties of the gear.



The sieve net has bigger mesh sizes than the cod-end and is placed inside the trawl. It works by letting small fish and crangon pass through the net whilst retaining larger specimens which are channelled to the outlet, which may be covered with an outlet-cover of a large mesh size to retain the commercial by-catch species.

The selective properties of sieve nets were studied by Polet (2003). The experiments were conducted using sieve nets of a commercially used (Netherlands and UK) design. Sieve net selectivity was high for larger fish >10cm and invertebrates, but proved to be poor for fish species (Plaice, Dab, Cod, Whiting, Sole) below the 10 cm (i.e. mainly the 0-group), with generally only one quarter being released through the outlet. Almost all marketable fish (Plaice, Dab, Cod, and Sole) were sorted out, except whiting which showed a poor selectivity. The selective properties for Dab and Plaice were very similar; below the 10 cm body length the catch reduction was very low [see figure 2.6], between the 10-15cm selectivity rises steeply, and at 20cm becomes 100%. Sole has a very distinct selection pattern; for the smallest specimens a large portion was sorted out, around 10cm the selectivity declined, and increased again for larger length classes. A 100% was only reached at about 25 cm. For Bib 100% selectivity was achieved for length classes of 25cm. Selectivity for Whiting was low with 100% selectivity in length classes above the 30 cm.

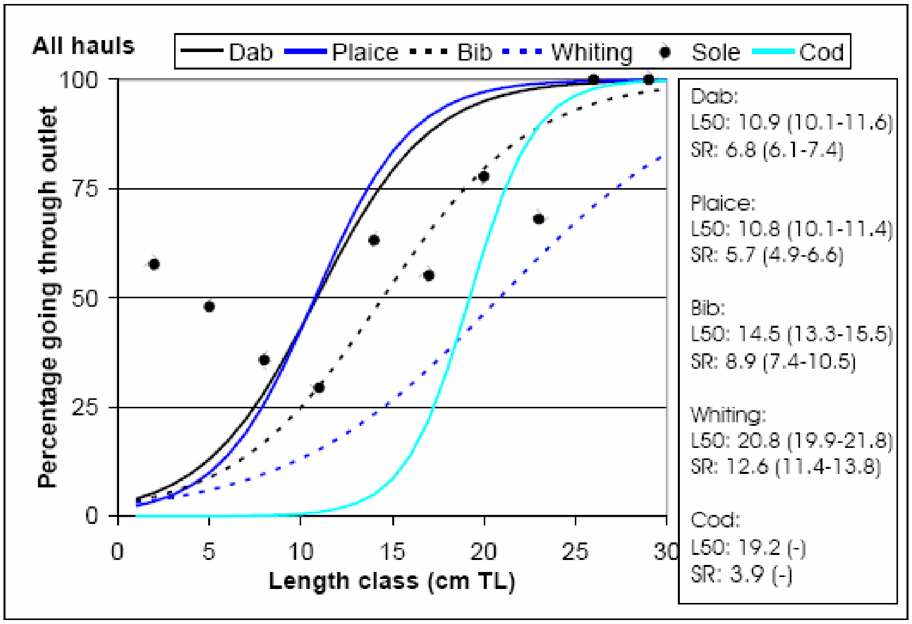


Fig. 2.6. Selectivity curves of Sieve net for different fish species (source: Polet 2003)

The reduction in by-catch of the unsorted main by-catch fraction (mainly containing invertebrates and debris) by using a sieve net, ranged between 28% and 49% depending on the season. The catch reductions of non-commercial fish and invertebrates at species level are shown in the figure below. Catch reduction varied between species from 23% to100% [see figure 2.7].

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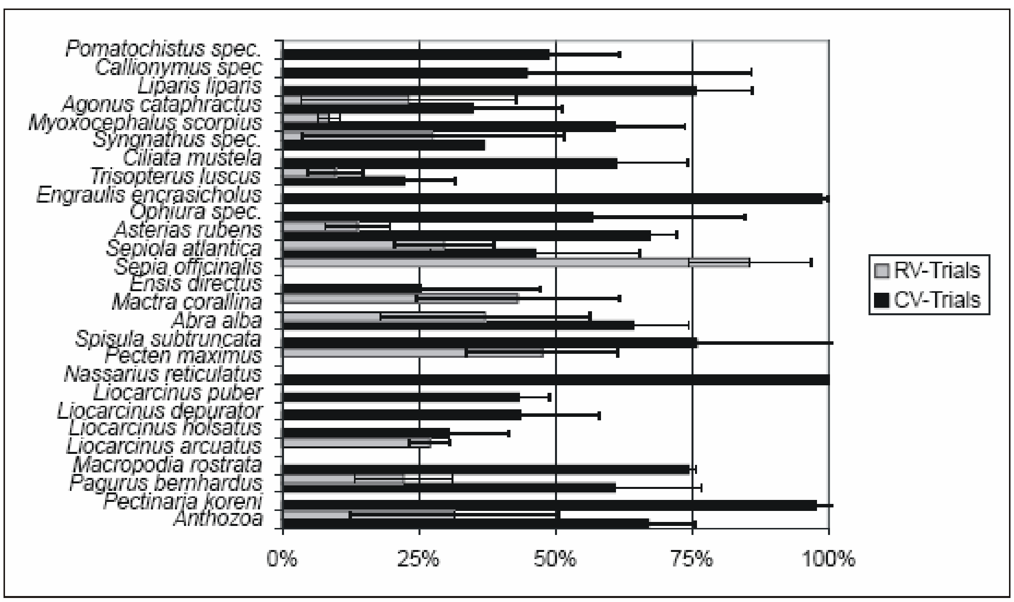

Fig. 2.7 The percentage of the different non-commercial fish and invertebrate species in the catch of the experimental net (source: Polet, 2003)

The selectivity of sieve nets varies across seasons and area. The sieve nets operate poorly when high amounts of seaweed and hydroids, which clog the meshes, are present. In summary, selective devices are useful in these areas where high numbers of 1-group fish are caught in the by-catch, but they will not help bring down by-catches of 0-group fish.

2.1.3 Trawl efficiency and variability in catch composition and size

The availability, accessibility and vulnerability of a single species is not constant, but will vary depending on various species characteristics and population dynamics (such as growth rate, reproduction patterns and migration- and feeding patterns). Because of this, by-catch composition and size in a given area fluctuates, showing both micro and macro temporal variation.

Large scale spatial variability in catches reflects geographical distribution and abundance of species. Seasonal trends in relative abundance and size composition of species in the catches may reflect the seasonal presence and abundance of a species in a particular area resulting from migration patterns. In addition seasonal trends may result from the reproductive cycle and growth and mortality patterns of a species; such factors govern recruitment into the fisheries at given times of the year as fish reach size at first capture; consequently (for this fishery when selective devices are used) such factors also govern the movement of the fishery as fish grow into bigger size-classes and are deselected by the (selective) gear.

On a smaller spatial-temporal scale, variation in the catch from two subsequent hauls or trips may be observed. This may reflect micro-distribution of the fish on the fishing grounds which depends on the patchiness and diversity of habitats. It also could be the result of the variability in catch ability of a fish species at a particular moment. The latter has, among other things, been brought into relation with the tidal-cycle. As research findings (RESCUE) in UK waters demonstrate, a correlation exists between the tidal state and the catch levels of many species, with peaks being observed at ebb tide, during both the day and the night. This is explained by foraging behavior. Fish will advance upon to the inter-tidal flats during high tide and congregate into channels during ebb. Furthermore, species with a preference for deeper waters over tidal flats show fluctuating abundance in accordance to the tidal cycle, for example Whiting and Cod advance into channels from deeper waters in order to forage on shrimp, which are particularly abundant in these channels during ebb.

On a larger time scale, inter-annual variation or trends in occurrence and abundance of a species in the catches may be explained by observing (1) Year-class strength; year-class is known to vary considerably in many fish species particularly in 0-group fish; (2) geographical repartition of age classes over an area or a shift of geographical distribution of a stock; (3) fishing effort exerted in previous seasons in the area where it sojourns; this may impact on the spawning stock biomass and fish recruitment;(4) high predation levels. In years of high predator abundance, prey species will suffer higher predation levels and thus will be lower in abundance

Because of the different seasonal and spatial effort patterns of the different fleets operating in the North Sea, shrimp trawl fleets will contribute in different ways to by-catches of non-target species.

2.2 By-catch and discard assessment for the EU *C. crangon* fleet

Data collection on *C. crangon* is subject to the provisions of the EU Data Collection Regulation (Council regulation 1543/2000 and commission regulations 1639/2001 and 1581/2004) since 2002. This provision requires the Member States to set up regular discard sampling programmes for their *C. crangon* fisheries. Implementation of this provision has remained absent. This is argued to be due to the high costs involved and the limited use that will be made of the data, as there are no formal stock assessments on *C. crangon*, and the year-classes of fish that are most widely discarded within this fishery which are below the age-at-first-recruitment, therefore being unsuitable data input for stock assessments (SGS rapport, 2006).

Despite the lack of consistent and robust data on by-catches, attempts have been made to characterize and quantify the by-catch in order to get a better understanding of the true magnitude and composition of the catches in this fishery in several independent studies.

2.2.1 RESCUE; an EU effort to assess by-catches in C*. crangon* fisheries

A major EU-wide contribution has come from the RESCUE project concerted by the EU and carried out in the year 1996. This is the most recent and ambitious attempt to scale discarding practices in the North Sea *C. crangon* fleet. The study is based on samples taken on board of commercial vessels throughout

the year, so as to account for seasonal variation after which the data has been extrapolated to fleet level. Nevertheless, the study is limited, as it focussed on the target species and 12 commercial fish species, all other by-catch was not recorded. The RESCUE study sampled catches *C. crangon* as well as for 11 commercial fish species; (1) Bib and Poor cod – *Trisopterus* spp. (not differentiated – in the text referred to as Bib), (2) Cod – *Gadus morhua,* (3) Whiting – *Merlangius merlangus*, (4) Gurnards – *Trigla* spp. (not differentiated), (5) Turbot – *Psetta maxima*, (6) Brill – *Scophthalmus rhombus*, (7) Flounder – *Platichtys flesus,* (8) Plaice – *Pleuronectes platessa*, (9) Dab - *Limanda limanda,* (10) Sole – Solea solea, (11) Solenette – *Buglossidium luteum.* Catches were sampled for these species throughout the Belgian, Danish, UK and German waters and consequently extrapolated to fleet level.
The Dutch sampling program failed and therefore no data exist for Dutch waters. To estimate Dutch by-catch and discarding quantities use was made of data derived from the Belgian (for C. crangon fisheries in the South of The Netherlands) and Danish (for C. crangon fisheries in the North of the Netherlands) by-catch sampling programmes. These figures are not very representative.

Use of a veil net in Danish Crangon fisheries is compulsory; therefore observed by-catches in this fleet are generally lower than in the other fleets.

2.2.2 By-catch sampling in German waters

German efforts to assess by-catches for the German fleet have been made throughout the second half of the 20th century within two major by-catch sampling programmes (FRCF and ESR).

During 35 years in the period from 1954 to1988 the Federal Research Centre for fisheries (FRCF Germany) carried out a long-term by-catch sampling programme (FRCF by-catch sampling programme) In this sampling programme buckets of 5kg unsorted catch (traditional non-selective trawl) were provided by several fishermen from the harbours along the German North Sea coast on a weekly to three times weekly basis. These served as sub-samples. Fishes in these sub samples were identified, counted and measured. No data were obtained concerning total catches and the edible shrimp fraction of each catch.

The ESR by-catch sampling programme was carried out in 1982 and from 1988 to 1992. This was done in the framework of the project Ecosystem Research Wadden Sea (ESR). Catches only covered the Northern half of the Schleswig-Holstein area (North Frisia). Similar to the FRCF programme, buckets of 5 kg unsorted catch were provided by fishermen as sub-samples in the season (June, August and October). In contrast to the FRCF project however, additional data was gathered on catch location, water depths, towing speed, total catch and consumption shrimp catch per haul. This allowed for swept area calculations and extrapolation to fleet level. Unlike FRCF data, ESR data could deliver catch fractions.

The data, that these sampling programmes have delivered, have been processed, analysed and employed in various studies. Tiews (1990) for example, produced historical *C. crangon* discard series on the basis the FRCF data. These are not publicly available and held by the Bundesforschungsanstalt Fur Fischerei in Hamburg, Germany. According to Purps (ECODISC), these data series are only reliable for giving relative and not absolute catch values. FRCF and ESR data were analysed by Berghahn and Purps (1998) for flatfish.

2.3 By-catch composition and quantification in North Sea *C. crangon* fisheries

2.3.1 By-catches and discarding in German fisheries

The German fleet operates primarily in the (German) Wadden Sea, therefore this is where most German by-catch sampling programmes have been concentrated. Research conducted by Berghahn et al. 1992 in the Wadden Sea delivered interesting insights into the species caught as by-catch. Species abundance in the sample catches were recorded and they were categorized as being resident species, near-resident species, species using the Wadden Sea as a nursery, species using the Wadden Sea as adults and Species not dependent on the Wadden Sea [see Table 2.1]

	Ostpreußen (25 hauls)						Seefuchs (7 hauls)					
	before sorting		Shaking sieve		Rotary sieve		before sorting		Shaking sieve		Rotary sieve	
	P	A	P	A	P	A	P	A	P	A	P	A
Resident species												
Eelpout *Zoarces viviparus* (L.)	+	2	+++	3	++	2	+	2	++	1	++	2
Gunell *Pholis gunellus* (L.)	+	2	+	5	++	4	+	2	+	4	+	2
Sculpin *Myoxocephalus scorpius* (L.)	+	3	---		---		---	--	---		---	
Sea snail *Liparis* spp.	---		---		---		+	++	---		++	1
Hooknose *Agonus cataphractus* L.	+++	15	++	26	++	12	+++	8	+++	9	+++	8
Shore crab *Carcinus maenas* (L.)	+	2	+	3	---		+	6	---		---	
Near-resident species												
Goby *Pomatoschistus* spp.	++	7	++	11	+++	12	+++	4	+++	3	+++	5
Pipefish *Syngnathus* spp.	+	4	+	1	+	2	+++	9	++	4	+++	2
Flounder *Platichthys flesus* (L.)	+	2	---		---		---		---		---	
Five-bearded Rockling *Ciliata mustelata* (L.)	+	2	+	1	+	1	+	1	---		++	1
Species using the Wadden Sea as a nursery												
Plaice *Pleuronectes platessa* (L.)	+++	17	++	3	---		+++	148	+++	97	+	2
Sole *Solea solea* (L.)	+++	4	+++	4	++	3	+++	37	+++	30	+++	7
Herring *Clupea harengus* L.	+++	4	+++	7	+++	6	+++	11	+++	25	++	13
Sprat *Sprattus sprattus* (L.)	+++	20	+++	30	++	14	+++	10	+++	9	+	1
Clupeidae	+	19	+	2	+	10	---		---		---	
Species visiting the Wadden Sea as adults												
Smelt *Osmerus eperlanus* L.	+	3	+	4	+	2	+++	14	+++	19	+++	4
Stickleback *Gasterosteus aculeatus* L.	---		---		+	1	---		---		---	
Species that are not dependent on the Wadden Sea												
Dab *Limanda limanda* (L.)	+++	43	+++	17	+++	7	+++	67	+++	68	+++	4
Lemon sole *Microstomus kitt* (Walb.)	+	4	+	1	---		---		---		---	
Solenette *Buglossidium luteum* (Risso)	+	1	---		---		---		---		---	
Witch *Glyptocephalus cynoglossus* (L.)	+	1	---		---		---		---		---	
Whiting	+++	11	+++	6	+++	8	+++	31	+++	52	+++	66

Table 2.1. Presence (P) and mean abundance (A) of species in sub-samples from the by-catch ---- not in any sub-samples; + in up to 1/3 of the samples; ++ in 1/3 to 2/3 of the sub-samples; +++ in more than 2/3 of the sub-samples; A= arithmetic mean (Source Berghahn et al., 1992)

The four most significant flatfish by-catch species for the German fleet (in both occurrence and numbers), according to Berghahn and Purps (1997) are Plaice (*Pleuronectes platessa*), Dab (*Limanada limanada*), (Flounder) (*Platichthys flesus*), Common Sole (*Solea solea*). Another 5 flatfish species encountered occasionally and in lower numbers; Turbot (*scophthalmus maximus*), Turbot (*scopthalmus rhombus*), Solenette (*Buglossidium luteum*), Lemon Sole (*Microstomus kitt*) and Witch (*Glyptocephalus cynoglossus*). Most of these species have been sampled in the RESCUE programme.

Walter and Becker (1997) sampled catches in Lower Saxony (Germany) in the main shrimp season in 1993. They recorded 37 fish and 28 invertebrate species (or higher taxa). The largest portion consisted of *C. crangon* of which only a small portion was of a marketable size. In total approximately 11% of the catch consisted of marketable shrimp (ca > 45mm body length), the remainder was discarded. The discards contained 64% undersized shrimps (<45mm body length), other invertebrates (8%) and fish (11%). In August large catches of jellyfish and quantities of Bryozoa (Electra pilosa) were encountered. Walter and Becker (1997) quantified the total catches of the Lower Saxony fleet between April-November to consist for 4,300 t of marketable shrimp, 4,000 t of fish, 27, 6000 t of undersized *C. crangon*, and 2,100 t of other invertebrates. The fish fraction contained primarily juveniles, which reflects the nursery function of the Wadden Sea. Flat fish such as plaice (Pleuonectes platessa), Flounder (Platichthys flesus), Dab (Limnada Limnada), Clupeid and Dadoid round-fish, and invertebrates (besides *C. crangon*) such as Shore crabs (Carcinus maenas) and Swimming crab (Liocarcinus holsatus) were the most common. A 14% of the samples was taken using selective trawls. Selective trawls are used 30 to 35% of the time in Lower Saxony, so the by-catch fractions may have been overestimated (using selective devices in 30% of the samples would have reduced discards by 10%).

By-catches and discarding of C. *crangon* (RESCUE)

During RESCUE discarding of the target species were sampled [See appendix 7]. For the German fleet total numbers of annual caught C c*rangon* (1996-1997) was 155,693 x 10^6 of which 27,278 x10^6 was landed and 128,415x10^6 were discarded (82% of total *C. crangon* catch). Undersized shrimp were most abundant in catches in the third quarter, followed by the fourth quarter. The discard fraction per 10,000 m^2 was highest in the 1st quarter (87%). This could be explained by the migration patterns of the different age classes in the shrimp population; with the larger individuals moving out of the Wadden Sea (German fishing grounds) into deeper off-shore waters. However, this is a speculation and cannot be derived from the data as no spatial catch data is given.

By-catches and discarding of non-target RESCUE species

10 of the 12 RESCUE by-catch species were encountered in the catches at various times of the year [See appendix 7. Only Bib and Poor-Cod remained absent from the catches. A remarkable presence of Dab (83,148,000) and Cod (17,322,000) was observed in the annual total catches of the German fleet. For Dab this by-catch consisted for 86% of 0-group Dab, which first occur in catches in the 3rd quarter onto the 4th quarter. During these quarters they occur in vast numbers in catches. On becoming 1-group Dab, their numbers in catches fall drastically. A 96% of the annually caught Cod belongs to the 0-group. The 0-group Cod is first encountered in the catches in the 3rd quarter after which its presence declines, and after becoming 1-group Cod disappears almost completely from the catches in the 2nd quarter. A phenomenal annual by-catch of Plaice (724,734,000) is observed. 98% of these are 0-group Plaice, which first become evident in the catches in the 2n quarter. Until the fourth quarter their presence increases, almost tripling the numbers per 10^4 m^2 swept area of the 2nd quarter. On becoming 1-group plaice their numbers decline, although in the 1st quarter the numbers are still high. However, German effort is low in the first three months of the year. This could explain the relatively low contribution of the 1-group in the annual fleet total. Whiting, Solenette and Flounder were mildly significant species in the by-catch, with total annual numbers for the German fleet; 9,808; 8.691; and 4296 respectively. Age groups were not distinguished for flounder. For Solenette, the 0-group was highly abundant, especially in the 3rd quarter. The 0-group represents 64% of the total annual Whiting catch, with another 35% coming from the 1-group. Both age groups proliferate in the 3rd quarter, although the 1-group is present in similar numbers in the 2nd quarter.

2.3.2 By-catches and discarding in Danish fisheries

Only the RESCIUE by-catch sampling programme can give us insight into by-catching and discarding in the Danish C. *crangon* fishery and waters.

By-catches and discarding of C. *crangon* (RESCUE)

During the study year, total annual *C. crangon* catches were estimated to amount to 4,804 x 10^6. A 71% of this is by-catch of undersized shrimp [See appendix 8] . By-catches of undersized shrimp range between the 60-70% throughout the year, peaking in Q1. Landed catches of shrimp peak in Q3 and remain high during Q4. This trend seems to be at odds with the earlier mentioned findings of the ICES working group on *C. crangon* , who argue that shrimp densities are especially high in spring months in the Danish waters.

By-catches and discarding of non-target RESCUE species

Bib and Poor cod remained absent from the catches throughout the year [See appendix 8]. Presence of Gurnards, Brill, Turbot, Flounder and Solenette was low in the Danish catches with numbers encountered per 10,000m^2 not coming above the 0.81. Solenette was present in catches through all quarters, whilst Gurnards and Turbot only showed up in the Q2 and Q3. Brill and Flounder only occurred during one quarter: in Q3 and Q2 respectively.

Cod and Whiting occurred in higher numbers in catches with annual totals amounting up to 3,037,000 and 1,118,000 respectively. For Cod this consisted mainly of 0-group Cod, which first shows up in the catches in peak quantities during the third quarter after which it declines slightly into Q4. The 1-group Cod occurs in catches in Q1 and Q2, after which it disappears entirely from the catch. Whiting is prolific in Q3 during which the 0-group catches peak after its first appearance in the Q2 catches. The 0-group Whiting almost entirely disappears after Q3. High numbers of 1-group Whiting occur in the catches of Q3 and occur slightly less in Q1.

Significant annual by-catches of Plaice (33,706,000) and Dab (52,440,000) are made by the Danish fleet. Plaice was represented entirely by the 1-group, which proliferated throughout the year, peaking in Q3. 1-group Plaice also occurred in high numbers in the first quarter. 0-group Dab is encountered for the fist time in Q2, remaining present in catches for the rest of the year and peaking in Q4 when Danish effort is low. As this 0-group grows into the next age group, they seem to become more vulnerable to the gear, 1group Dab occurring in astronomical numbers in the catches of Q1. 1-goup Dab disappears entirely from the catches thereafter, suggesting a migration to deeper waters.

2.3.3 By-catches and discarding in Belgian fisheries

Only the RESCUE by-catch sampling programme can give us insight into by-catching and discarding in Belgian C. crangon fishery and waters.

By-catches and discarding of C. crangon (RESCUE)

In winter time *Crangon* densities are very low, as are catches and discards. The discard ratio, however, was at a maximum (67%) [See appendix 9] . In spring discards and catches gradually rose and reached a maximum in Q3. In autumn, catches and densities dropped to almost half of the maximum. Total annual shrimp discards at fleet level, contained more than double the amount of shrimps compared to shrimps landed.

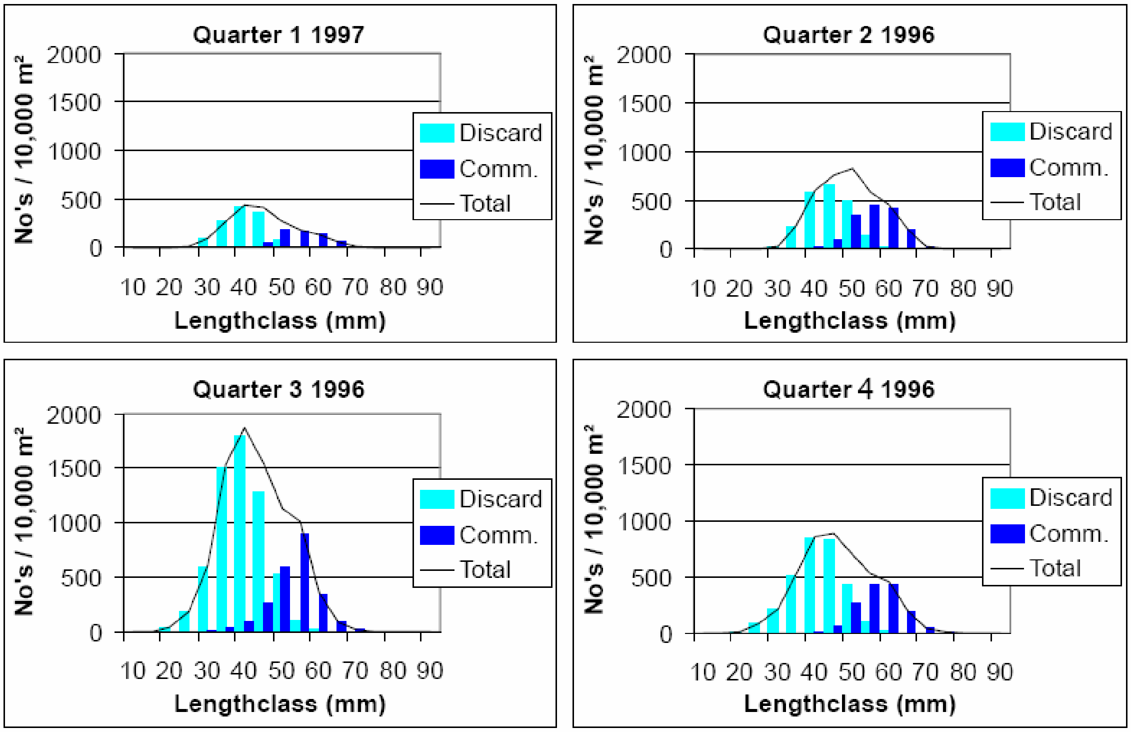

Fig 2.7. C. crangon discarded and landed in Belgian waters per quarter (Source: Polet, H. 2003, data RESCUE)

By-catches and discarding of non-target RESCUE species

In the sampling program all RESCUE by-catch species were encountered except for Brill [See appendix 9]. Turbot and Gurnards were rarely observed in catches. Cod and Flounder occurred in low numbers, with 551 and 268 individuals caught annually over the whole Belgian fleet. For Cod, contributions came from the 1-group (Q4 and Q1), as well as the 2+ group (Q1).

Whiting, Dab and Bib were the most prominent by-catch species in the Belgian shrimp fishery. The annual catches of Whiting (10,239,000) primarily consisted of 0-group Whiting (8,132,000) and to a lesser extent the 1-group (1,929). The 0-group Whiting appeared in the catches in Q3 in significant numbers, declining into Q4. The 1-group Whiting is especially prolific in the Q2, when other age classes are on a low. In Q2, mainly Age-1 fish were caught, and in Q3 and Q4 Age-1 fish catches dropped to a low level. The discard rates for Whiting were highest in Q2, Q3 and Q4, and were almost zero in Q1. Dab was discarded all year round. Contributions come from all age groups, with the 0-group first appearing in the Q3 and becoming highly prolific in the Q4. As the Dab grow into the 1-group, they become increasingly available to capture (Polet, 2003) and occur in especially high numbers in the Q4. Quantities of group-1 Dab steadily decreased through Q3 and 4, as they moved to deeper waters (polet, 2003). The 2+ group occur in high numbers in the Q2, in contrast to very low numbers of the2+ group being caught in the Q3 and Q4. Bib had a pronounced seasonal distribution, with nearly nil abundance in Q1, maximum abundance in Q3, and intermediate abundance in Q2 and Q4.

Plaice, Sole, Cod and Flounder held an intermediate position with regard to occurrence in by-catch. Plaice of group-0 was first seen in the catches in Q3 and the numbers caught, gradually increased through Q4. In Q1. When these fish had grown to Age 1, they still appeared in the catches, but in somewhat lower numbers. Although Plaice was discarded all year through, the catches showed a clear minimum in Q2. Group-0 Sole first turned up in the catches in Q3 and their numbers gradually decreased into Q4. As these fish grew to group-1, they kept on being caught through Q1, Q2 and Q3. In Q4, Group-1 fish were almost absent from the catches. Sole was discarded all year through with a clear peak in Q3. The by-catch of Cod was highest in Q1 (group 2+), at a lower level in Q4 and dropped to almost zero in Q2 and Q 3. Because *crangon* directed fishing effort is low in the first quarter, when the 2+ group proliferates, contributions of this by-catch to the annual fleet level totals will be relatively mild. No 0-group Cod is caught. Also for Flounder the highest catches were observed in Q1. Adult Flounder were caught over all quarters. Dab, Flounder and Whiting of marketable size are regularly caught in the Belgian shrimp fishery and represent a significant part of the landings. Marketable Plaice, Sole and Cod are caught as well, although the numbers are relatively small.

RESCUE catch fractions

The average catch fractions exhibited in the Belgian fleet, over all 108 hauls done during the VAN MARLEN ET AL. 1998 study, with a 95% confidence interval, expressed as percentage of numbers of fish caught, were as follows: 45.1% main by-catch (42. 3% - 47.8%); 26.3% discard shrimp (24.1% - 28.5%); 28.7 % Commercial shrimp (26.3% - 31%). The mean discard ratio was 71.3% (68.9 % -73.7%), the minimum discard rate 37.1% and the maximum 99% (Polet, H. 2003).

2.3.4 By-catches and discarding in UK fisheries

The RESCUE by-catch sampling programme has been the most thorough attempt to asses by-catching and discarding in the UK C. *crangon* fishery and waters. Research into gear selectivity by Tom Catchpole (still under way, 2006) has delivered a very complete list of by-catches species (fish as well as crustaceans) in The Wash C.*crangon* fishery, which can be viewed below.

3 beard Rockling	*Gaidropsarus vularis*	Poor cod	*Trisopterus minutus*
Bass	*Dicentrarchus labrax*	Sand sole	*Pegusa lascaris*
Brill	*Scothalmus rhombus*	Sandeel	*Ammodytes tobianus*
Brittle star	*Ophiuroidea*	Sea scorpion	*Tarulus spp*
Cod	*Gadus morhua*	Sea snail	*Liparis liparis*
Dab	*Limanda limanda*	Sepiola	*Sepiola sepiola*
Dragonet	*Callionymus lyra*	Shore/green crab	*Carcinus maenas*
Esmarks eel pout	*Lycodes esmarkii*	Smelt	*Osmerus eperlanus*
Flounder	*Platichthys flesus*	Spider crab	*Macropodia spp*
Goby	*Gobius spp*	Sprat	*Sprattus sprattus*
Hermit crab	*Pagurus bernhardus*	Squid	*Loligo spp*
Herring	*Clupea harengus*	Starfish	*Asterias rubens*
Lemon sole	*Microstomus kitt*	Swimming crab	*Liocarcinus depurator*
Long rough dab	*Hippoglossoides platessoides*	Thornback ray	*Raja clavata*
Pipefish	*Syngnathus spp*	Urchin	*?*
Plaice	*Pleuronectes platessa*	Weaverfish	*Echiichthys vipera*
Pogge	*Agonus cataphractus*	Whiting	*Merlangius merlangus*
Pollock	*Pollachius pollachius*		

By-catches and discarding of C. crangon (RESCUE)

During the sampling year 2,673 x 10^6 *C. crangon* were estimated to be caught at fleet level [See appendix 10]. A 49% of this was discarded with highest ratios of shrimp, this discarding occurring in the third quarter (54%).

High densities of *C. crangon* occur in the Wash in Q3 through to Q4, with similar high landings and discards being observed. Densities are low for the winter and spring months with similar low levels of *C. crangon* in the catches and by-catches.

By-catches and discarding of non-target RESCUE species

Bib, Poor cod, Gurnards, Brill and Turbot remained absent in the Wash catch sampling programme throughout the year [See appendix 10] .

Catches of Dab, Cod, Solenette and Flounder were intermediate with total annual numbers for the Danish fleet of 5,465,000; 4,552,000; 1,386,000 and 1,040,000 respectively. Dab is highly represented by the 1-group. The 0-group grows into the fishery on becoming 1-group Dab and become increasingly prolific in catches, reaching a peak in Q2 and declining from there on and disappearing in the fourth quarter when UK shrimp directed effort is at its maximum. Cod is entirely absent from the catches in Q2. The 0-group first shows up in the third quarter increasing in presence in the Q4. In Q1, 1-group Cod is encountered. Solenette is represented by all age groups, especially the 0-group, which first shows up in catches in the Q3 and increases in the catches of Q4. The 1-group Solenette catches are low in Q1 and Q2, higher in Q3 and decline again in Q4. Flounder catches are low, almost absent for the first two quarters. The annual Flounder catches mainly consist of 1-group and 2-group Flounder, which show up in the Q3 and Q4 catches. The 0-group Flounder almost remains absent from catches.

Plaice and Whiting are the two most significant of the by-catch species in UK fisheries with total annual numbers of 9,920,000 and 12,874,000 respectively. For both species, catches especially concern the 0-group and 1-group. The 0-group Plaice shows up in the by-catches in Q3 in relatively large numbers, remaining highly present in Q4. 1-group Plaice is remains present throughout the year with especially high numbers in Q1 and Q2. It would seem plausible, that due to the lower effort levels in the first two quarters of the year, that the 1-group fails to make a similar contribution to the annual catch totals when compared to the 0-group, despite its high presence per 10,000m^2 throughout the year. Whiting is prolific in the catches of Q3 and Q4, and for the 1-goup in Q1 as well. The 0-group comes into the by-catch in Q3 and attains remarkable high numbers in catches of the fourth quarter. On becoming 1-group Whiting, numbers remain high in catches falling to a low in Q3. The. 1-group Whiting show up again in the Q3 and Q4.

2.3.5 Quantification of total by-catches and discarding in North Sea C. crangon fleet

Quantification of by-catches in the North Sea C*. crangon* fishery is based on the results of the RESCUE study. Only the by-catches of the twelve by-catch fish species are quantified and they are dealt with individually in this paragraph in descending order of significance. This also allows us to determine which fleets (roughly corresponding to national waters) are contributing in which seasons to the by-catches.

Plaice – Pleuronectes platessa

Plaice has the highest annual discard rate in North Sea *C. crangon* fisheries and is encountered throughout the year in all waters. The 0-year Plaice is first observed in catches in Q2 along the German coast and in Q3 over all other areas, except Denmark, where 0-group Plaice remains absent on shrimp grounds. From then on densities of 0-group Plaice gradually increase in Q4, after which they become 1-group Plaice. Overall densities of 0-group plaice were 50 times higher in German coastal waters then on the estuarine shrimp grounds of English east coast, and 200 times higher than on the Belgian offshore shrimp grounds. This confirms that the Wadden Sea is an important nursery for 0-year plaice (RESCUE). The 0-group Plaice has an estuarine distribution from Esjberg to Belgium, and is most abundant in the German Bight and the Wadden Sea. The major part of the 0-goup Plaice is said to be geographically located in the shallow areas (<10m) of the German and Dutch Wadden Sea, where they abound between June and December (ECODISC). Densities of 1-group Plaice peak in Q3 on Danish the Danish coast and in Q2 on the English coast and gradually tail-off from there on, as they move into deeper waters further offshore as they grow. This also explains why, apart from Belgian waters, no evidence of 2+-group plaice is observed on the shrimp grounds.

	DENMARK			GERMANY			BELGIUM			UK		
Age-class	**0**	**1**	**2**	**0**	**1**	**2**	**0**	**1**	**2**	**0**	**1**	**2**
Q1	0	88.2	0	0	**225.89**	0	0	9.8	0.96	0	21.37	0.04
Q2	0	15.53	0	564.6	20.2	0.1	0	1.88	0.7	0	24.26	0
Q3	0	**151.72**	0	**1188.08**	1.54	0	6.78	2.91	0.1	18.32	12.84	0.29
Q4	0	44.07	0	**1607.39**	0.77	0	8.27	0.53	0.07	29.36	7.18	0.03

Table. 2.2. numbers of Plaice caught per swept area (10,000m^2) (data source: RESCUE)

Country	*Discarded*	*Landed*	*Totals*
Dk	33.706.000	0	33.706.000
D	724.734.000	0	724.734.000
NL-north	151.478.000	0	151.478.000
NL-south	6.025.000	132.000	6.157.000
B	2.228.000	43.000	2.271.000
UK	9.920.000	0	9.920.000
Totals	928.091.000	175.000	**928.266.000**

Table 2.3. Tot. no. caught annually (1996/97) (source: RESCUE)

Dab - Limanda limanda

Dab has a high annual by-catch rate in North Sea *C. crangon* fisheries. High densities of Dab are encountered on all shrimp grounds. 0-group Dab first appears in catches in Q3, except in Denmark where they appear in Q2, upon appearance, numbers show a considerable increase into subsequent quarter(s). On becoming 1-group Dab, they become increasingly sensitive to capture, up to Q2. There after, numbers of 1-group Dab steadily decrease through Q3 and Q4, as they move into deeper waters. Dab of the 2+ -group is encountered in Belgian catches, particularly in Q2, and to a much lesser extent on German and English East coast. In the Danish catches, the 2+ Dab group is absent. Bolle et al.,(1994) found settlement of Dab in both offshore and coastal areas of the southern North Sea. Highest densities of 0-group Dab were recorded in the coastal zone. Nevertheless the authors did not think that the coastal zone was necessarily the most important nursery area for Dab, since it only covers a small part of the North Sea. The overlap of the 0-group with shrimp grounds is much less pronounced for Dab than for Plaice.

	DENMARK			**GERMANY**			**BELGIUM**			**UK**		
Age-class	**0**	**1**	**2**	**0**	**1**	**2**	**0**	**1**	**2**	**0**	**1**	**2**
Q1	0	**408.57**	0	0	41.12	6.22	0	6,66	6,67	0	20.35	2.86
Q2	94.52	0	0	0	23.97	0.27	0	15.31	21.23	0	38.61	3.79
Q3	15.24	0	0	**144.44**	12.57	0	3.33	6.06	0.14	1	16.89	0.31
Q4	**203.52**	0	0	**222.81**	0	0	12.82	2.67	1.02	4.6	1.61	0.56

Table. 2.4 numbers of Dab caught per swept area (10,000m^2) (data source: RESCUE)

Country	*discarded*	*landed*	*Total*
Dk	52,440,000	0	52,440,000
D	83,148,000	0	83,148,000
NL-north	288,180,000	0	288,180,000
NL-south	13,570,000	2,033,000	15,603,000
B	4,489,000	572,000	5,061,000
UK	5,462,000	0	5,462,000
Total	447,289,000	2,605,000	**449,894,000**

Table 2.5 Tot. no. caught annually (1996/97) (source: RESCUE)

Whiting – Merlangius merlangus

Whiting is encountered in the by-catch throughout the year and along the entire coastline. The 0-group Whiting appears in catches in Q2 in German and Danish waters and in the Q3 in UK and Belgian waters. In Danish, German and Belgian waters, peak catches of Whiting occur in the third quarter, whilst in the UK waters this peak occurs in the fourth quarter. In Q1 catches in Danish, German and Belgian waters, all ages drop to a much lower or even to zero level. In Belgian waters significant densities of one-year Whiting are encountered, this quarter corresponds to relatively low Belgian fishing effort. It would be reasonable to assume that the largest part of the Whiting by-catch of Belgian fisheries consists of the 0-group, this would also apply to NL south and German fisheries.

	DENMARK			GERMANY			BELGIUM			UK		
age-class	**0**	**1**	**2**	**0**	**1**	**2**	**0**		**2**	**0**	**1**	**2**
Q1	0	1.23	0	0	1.38	0.15	0.15	0.19	0.02	0	28.47	0.12
Q2	1.21	0	0	2.13	5.69	0.21	1.84	22.53	2.07	0	5.18	0.04
Q3	3.99	2.17	0	22.76	7.12	0.05	54.98	1.09	0.17	19.56	14.88	0.25
Q4	0.14	0	0	0.73	0.22	0	22.42	4.77	0.38	51.2	8.25	0.47

Table 2.6. Numbers of Whiting caught per swept area (10,000m^2) (data source: RESCUE)

country	***discarded***	***landed***	total
Dk	1,118,000	0	1,118,000
D	9,808,000	0	9,808,000
NL-north	5,011,000	0	5,011,000
NL-south	17,333,000	2,432,000	19,765,000
B	9,189,000	1,050,000	10,239,000
UK	12,874,000	0	12,874,000
Total	55,333,000	3,482,000	**58,815,000**

Table 2.7 Tot. no. caught annually (1996/97) (source: RESCUE)

Cod – Gadus *morhua*

Cod is a round fish. Juvenile Cod is especially encountered in Danish, German, northern Dutch and UK waters. The juveniles (especially 0-year) arrive in the Q3 and stay till Q1, after which they decline. In Belgium coastal waters juvenile cod of 1-year were seen in observable numbers in Q4 and Q1 only. There seems to be an over-all in-year north-south migration, with decreasing numbers from the first quarter onwards in the northern areas (German and Danish coast) and increasing numbers in southern areas (Belgian coast). As Cod reach legal landing-seize, they may be landed.

	DENMARK			GERMANY			BELGIUM			UK		
Age-class	**0**	**1**	**2**	**0**	**1**	**2**	**0**	**1**	**2**	**0**	**1**	**2**
Q1	0	1.86	0	0	16	0.83	0	3.81	5.95	0	9.44	0
Q2	0	0.02	0	0.19	0.02	0	0	0	0.02	0	0	0
Q3	11.76	0	0	53.44	0.06	0	0	0.12	0.02	8.82	2.5	0
Q4	9.02	0	0	21.09	0.55	0	0	2.83	0.65	17.9	4.63	0.02

Table 2.8. Numbers of Cod caught per swept area (10,000m^2) (data source: RESCUE)

country	***discarded***	***landed***	Total
Dk	3,037,000	0	3,037,000
D	17,322,000	0	17,322,000
NL-north	14,151,000	0	14,151,000
NL-south	2,731,000	140,000	2,871,000
B	484,000	67,000	551,000
UK	4,552,000	0	4,552,000
Total	42,277,000	207,000	**42,484,000**

Table 2.9.Tot. no. caught annually (1996/97) (source: RESCUE)

Sole – *Solea solea*

Sole has an intermediate position in by-catches of North Sea *C. crangon* fleet. The 0-group Sole is first observed in significant numbers in catches in Q3, with the largest 0-group Sole catches in German waters, followed by Belgium, whereupon densities gradually decrease into Q1 of the following year. From Esjberg to Belgium, 0-group Plaice and Sole are most abundant in the German Bight and the Wadden Sea. After

Q3, Sole disappears from the catch almost entirely. Limited densities of 2+ Sole are encountered in Belgian, UK and German waters in particularly Q2 and Q3, which correspond roughly with the main spawning season of Sole in the southern North Sea. According to the low penetration of bottom by the gear, the shrimp trawl has a low catching efficiency for Sole (Berghahn and Purps 1998).

	DENMARK			GERMANY			BELGIUM			UK		
age-class	**0**	**1**	**2**	**0**	**1**	**2**	**0**	**1**	**2**	**0**	**1**	**2**
Q1	0	0.81	0	0	6.79	0.19	0	2,79	0,01	0	0.04	0
Q2	0.05	0	0	0.07	0.46	0.33	0.01	3.48	1.14	0	0.04	0
Q3	0.25	0	0	28.9	0.29	0	4.98	3.24	0.51	0.43	4.13	0.43
Q4	0	0.3	0	6.34	0	0	3.73	0.1	0.03	5.72	0.34	0.02

Table 2.10. Numbers of Sole caught per swept area (10,000m^2) (data source: RESCUE)

country	*discarded*	*landed*	*Total*
Dk	111,000	0	111,000
D	8,691,000	0	8,691,000
NL-north	554,000	0	554,000
NL-south	3,455,000	257,000	3,712,000
B	1,519,000	100,000	1,619,000
UK	1,386,000	0	1,386,000
Total	15,716,000	357,000	**16,073,000**

Table. 2.11 Tot. no. caught annually (1996/97) (source: RESCUE)

Bib and Poor cod - Trisopterus luscus/minutus

Bib and Poor-Cod is a noteworthy by-catch in Belgium and in the South of the Netherlands. It has a pronounced spatial and seasonal distribution. Densities are nil in Q1 (winter), maximum densities in the Q3 (summer) and moderate densities in Q2 (spring) and Q3 (autumn). Bib and Poor cod prefer open waters.

	DENMARK	GERMANY	BELGIUM	UK
Q1	0	0	0.21	0
Q2	0	0	11.72	0
Q3	0	0	32.78	0
Q4	0	0	9.67	0

Table 2.12 Numbers of Bib and Dab caught per swept area (10,000m^2) (data source: RESCUE)

Country	*discarded*	*landed*	*total*
Dk	0	0	0
D	0	0	0
NL-north	0	0	0
NL-south	9,475,00	36,000	9,511,000
B	5,080,00	10,000	5,090,000
UK	0 0	0	0
Total	1,455,500	46,000	**14,601,000**

Table 2.13. Tot. no. caught annually (1996/97) (source: RESCUE)

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Gurnards – *Trigla* spp.

Comparatively Gurnards discards are low. Similar to Bib and Poor cod, sensible numbers are recorded in Belgian waters especially in Q2 and in German waters in Q2 and Q3. Gurnards are typical spring species with main occurrence limited to Q2 (VAN MARLEN ET AL. 1998 1996). The relatively high total by-catches (when compared to relative numbers per swept area) of Denmark when compared to Belgium, could be explained by the typical effort distributions and levels of the two countries. Belgium has a relatively low overall effort and major contributions coming from the autumn fishery when Gurnards are absent, and Denmark has a relatively high overall effort level with more contributions coming from the spring season, when gurnards are more plentiful.

	DENMARK	GERMANY	BELGIUM	UK
Q1	0	0	0	0
Q2	0.01	0.32	0.53	0
Q3	0.10	0.39	0	0
Q4	0	0	0.01	0

Table. 2.14. Numbers of Gurnards caught per swept area (10,000m^2) (data source: RESCUE)

country	*discarded*	*landed*	*total*
Dk	17,000	0	17,000
D	184,000	0	184,000
NL-north	74,000	0	74,000
NL-south	119,000	1,000	120,000
B	33,000	0	33,000
UK	0	0	0
Total	427,000	1,000	**428,000**

Table. 2.15. Tot. no. caught annually (1996/97) (source: RESCUE)

Flounder – Platichtys flesus

Flounder is a flatfish species and has an estuarine distribution. About a 1/3 of 0-group and 1-group Flounder population inhabit the rivers, with the 0-group showing a preference for oligophaline and limnetic habitats (Kerstan, 1991). Here, they are out of reach of the shrimp trawlers. If present at all on shrimp grounds, juvenile Flounder will appear in catches in Q4 and Q1. The densities are considerably higher in shallow shrimp grounds of German Wadden Sea and The Wash- and The Humber estuaries. Interestingly, more abundant in the catches of the Belgian fleet, was adult Flounder (RESCUE).

	DENMARK	GERMANY	BELGIUM	UK		
age-class				**0**	**1**	**2**
Q1	0	10.41	4.42	0	0	0.15
Q2	0.63	6.56	0.56	0	0	0.15
Q3	0	1.12	1.04	0.03	3.28	2.23
Q4	0	10.98	0.47	0.08	2.39	1.37

Table 2.16. Numbers of Flounder caught per swept area (10,000m^2) (data source: RESCUE)

country	*discarded*	*landed*	total
Dk	55,000	0	55,000
D	4,297,000	0	4,297,000
NL-north	366,000	0	366,000
NL-south	1,092,000	273,000	1,365,000
B	173,000	95,000	268,000
UK	1,040,000	0	1,040,000
Total	7,023,000	368,000	**7,391,000**

Table 2.17. Tot. no. caught annually (1996/97) (source: RESCUE)

Turbot – Psetta maxima

Total annual discards of Turbot are low. Main occurrence is in Q3 and is basically absent in all waters during Q1 and Q4.

	DENMARK	GERMANY	BELGIUM	UK
Q1	0	0	0.02	0
Q2	0.10	0.16	0	0
Q3	0.62	0.23	0	0
Q4	0	0	0	0

Table 2.18. Numbers of Turbot caught per swept area (10,000m^2) (data source: RESCUE)

country	*discarded*	*landed*	total
Dk	104,000	0	104,000
D	100,000	0	100,000
NL-north	457,000	0	457,000
NL-south	4,000	0	4,000
B	1,000	0	1,000
UK	0	0	0
Total	666,000	0	**666,000**

Table 2.19. Tot. no. caught annually (1996/97) (source: RESCUE)

Brill – Scophthalmus rhombus

Annual discards are low for Brill. Brill shows a strong northerly distribution. Brill abounds in Q3 in Denmark, for Germany, although in lower numbers, in the Q4 and Q1. Germany has a virtually 0 effort level in the winter months of December, January and February, therefore total national by-catches of Brill will remain limited.

	DENMARK	GERMANY	BELGIUM	UK
Q1	0	0.09	0	0
Q2	0	0	0	0
Q3	0.67	0	0	0
Q4	0	0.18	0	0

Table 2.20. Numbers of Brill caught per swept area (10,000m^2) (data source: RESCUE)

country	*discarded*	*landed*	total
Dk	103,000	0	103,000
D	33,000	0	33,000
NL-north	430,000	0	430,000
NL-south	0	0	0
B	0	0	0
UK	0	0	0
Total	566,000	0	**566,000**

Table 2.21. Tot. no. caught annually (1996/97) (source: RESCUE)

2.3.6 Main observations with respect to by-catches and discarding in C. *crangon* fisheries

The by-catch sampling programmes that have been conducted, have given us a feel of the composition of by-catches in this fishery. Quantification of by-catches has been limited to the commercial North Sea species and the target species itself. These represent an important part of the fish by-catches (at least in German waters). The by-catch of non-commercial fish species and invertebrates has not received a lot of attention.

Large quantities of undersized C. *crangon* and juvenile fish are caught in this fishery. The latter especially applies to those segments of the fleet (German fleet) that operate the estuarine areas, especially in the spring and summer seasons. This reflects the nursery function of the coastal shallows and estuaries.

Selectivity studies and the by-catch sampling programme in the Danish fleet have shown that sieve nets help to reduce by-catches of the larger fish specimens. Thus for those fleet segments operating in deeper waters, where relatively less smaller by-catch occur, sieve nets can contribute to reducing by-catches. Moreover, the by-catches of invertebrate species will be reduced. The smaller by-catch remains a ‘problem’ to this fishery, even with full employment of sieve nets.

The RESCUE study, although giving reasonable estimates of by-catch quantities of the major commercial fish species, is not very instructive when it comes to fisheries intervention. RESCUE data suffices as input data for impact assessment so as to determine what these absolute by-catch numbers mean on a population level, and where intervention is warranted. But it does not tell us exactly where and when needs to be intervened if by-catches are to be effectively reduced. Moreover, management options such as displacement of effort, closed seasons, or gear improvements, can on basis of such data not be properly evaluated. These short-comings are simply result of the fact that the data lacks spatial specificity.

2.4 Assessment and quantification of discard mortality

Discarding would not form such a problem if it could be decently returned to the waters in perfect condition. Throughout the catching, sorting and discarding procedures, direct and indirect discard mortality is induced.

During the capture, fish may suffer injuries through net contact, compression, or the crushing or abrasive action of other species or objects in the cod-end, and to the pressure difference experienced in hauling (Lancaster, 1999). The severity of damage inflicted during capture will depend on the net design and materials, the duration of the haul and the towing speed (Lancaster, 1999).

Once on board, prolonged exposure to air, high temperatures and direct sunlight may lead to lethal levels of stress and desiccation. The length and extent of exposure will depend on the speed at which the catch can be handled, which will vary in accordance to catch size and to on board sorting equipment and procedures. Returning discards to the sea via a continuous flow system opposed to collecting discards in baskets prior to being discarded, will obviously limit exposure. Sorting is regarded as the main source of mortality, during which significant mechanical damage may be inflicted on fish. Methods and equipment used to sort catch will greatly determine the extent of damage.

Physical injuries may be recoverable, while others are fatal. Although physical injuries suffered during catching and handling may not lead to direct mortality, they may strongly affect the survival chance once back in the sea, by for instance the reduced ability to avoid predation or the reduced ability to compete for food. Furthermore, wounds may become infected, resulting in further reduced survivability and mortality.

The damaging effects of the catching and handling processes will vary per species and age class, with certain species and age-groups being more fragile, and thus more susceptible to the damaging potential of the gear and processes. Similarly, the survivability of fish suffering from exposure and physical injuries is observed to be highly dependent on the species and age and/or length-class (Berghahn et al., 1992; referred to by Lancaster. J).

Lastly, after being disposed of overboard, discards may suffer the effects of predation by both avian and marine predators, leading to further mortality rates.

2.7.1 Discard mortality of target species

The survivability of *C. crangon* is strongly influenced by environmental conditions as well as catching and sorting methods. High mortality is observed under discards of *C. crangon*. Several studies have been dedicated to understand and quantify discards mortality.

Gamito and Cabral (2003) studied the influence of temperature of the container where the organisms are stored and of sorting time and haul duration on discard mortality under *C. crangon* in the shrimp bean trawl fishery of the Tagus estuary in Spain. Their results indicate that mortality levels are higher with increasing temperatures of the sorting container (and corresponding higher air temperatures). This increase was, however, only observed for temperatures higher than 20 C, with a mean mortality rate of 75% in the interval of 20C to 30C, and 95% for temperatures between 40C and 50 C. According to Gamito and Cabral, this positive relationship between temperature and mortality is supported by other studies such as those by van Beek et al.,(1990) and Ross and Hokenson, (1997), despite the fact that van Beek only researched temperatures between the 8C and 18C in his study. The sorting time was not observed to influence mortality. This is in conflict with other research findings of notably van Beek et al. (1990) and Richards et al. (1995), who observed a positive relationship between discards mortality and sorting time. Richards et al. argue that the most important variable affecting discard mortality is deck time. This discrepancy in research findings is assumed be due to the differences in studied sorting times. Relatively short sorting times were studied by Gamito and Cabral (5 and 10 minutes) in contrast to other studies which experimented with much longer sorting times, observing correlations between mortality and sorting time, with sorting times above the 15 (Ross and Hokenson (1997))and 20 minutes (Richards et al. 1995). Similar to the studies of Beek et al.,(1990) and Ross and Hokenson (1997), haul duration was observed to affect mortality of discard shrimp significantly. This positive correlation was evident with each increasing haul length, mean mortality increasing from 7 to 75% when haul duration was extended from 10 to 30 minutes. This slightly contrasts the study results of Richards et. al that only exhibit this correlation when the haul duration exceeds the 2 hours.

In the study done by Revill (2000), an attempt is made to determine the survival rates of discarded *C. crangon* in UK *crangon* fisheries. Experiments were done to determine the effect of trawling, of exposure to air i.e. deck time and ambient temperatures on discard mortality, and the influence of the sorting process using either flatbed or a rotary riddle.

In his study, Revill (2000) found trawling to lead to a mean discard mortality of 10%. Despite a minor difference in induced mortality between the two sorting devices (with the rotary riddle leading to a 1% higher mortality than the flatbed riddle), the study results show that riddling, either by rotary riddle or flat bed riddle, had a negligible effect on the discard mortality of *C. crangon*. Lancaster (1999) came to similar conclusions in her study on *C. crangon* discard survival. She found no difference in survival rate between the rotary and flatbed riddle and observed that riddling induced mortality only by 4%. This indicates that mechanical damage inflicted upon the shrimp during riddling does not affect survival rates significantly. Although a larger incidence of Shell Disease amongst *C. crangon* as compared to other crustaceans in the trawled area was observed by Nottage (1982), Rosen (1970) argues, that mortality induced through bacterial infections of the wounds inflicted by the catching and sorting processes is not significant, as *C. crangon* tend to recover after moulting.

Revill (2000), also demonstrated the negative relationship between shrimp survival and duration of the exposure to air, sun, and the ambient temperature. The mortality increased with increasing temperatures and length of exposure. At higher temperatures, their tolerance to exposure reduces. With exposure time below 60 minutes, significant mortality was only observed at temperatures higher than 14C, with a 4% mortality after 30 minutes, and more than a 50% mortality after 75 minutes of exposure.

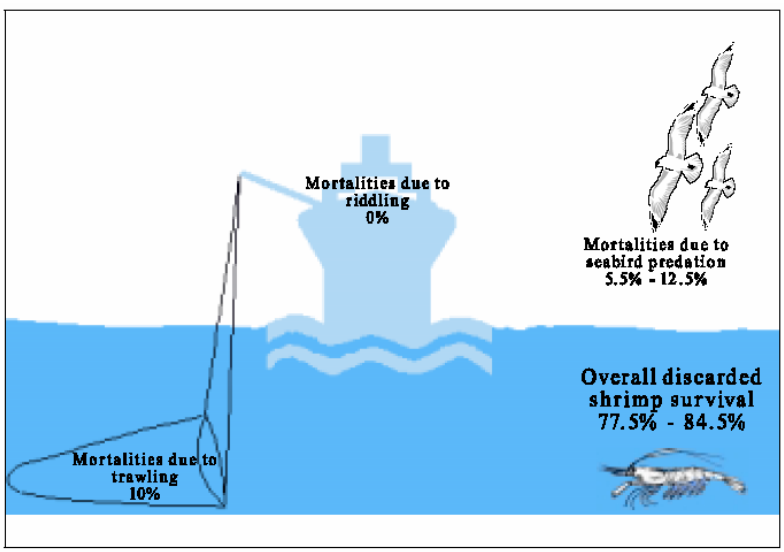


Fig. 2.8. discard mortality in C. crangon (source: Revill, 2000)

In his study Revill (2000) used the bird predation rates estimated by Walter and Becker (1997). He estimated mortality due to avian predation to be 6-14%. Using this rate, Revill (2000) estimated overall survival accounting for trawling, sorting processes and avian predation of *C. crangon* discards to range between the 70-85%, with the mean survival of 78%. This result is supported by the findings of Lancaster (1999), who estimated a 77-80% survival rate, and Mistakidis (1958), who estimated discard survival to be 75%. When using a predation rate of 5.5-12.5 %, estimated *Crangon* survival ranged between the 77.5-84.5% [see fig. 2.8.]. Exposure to air was not considered when estimating this overall mortality rate. Revill found that 57% of UK vessels operate continuous flow mechanisms to discard shrimp, opposed to 43% discarding manually. The former returns discard to sea almost immediately. Lengthy exposure of *C. crangon* is therefore only relevant for 43% of the vessels and observations showed that this delay is generally no more than one hour.

2.7.2 Discard mortality of non-target species

Several studies have been dedicated to understanding the cause and extent of discard mortality, and to quantify this for particular species. Mortality is highly species dependant, as the various studies have pointed out. Also size class is a strong determining factor. Species and size class will influence the sensitivity of the fish to stress and to deccidation suffered during onboard handling, but, also the extent and kind of injuries suffered from the catching, handling and riddling processes and their recovery potential. Finally, fish dependent variables such as size and body shape will influence the extent to which the specimens will be deselected during the sorting process.

Species dependant damages assessment

Berghahn et al. (1992) found that for gadoid fish, such as Cod, Bib and Whiting, as well as for Sprat and Herring, discard mortality is as high as 100%. These findings are supported by the work of Lancaster (1999), who observed discard mortality for Whiting. This high mortality is ascribed to the depressurization of the swim bladder. Flatfish do not have a swim-bladder, hence, as Lancaster points out, the effect of depressurization is much less.

Lancaster as well as Ludemann (1993) and Kelle (1976, 1977) made detailed observations of the injuries inflicted on discards during the trawling, sorting and handling processes. According to Lancaster, all three achieved similar findings. The kind and extent of injuries varied per species and size class. The most common injuries occurring in flatfish such as Dab and Plaice were: haemorrhages to the head, body and fins and, fissures between the fin rays and broken fin rays. Scale loss was very common in Dabs, but not in Plaice. It appears that large fish are more susceptible to fatal haemorrhages, with fatality increasing with higher temperature. Smaller fish are more susceptible to fin fissures. Moreover, as pointed out by Bereiter-Hahn 1986 (Lancaster, J. 1999), the protective layer of the skin may be destroyed.
Some of these injuries are recoverable, others are fatal. According to Lancaster, Kelle (1977) found haemorrhages in the brain to be fatal as well. External injuries do not necessarily lead to mortality; this depends on the severity and recoverability of the injuries. A 30% or more scale loss is considered to be fatal. Less than 30% of scale loss or of fin fissures was considered to have potential to recover (Kelle 1977). The protective layer on the skin may take several hours to several days to recover.

Trawling induced mortality

Discard mortality related to the trawling procedure is strongly related to the haul duration, catch composition and volume of the catch. This will influence the crushing, compressive and abrasive forces exerted in the trawl and consequently injuries suffered by the fish.

Kelle (1977) showed that Plaice could be prevented from breathing when compressed in the cod-end, leading to bleedings in the brain. This is argued to cause haemorrhages in the brain. Van Beek et al. (1990) (in Lancaster), attributed haemorrhages on the body observed in discards were due to the pressing and scraping of various objects in the cod-end. Other damages may occur in the form of scale loss or fin fissures.

In his study on discard mortality, Berghahn et al. showed that haul duration influenced discard mortality in Plaice, and that longer hauls of 15-30 minutes led to increased mortality. The hauls in commercial fisheries may range from 30 minutes, when shrimp abundance is high, to 180 min, when shrimp abundance is low (Berghahn et al. 1992), thus potentially effecting discard mortality. Other research results in the study by Berghahn et al 1992 indicate substantial mortality of particular discard species just after catching (with haul duration of 1 hour) and prior to sorting. The 4.5-9cm Plaice for instance, suffered a mean mortality of 70% after trawling. This fraction decreased with increasing size however. For Dab this average was 11.9 %, thus indicating an induced mortality through trawling. In support of this are the findings of Kaiser and Spencer (1995), who found mortality in Plaice and Dab to be 61% and 76% respectively after capture.

In contrast perhaps, are the research findings of Bodekke (1989), who reported that in Dutch shrimp fisheries undersized flatfish survived trawling rather well, provided the towing speed is low (4.8 mph) and the duration of the haul is no longer than an hour.

Lancaster herself, dedicated a study towards discard mortality due to trawling for Plaice, Dab and Whiting in Solway Firth (west-coast England). Her study results show survivability in Plaice and Dab after capture of 97% and 89% respectively. It is not clear from her work, with what haul duration and volume she worked. Lancaster also assessed fish for injuries before and after riddling. Fish were checked for fin fissures, scale loss and haemorrhages. The lowest occurrence if haemorrhages and fin fissures was found in fish taken from the trawl.

Mortality induced through efficiency of sorting equipment

The efficiency of the sorting equipment determines mortality in discards significantly as any by-catch, that is not deselected, will pass into the cooker with the commercial shrimp fraction and therefore will die.

The effect of the efficiency on discards mortality was studied by Berghahn et al.(1992), as well as Lancaster, J. (1999). Berghahn et al. found, that after rotary sieve sorting; only Whiting and Swim Crabs were relatively abundant in the commercial shrimp fraction. The sorting eliminated the large, as well as many small individuals of most by-catch species. The sorting efficiency was substantially higher for the rotary sieve as the length range of the different species in the commercial shrimp fraction shifted markedly to smaller sizes. Efficiency, effects discard survival by reducing mortality when employing a rotary sieve This effect was observed for Dab as well as Plaice and Swimming Crabs. This did not apply to Gobies, due to their shrimp like body shape and size. From the 0-group Plaice, between the 4-8cm length, less than 6-16% were not deselected by the shaking sieve. This percentage increased to 29% in summer, when the new year-class was caught. Depending on the abundance in the catch, 20-90% of the 5 and 6 cm length groups and 5-35% of the 7cm length group, but almost no 8cm specimens, were encountered in the commercial shrimp fraction. No Plaice was observed in the edible shrimp fraction of the Rotary sieve. For Dab, in the period that young Dab are abundant, 27% of the 3cm length class and 41% and 48% of the 4 and 5 cm Dab were encountered in the commercial shrimp fraction. For the rotary sieve, this fraction (for the length class 3-5cm) was only 2-9%. Similar to Plaice, selectivity increased Swimming Crabs for the large individuals. The rotary sieve proved more efficient at deselecting discards. The above mentioned results indicate that selectivity is strongly related to length class, species and species abundance in the catch.

Lancaster, in her study, found that for Plaice 19% was not deselected by the sorting device, using a shaking sieve. This fraction was 24% for Dab and 17% for Whiting.

Mortality induced through riddling

According to Lancaster, in European shrimp fisheries the riddling process is regarded to be the main cause of fish mortality, leading to exposure of the fish and lethal internal and external injuries. In the study by Lancaster, assessment of the kind and extent of injuries suffered by fish is highest during the riddling process, more so than for the trawling. Cases of injuries such as haemorrhages to the brain, body and fins were observed in almost 100% of flatfish having passed through the sorting device. Injuries differed per species and size of specimen, and also showed strong variability depending on the sorting device used.

Berghahn et al. (1992) studied the survival of various fish species, in the Wadden Sea using a traditional shaking sieve, and a haul length of 60 minutes. 10 species were investigated, including: Plaice, Dab, Flounder, Sole, Lemon Sole, Whiting, Sculpin, Hooknose, Eelpout, Dragonet (Callionymus lyra). The study results showed that mortality for Whiting prior to riddling already ranged between the 65-83%, and was a 100% after riddling. The results show that the few specimens of Dragonet also suffered from high sorting mortality (73%). However, amongst the highly abundant by-catch species Sculpin, Hooknose and Eelpout, the mortality remained low after sorting. Juvenile flatfish showed inter-species variation in by-catch mortality after sorting. Sorting induced mortality of flatfish varied depending on size and species. Smaller Plaice, generally suffered higher mortality, both during the trawling as well as during the sorting process than the larger Plaice; mortality increasing from a mean of 70% after catching to a mean of 91% after sorting in 4.5-9cm Plaice, compared to a mean mortality of 0% after catching to a mean of 20% in 9-6 cm Plaice . Flounder, Sole and Lemon Sole suffered mean mortalities of 28, 26 and 9% respectively after sieving (including mortality due to catching). Mortality of Dab increased from a mean of 11.9% to 32.6%. In their study, they compared the mortality of juvenile Plaice after different sorting treatments, and no differences were found between the rotary riddle or shaking sieve. This indicates, that the rotary sieve only reduces discard mortality, due to higher sorting efficiency.

In the study Lancaster, the proportion alive in the discards after the process of trawling and sorting, was observed to be 53% for Plaice and 49% for Dab and 0% for whiting. According to Lancaster, Kelle (1976), the survival of Plaice and Sole was estimated to be reduced from 50-60% after trawling, to 20 % in Plaice and 30% in Sole, after flatbed riddling.

Handling time and on deck conditions

Prolonged exposure to air causes stress and desiccation, which frequently results in discards mortality. According to Kelle (1976), the fatality of exposure is determined by the duration of the sorting procedure, temperature, and the presence of sunlight. Lancaster (1999) demonstrated the effect of temperature on discards mortality in her study. On deck temperatures were demonstrated to influence survivability negatively, and Plaice showed higher on deck mortality rates in summer. The occurrence of fatal haemorrhages and fin fissures increased significantly with higher temperatures for Dab, however, this did not manifest itself in an increased mortality.

Avian predation

Predation by seabirds on discards is a well known phenomenon in fisheries. Survivability of discarded fish is low. Walter and Becker (1997) found large numbers of moribund and damaged fish floating on the surface, which were unable to avoid predation. Only heavy species (hermit crabs) and undamaged mobile individuals may sink or escape (Walter and Becker, 1997). In the study by Lancaster in Solway, the scavenging birds appeared to prefer discarded round fish to flatfish; this is in agreement with the study of Hudson and Furness (1988). At times that the discards contained a high fraction of round fish species, such as Cod and Whiting, and the probability of flatfish avoiding predation was higher. A 38 % of living discarded flatfish fell prey to seabirds in Solway Firth, with survival rates of 34% in Plaice, 31% in Dab an 0% in Whiting.

Source	Area, season	Flatfish (%)	Roundfish (%)	Invertebrates (%)	
Hudson and Furness (1988)	Shetland, summer	5	58		—
Garthe (1993)	Around Helgoland,				
	summer	30	79		11
	winter	31	85		56
	North Sea,				
	spring/summer	8	84		—
Camphuysen (1993)	Southern North Sea, summer	34	85		0.3
Camphuysen (1994)	Southern North Sea, summer	31	71		0.3
Garthe and Hüppop (1994a)	Skagerrak/Kattegat,				
	winter, day	16	86		—
	winter, night	24	48		—
Garthe and Hüppop (1994b)	North Sea, summer	8	84		—
Camphuysen *et al.* (1993)	North Sea, winter	36	92		17
Camphuysen *et al.* (1995)	North Sea, spring	22	76		
	summer	10	70		6
	autumn	20	82		
				10	*Crangon crangon*
				0–33	*Carcinus maenas*
				8–13	*Liocarcinus holsatus*
	Wadden Sea			0–76	*Asterias rubens*
This study	spring/autumn	33–68	46–91	75–100	*Allotheutis subulata*
		41 (mass)	79 (mass)	23 (mass)	(excl. *C. crangon)*

Table 2.22. Numerical consumption rates of experimentally discarded flatfish, roundfish, and invertebrates of different studies. (Source Walter and Becker, 1997)

Benthic predation and long term survivability

After passing through the shaking sieve, almost all observed specimens demonstrated distorted behaviour (Berghahn et al. 1992); showing almost no feeding and no burying behaviour. Furthermore, according to Berghahn et al. (1992) all surviving flatfish sustained some form of injury. These effects, according to Lancaster may render fish less able to compete successfully for food and avoid predation by benthic scavengers, such as Hermit Crabs, Dab, Whiting, Starfish and *C. crangon*. In Lancaster's study, laboratory experiments showed *C. crangon* predating on living injured fish indicating a higher susceptibility to predation for injured fish. This is also argued by Kaiser and Spencer (1996). Open wounds also imply an increased risk of infection. Tempelman (1965), according to Lancaster, found that infection by lymphocytes virus was facilitated by injuries to the skin. This is supported by the study of Berghahn et al.(1992), who observed an epidemic outburst of early lymphocytes in Dab after sorting.

The full effect of sustained injuries on discards mortality may only become evident over a longer period of time. Even when injured specimens manage to avoid predation, mortality may occur long after being discarded overboard. In the study of Berghahn et al. account for this was taken by keeping samples in the laboratory for several days and assessing mortality accordingly. During Lancaster's study assessments were made of the injuries occurring in the living discards. These were used to indicate the survival chance of the living discarded specimens, accounting for the recovery potential from injuries on a species basis. Overall, 38% of all Dabs and 58% of all Plaice had head-haemorrhages or over 30% scale loss, and were therefore regarded as fatally injured prior to being discarded.

Overall discard survivability

Survivability in round-fish is close to 100%. Mortality in invertebrate by-catch species has not been extensively studied but is argued to be low (as C. crangon mortality illustrates) as these species are generally robust. Overall discard survivability of flatfish species, taking initial survival (survival rate one hour after trawling and sorting), long term injury mortality, and bird predation into account, is estimated to be a maximum of 14% for Plaice and 19% for Dab. This survivability may further be reduced, when account is taken for the mortality resulting from the reduced potential of injured fish to compete or sustain predation by benthic predators.

2.5 Reflections and insights

2.5.1 Summary of discarding practices and by-catch assessment in *C. crangon* fisheries

The standard shrimp trawl is highly unselective gear. Cod-end selectivity is especially low for fish, preventing even small captured juvenile fish from escaping. Trawl selectivity for *C. crangon* is also reasonably low. Sieve nets offer some improvement, releasing the large fish that enter the trawl, however, low selectivity for small by-catch, with measurements similar to commercial shrimps, remains. In addition to this, the fishery is a bottom-trawling fishery, operating in shallow coastal waters and estuaries, where high densities of especially juvenile fish occur, especially during the main shrimp season. The combination of the two makes by-catch a fundamental problem to this fishery.

In order to quantify discarding in this fishery and to carry out impact assessment on by-catch stocks, by-catch sampling programs have attempted to express by-catch in terms of composition and quantity. The emphasis in most sampling programs has been placed on commercial species, especially when it comes to quantification. A considerable variety of species are caught including fish, crustaceans and bivalves. Catch composition is highly variable through both space and time, on a macro as well as a micro level, and reflects geographical distribution of species, seasonal abundance and migration and growth patterns. The quantity of the total by-catch depends on the seasonal and spatial distribution of fishing effort.

A general observation in all sampling programs is the high numbers of juvenile fish being caught. This is ascribed to the correspondence between high seasonal abundance of shrimp and juvenile fish on the major shrimp grounds (particularly the Wadden Sea which serves as a nursery for many North Sea). The RESCUE sampling program assessed by-catches of the entire *C. crangon* fleet for several commercial species. Especially high catches of juvenile Plaice and Dab were caught. The way that the national fleets contribute to these totals varies and reflects, albeit roughly, the major spatial concentration of effort of the national fleets. The produced figures of the RESCUE study reflect by-catches of one year, so care must be taken when using the absolute numbers of these quantified by-catches. More over, the method employed for extrapolation of sampling results to fleet level did not consider spatial effort distribution of fleet (as this is not available), but used an approximation of the total swept area of the national fleet, based on total effort of fleet per quarter. Segments of the fleet operating in international waters or nuances in distribution of effort over estuarine waters and coastal waters are not accounted for, leading to perhaps misleading figures. Another major inaccuracy in total numbers of by-catch derives from the way Dutch figures on by-catch were obtained.

By-catch and discarding create a problem because of the discard mortality. Trawling, sorting, handling and discarding processes lead to considerable discard mortality, albeit being species and specimen-size dependent. Round fish (Whiting, Bib, Cod, Herring, Sprat) mortality is close to a 100%. Flatfish have higher survival rates, larger specimens generally suffering lower mortality than smaller specimens. Mortalities in Dab and Plaice have been well researched; overall survivability was estimated at a 19 % and 14 % for Dab and Plaice respectively. Flat-fish mortality is particularly caused in the trawling and sorting processes, moreover avian predation after discarding is high. The different sorting devices used in the *C. crangon* fishery did not deliver significant differences in terms of mortality.

C. crangon are crustaceans thereby making them less susceptible to the damaging properties of the different processes, moreover, their potential to recover from injuries is higher. *C. crangon* survivability ranges around 77,5%-84,5%, a range that is well supported throughout literature. The main sources of mortality were trawling and avian predation and mortalities increased significantly with increased trawl time, as for flatfish. No study has been conducted towards determining survivability in discards of other invertebrate species, but this is generally considered to be high. This also suggests that quantification of invertebrate by-catches is not such a priority.

2.5.2 Management implications; intervention in fisheries and management measures

The main concern in this fishery, in terms of by-catches, is most certainly the high by-catches of juvenile round-fish and flatfish. This is implicit in the low selectivity of the trawl (with and without sieve nets) for these specimens, their high abundance on the major shrimp grounds in the main shrimp season, combined with their low overall survivability, suggesting that this problem may not readily be overcome. However, whether these high absolute mortalities of juveniles are having a significant effect on populations is not something that may be determined on the basis of such quantitative figures. Population and community effects require single and multi stock assessments, which will be addressed in the following chapters.

Nevertheless, if reducing by-catch and total induced mortality is made a management priority, this chapter has a few interesting points to contribute.

- Firstly, to effectively reduce the problem, efforts will have to be made on a wide scale, and measures must be specific and in response to the spatial and seasonal differences in by-catch composition.

- Secondly, the measures should focus in the first place on bringing down by-catches and only in the second place on reducing discard mortality, the later only being relevant for juvenile round-fish. It was demonstrated, that selective devices are effective in reducing by-catch of larger fish. Trawl improvements should focus on enhancing selectivity of small juvenile fish, while at the same time preventing excessive losses of commercial sized shrimp. In this context, improvements of the trawl which enhance the escape opportunities of juveniles before entering the cod-end seem most promising.

- Thirdly, it is questionable if closed seasons or areas will be acceptable, as this will likely imply the closure of the most important shrimp grounds in the high season.

- Fourthly, discards mortality in flatfish may be reduced by limiting trawl time per handling time and by implementing subsurface discarding in order to reduce avian predation.

- And finally, effort limitation will most certainly contribute in bringing down total induced mortality. This is another plight for reinstalling the sector imposed effort limitations.

2.5.3 Improving by-catch assessment in North Sea C*. crangon* fisheries

If we wish to achieve a better understanding of by-catching and discarding practices in C. crangon fisheries in the North Sea we ought to consider the following:

- Better by-catch assessment in North Sea C. *crangon* fisheries requires more consistent by-catch sampling efforts to be made both across countries and across years, in which spatial and temporal variability is accounted for and visualized in the data.

- To achieve spatial and temporal specificity we should consider stratifying by-catch sampling and data storage and presentation. A sensible stratification of by-catch samples would account for both spatial as well as temporal variance in species composition and abundance. Stratification by season for each distinct area defined by; hydrological conditions (estuarine and coastal waters), depth band (shallow and deep) and latitude, would seem appropriate.

- This by-catch sampling should also include non commercial fish species.

- When overlaying such a ‘map’ with spatial effort data, the deliverance of a more accurate and more continuous quantification of by-catches in this fishery becomes a much easier task.

- The extra advantage of this is that it will illuminate where, when and which measures can be taken to reduce the fractions of the by-catch.

Chapter 3

DIRECT EFFECTS ON THE POPULATION OF THE TARGET-SPECIES

This chapter attempts to asses whether and how fishing mortality in (market-sized as well as undersized) C. crangon affects C. crangon population size and structure. Such an assessment will allow us to determine whether or not, in terms of target-species, the fishery is exploiting at sustainable levels.

3.1 Data coverage and quality and impact assessment

Despite the data collection and research efforts of the various member states and fisheries under the provisions of the EU Data Collection Regulation, and the economic importance of the *C. crangon* fishery, no formal assessment of the state of the North Sea *C. crangon* stock has been conducted or may readily be carried out. This is related to the major uncertainties which remain, despite extensive studies, concerning the natural history of this species, particularly in terms of its growth rate, instantaneous mortality rates and patterns, spatial distribution, factors determining reproductive success and timing of the life cycle. These uncertainties make it impossible to conduct a proper stock assessment.

Currently our assessments of the *C. crangon* stocks and the way the fishery interacts with these are based on the analysis of the time-series derived from fisheries statistics (landings, effort and fleet characteristics), young demersal fish surveys (DYFS) and commercial catch assessments (CCS). Time-series of effort and landings allow for the derivation of catch per unit effort series and illuminate trends in stock abundance. Observing such trends, together with the acquired knowledge of the technical developments of the fleet, will give an indication of stock abundances and whether stocks are being overexploited.

Monitoring of *C. crangon* stocks is undertaken using the data collected during the Demersal Young Fish Surveys (DYFS). These surveys are carried out every autumn, since 1969, during which stations located throughout the coastal waters from the border of Belgium (including the Scheldt Estuary) up to Esbjerg (Denmark) are visited. These surveys were originally embedded in international cooperation with the participation of The Netherlands, Belgium and Germany. However, according to Welleman and Daan (2001) these data have not been integrated properly. Moreover, only the Dutch input has been consistent. These surveys provide data that allow for a determination of abundance and size-distribution per swept area, stratified per depth band (from 2-20m iso-bath), bringing in a spatial dimension in shrimp abundance. Commercial catch samples (CCS), conducted by both the Netherlands (1975-1994/5) and Germany (1955-1993,) have also proven useful in assessing the *C. crangon* stocks and interrelationships with the fishery. Such samples give data on size composition of catch and egg-bearance.

The ICES *C. crangon* workgroup (WGCRAN) collates several fisheries' statistics and survey data to distinguish time trends in landings, effort and catch per unit effort as well as seasonal and spatial effort and abundance patterns, in order to monitor the state of the *C. crangon* stocks and spatial and temporal trends in abundance. Observing trends in both spatial-temporal shrimp abundance and the fishery may envisage interrelationships between the fishery and the stocks, and enable management advice to be established.

Temming et al. conducted an extensive study in 1996 and collected and processed all available data on shrimp directed fishing effort, and *C. crangon* in the Netherlands and Germany in order to validate whether fishing effort has increased and whether this supposed increase in effort has affected the biological parameters of the shrimp stock (abundance, number of egg-bearing shrimp, size composition). They used fishery effort statistics as well as the biological fish surveys (DYFS) and commercial catch samples (CCS) conducted in both countries. This study is unique in the way that it has experimented with different methods of effort approximation.

Despite these efforts, our incomplete understanding of the stock dynamics will continue to severely thwart attempts to abstract robust conclusions from observed trends produced by fisheries statistics and the surveys, to bring this in relation to the fishery and to consequently base mature and effective management advice on this.

3.2 Impact assessment of the C. crangon fishery on C. crangon populations

The limited understanding we have of stock dynamics severely hampers our ability to understand interrelationships between the fishery and C. crangon populations. Changes in population abundance and structure are addressed in the following paragraphs in which an attempt is made to bring these changes into relation with the fishery.

A fundamental problem we bump into during any assessment of effects on C. crangon populations is that the population boundaries have not yet been defined for continental Europe. Henderson et al. (1990, in Revill et al., 2000) identified that boundaries between populations of *C. crangon* exist and demonstrated that these correspond to bodies of water with different hydrological properties. Two populations were distinguished along the east England coast in the North Sea. One of these populations is thought to extend across the channel along the Belgian and Dutch coastline. The population structures and boundaries along the coast of mainland Europe have not been researched and are therefore unknown.

3.2.1 Effects of fishing mortality on C. crangon abundance

Inter-annual variation in densities of *C. crangon* can be substantial and is observed in all areas where *C. crangon* occur. Such dynamics correlate with various physical and biological environmental factors, such as predation levels and winter temperatures, and have no necessary relation to the fishery. No reliable estimates exist of *C, crangon* biomass for the North Sea stock. Therefore we cannot effectively determine the relative magnitude of the fishing mortality in terms of *C. crangon* biomass. Very high natural mortalities are encountered in *C. crangon* populations (Bodekke, 1989 in Revill et al., 2000). It was estimated that only 0.2 percent of larvae will survive to reach the adult stage of sizes over 53mm in total length (Redant, 1987). Fishing mortality has been estimated to be 5% and 6.6-11.4 % of the natural mortality by Rauck and Zeilstra (1987) and Bodekke and Becker (1977) respectively (in Lavalije and Dankers, 1993).

Despite these high natural mortalities, in order to detect whether the fishery is having an effect on population abundance, and in the absence of reliable stock assessment parameters, we are interested in trends that may be envisaged by observing fishery statistics on landings and Landings per unit effort (LpUE) and survey data on abundance per swept area.

Observing the national fishery statistics on landings, effort and LpUE in chapter 1 does not indicate that the North Sea *C. crangon* stocks are being overexploited. Total landings have increased steadily over the last decade and have been exceptionally high during the last two. On a national fleet level, increasing landings are reported for the Dutch, German and Danish fleet, with corresponding increases in LpUE. This indicates a higher catch efficiency which may be explained either by more effective fishing gears and techniques or by an increase in shrimp abundance. Landings of the Belgium fleet show a continuous decline, as does the time series of LpUE. Similarly, the UK landings, as well as LpUE, have also dropped in the last four years. This decline, which could be indicative of overexploitation, has been investigated by the ICES WGCRAN (2005) by analysing the long time-series of spatial abundance (per swept area) derived from the DYFS. These time-series, when stratified per depth and latitude, point towards a trend of continuously falling densities in shallow inshore waters (Southern East Frisia, Eastern Dutch Wadden Sea and the Scheldt Estuary) and more southern waters (the Scheldt Estuary and in the Eastern Wadden Sea) as opposed to an increase in *C. crangon* densities in deeper, off-shore waters (Danish waters, Northern East Frisia, Dutch coast) and more northern waters (along the German Wadden Coast, the Dutch Wadden Coast and in the Western Wadden Sea). Such trends were argued by the WGCRAN (2005) to suggest that *C. crangon* stocks are perhaps being driven into deeper or more northern waters, presumably avoiding increasing maximum summer and autumn water temperatures. However, as Tulp (WG meeting 2006) points out, this trend may not necessarily imply a displacement of shrimp stocks following a temperature gradient, but could also be the result of a shift in predator abundance or change in migration patterns (phenology). Obviously these hypotheses need to be tested before any definite answers can be deduced.

In their study, Temming et al. (2000) carried out more thorough research into shrimp abundance and the way that the fishery or environmental variables such as predator abundance and winter temperatures may have impacted upon this. They used both LpUE (LpUE is an index for abundance) and survey data to estimate shrimp abundance. Depending on the effort proxy that was chosen, the LpUE of the Dutch fleet was shown to either stagnate or decline over the period 1979 to 1995 (see par. 1.2.6). Similar findings apply to trends observed in German LpUE (1986-1996) (see par 1.2.6). This would indicate that shrimp abundance has remained stable, or, in the case of declining LpUE, has decreased. Total shrimp directed effort increased for both the countries in the same period, which would suggest that declining *C. crangon* abundance might be related to the activities of the *C. crangon* fishery. However, no such claims were made in this study. The DYFS abundances did not show a consistent trend (Temming et al., 1996). The high abundances of *C. crangon* of commercial size correlated significantly with low temperatures in the preceding winter. Overall variability was high and some years showed especially low abundances, correlating with low landings and high gadoid fish densities. Apart from these extreme years, the correlation between crangon abundance and predator abundance was low. Predator abundances did not show a trend over time and could not explain an increase in shrimp mortality.

Boddeke (1976,b in Lavalije and Dankers, 1993) dedicated a study to assessing the effect that the fishery has on *C. crangon* abundance. His comparative study, in which he sampled two similar areas, demonstrated that in the area in which no juvenile shrimp were being caught, catches of consumption shrimp increased as opposed to the other area. This would indicate that the fishery is having a direct effect on shrimp abundance and that restrictive measures may improve shrimp catches.

3.2.2 Effects of fishing mortality on seasonal C. crangon abundance

Shrimp abundance and biomass show strong seasonal patterns. In accordance to this, the fishery is also characterized by seasonality, the traditional shrimp season taking place in late summer and autumn, and a smaller contribution coming from the spring season (except in Denmark where the main shrimp season is traditionally in spring). Only a few vessels continue fishing during the winter months. It is argued that the way the fishing will impact on population densities and biomass varies across the seasons and relates to the reproduction cycle of the *C. crangon* and the seasonal variability in growth rates and mortality rates. The spawning season of *C. crangon* is prolonged, lasting nine to ten months of the year. It begins early winter and lasts until late summer (Lancaster, 1999). The spawns are generally distinguished as belonging to either the winter spawn, early summer spawn (larvae in April) or late summer spawn (larvae in October). This distinction is made because the egg-development and growth and mortality rates of the recruits arising from each of these spawns are distinct and are strongly correlated to seasonally fluctuating environmental conditions (temperature, salinity and predator abundance) (Del Norte-Campos and Temming, 1998). Moreover, because of these differences, the three spawns may contribute differentially to stock biomass and densities and consequently the fishery (Del Norte-Campos and Temming, 1998; Neudecker, 2001). A lot of uncertainty nevertheless remains concerning this as there continues to be ambiguity in reported growth and instantaneous mortality rates and the way this varies across seasons and between, as well as within cohorts. There seems to be strong evidence however that the cumulative effects of growth rates and lower predation could lead to a higher survivability in the recruits arising from the winter eggs. This would imply a higher contribution of winter eggs to the *C. crangon* stocks and autumn fishery (Del Norte-Campos and Temming, 1998; Kuipers and Dappers, 1984; and Neudecker, 2001).

If these observations and claims are true, then it seems reasonable to assume that the winter fishery may have a bigger effect on the stock densities and biomass than the summer and autumn fishery by extracting the most ‘productive’ share of the stock. This will consequently impact on the catches of the summer and autumn fishery. Considering this, the development of the winter fishery that has followed from the introduction of larger, more powerful vessels is not necessarily positive. To benefit *C. crangon* stocks and to optimize catches, it could be sensible to impose restrictions on the winter fishery (November-March) (Neudecker, 2001; Del Norte-Campos and Temming, 1998). To warrant such measures more research will have to eradicate or explain the discrepancies in research findings that are leading to uncertainties. Research will especially need to be devoted to shedding more light on seasonal variability in growth and mortality rates, the way that environmental factors influence these and how they lead to variability in development patterns and mortalities between and within cohorts.

3.2.3 Effects of fishing mortality on population structure

Instantaneous mortality rates and abundance varies within a population across age-classes. Moreover the fishery targets the larger >45mm specimens resulting in disproportional fishing mortality within populations. An effect on population structure can therefore be ruled out.

In the study by Temming et al. (2000), analysis of CCS data showed marked changes in the population structure. Attempts were made to asses the cause of these trends and potential correlation to the fishery. From both time-series developed from the CCS data of the Netherlands and Germany, a decrease in the proportion of large shrimp in the catches could be observed. Especially in the German series, this decrease was pronounced as the German CCS covers a longer time period. The percentage of large shrimp in the catches of both countries were similar near the end of the CCS series. No attempts were made however to assess the possible contribution of the fishery to these trends. This trend in size distribution could not be observed in the DYFS data. The CCS data of Germany showed a marked decrease in the proportion of egg-bearing shrimp of the commercial size (>55mm) over the 3.5 decades of observation. This decrease was observed in all length classes contributing to egg-production. Temming et al.(2000) conclude that this must have resulted in a decrease in reproductive output of *C. crangon* in German coastal waters. The reason for this trend is not yet clear, nor is it clear whether this trend has persisted after 1992. In contrast to German data, no such trends were exhibited by the Dutch CCS data. The percentage of egg-bearing shrimp in Dutch samples has been consistently higher than in the German samples. An analysis of Dutch data by size-class revealed a surprisingly high contribution of small length classes (<50mm) to the proportion of egg-bearing shrimp. However Temming et al. (2000) showed that these egg-bearing shrimp (<50mm) are most likely to be of the species *Crangon allmanni* which also inhabit these waters. If this should generally be true, then a large proportion of the Dutch commercial catch will consist of *C. allmanni* (Temming et al. 2000). The same may apply for certain German waters. This deserves further investigation, as understating the contribution of *C. allmanni* to the commercial catches can lead to incorrect conclusions regarding interrelationships between the fishery and *C. crangon* stocks and consequently, to incorrect management advice.

3.3 Reflections and insights

3.3.1 Summarizing the effects of the *C. crangon* fishery on *C. crangon* populations

With the available knowledge and data, our assessment of the effects of fishing mortality (commercial-sized *C. crangon* as well as juvenile discard mortality) on populations is limited. The meaning of the observed population trends, and the role that the fishery has had to play in this, are speculative and have received only minor attention. No definite answers can be given concerning (a) whether we are fishing at an optimal level (b) how the North Sea *C. crangon* stocks have reacted to fishing pressure exerted by the fishery over the last century (c) or whether they will sustain high(er) effort levels. It is questionable whether such a prediction is feasible considering we are dealing with a highly dynamic species.

The four key points that the literature makes with respect to population effects of fishing mortality are as follows:

- On the basis of LpUEs series and landings statistics, over-exploitation of *C. crangon* does not seem to be taking place. However there might be some danger in using LpUE data to derive such conclusions, as fluctuations in LpUE seem to be predominantly driven by natural factors and can rise and fall magnificently between years. This creates a lot of ‘noise, making it difficult to discern fishery induced changes, making therefore it a rather unreliable measure to base definite statements on. Longer time-series of LpUEs show a slight declining trend indicating falling *C. crangon* abundance. When brought into relation with the observed increase in effort over the same period, this might suggest that the fishery has affected *C. crangon* abundance noticeably. These abundance trends were not supported by all data. Moreover, a decline in abundance is an obvious result of fishing and does not necessarily imply that over-exploitation is occurring.

- An effect on shrimp abundance was observed when juvenile *C. crangon* were no longer caught, resulting in consistently higher catches. This indicates that juvenile fishing mortality noticeably affects biomass of the catch-able population. This observation was based on the results of a single experimental study.

- It is suggested that the winter fishery may have an impact on in-year *C. crangon* densities and consequently, catches. This hypothesis has not been researched.

- Changes have been observed in the size-structure of *C. crangon* populations, with a trend towards smaller fractions of large shrimp. Such population changes are generally considered to be typical effects of fishing, which extracts the large specimens, and would suggest that the *C. crangon* fishery is affecting populations. This result could not be obtained using DYFS data and is therefore ambiguous.

3.3.2 Management implication: fisheries intervention and management measures

There is no indication of over-exploitation at current effort levels and therefore immediate intervention is not warranted. There is, however, an indication that limiting by-catches of juvenile shrimp and the extraction of the mature specimens in the winter months affects shrimp abundance and consequently catches. It could be in the interest of the fishery itself to reduce by-catches of juvenile *C. crangon* and to limit fishing in the winter months, thereby optimizing catches. Whatever management measures are deemed suitable to optimize catches, it is obvious that these must be flexible and responsive to natural population dynamics.

3.3.3 Improving impact assessment in *C. crangon* fisheries

Achieving a better understanding of interrelationships between the fishery and *C. crangon* populations allows us to predict how stocks might react to changes in the fishery and to better adept seasonal effort and catches to the dynamics of the stock in order to limit the detrimental effects on the *C. crangon* population, prevent overexploitation, and optimize catches and profits to the fishery. This requires the development of tools to conduct a proper stock assessment as well as tools that strengthen our capacity to bring observed changes in stocks into relation with the fishery and/or other environmental variables. Research needs to focus on gaining a better understanding of:

- The growth and mortality rates of the species and the way these are influenced by and fluctuate in accordance with environmental variables.

- The spatial distribution of these species and the seasonal and inter-annual variation in this in relation to migrations, recruitment and mortality patterns.

In combination with spatial and seasonal effort distribution, this will enable impact assessment. To define population effects it may be necessary to define the population boundaries of North Sea *C. crangon* and to determine what the contribution of *C. allmanni* is in *C. crangon* catches.

Efforts to improve our understanding of the *C. crangon* as a species and North Sea stock are being made. The University of Hamburg is actively engaged in research into the natural history of the species. This is largely being conducted under the direction of Prof. A. Temming. Parallel to this, the WGCRAN group will be dedicating their time and effort to collating the data produced over the years by the DFS in order to produce estimates of *C. crangon* biomass (based on swept area) and its distribution. Expected obstacles concerning determining the relative and absolute efficiencies of the different survey gears, used in the various national surveys, are envisaged to be overcome. By doing this, the WGCRAN group hopes to develop tools so that they may provide management advice in future.

Chapter 4

DIRECT EFFECTS ON POPULATIONS OF NON-TARGET SPECIES

The question that has been gaining weight and urgency throughout the previous chapters is: what do these absolute by-catch figures mean for populations and the marine ecosystem? Total discard mortality may be estimated using absolute by-catch figures and discard mortality rates. However without some sort of impact assessment these quantitative figures will remain more or less meaningless and offer us very little to talk about indeed. Before we can evaluate the fishery at all, we need to know in which ways and to what extent fishing induced mortality affects populations. This should focus on the effects of juvenile fish mortality, considering the by-catch and discards mortality in the *C. crangon* fishery concerns primarily 0-group and 1-group fish.

4.1 Data coverage and quality and impact assessment

There are many ways in which a fishery may alter the identity and state of a population: total biomass, size-structure, spawning stock biomass and genetic composition are some examples of population features that may be affected. Assessing the extent to which juvenile mortality impacts on any such population features is not a straightforward procedure and will require at least some knowledge of the population biology and dynamics (growth-, reproduction- and mortality rates) of the species in question. Such information is not available for all species. In such circumstances, effects of fishing mortality may be illuminated via trend analysis obtained from fish-surveys or fishery data (densities per swept area, landings and LpUE figures, catch size-composition, etc). These methods are much more speculative because the effects cannot be directly discerned from the effects of environmental factors and other fisheries. Despite this interpretation problem, such analysis can indicate how stocks are developing and signal negative trends in terms of abundance, size-composition etc, on the basis of which intervention may be warranted. Generally though, the biology and dynamics of populations of commercial species have been particularly well studied, or else have been monitored through surveys and fisheries statistics. Plaice, Cod, Whiting and Sole are species for which biological data exist, allowing for a direct calculation of impacts.

4.2 Effects on populations of non-target species

4.2.1 Fish-surveys and species abundance

North Sea fish-survey data demonstrate that changes in demersal fish abundance have taken place. These changes have been brought into relation with fishing activities. The contribution to this by the *C. crangon* fishery cannot be directly discerned. We must remember that as opposed to the flatfish fishery targeting these species which inflicts mortality primarily in the larger size-classes, the *C. crangon* fishery inflicts mortality in the smaller size-classes (juveniles). This is important when we want to assess the relative impact that the *C. crangon* fishery has on such populations and the contribution it is making to the dwindling stocks of North Sea demersal fish species.

4.2.2 Effects fishing mortality on year-class strength in 0-group Plaice and Sole

The study by Berghahn and Purps (1998) investigated the impact of discard mortality in Schleswig Holstein *C. crangon* fisheries on the year-class strength of North Sea 0-group Plaice (*Pleuronectes platessa.L*) and 0-group Sole (*Solea Solea L.)* for the years 1982 to1992. Fishing mortality in *C. crangon* fisheries for these species is highest in this age group. The effect on year-class strength was estimated on the basis of the two independent by-catch programmes (FRCF and ESR). By-catch fractions were extrapolated to fleet level using total landings data. In order to prevent an underestimation of the effect on year-class strength, several worst-case assumptions were made: (1) no re-catch of survivors from discards; (2) by-catch mortality was taken from the study of Berghahn et al.(1992) and was assumed to be at a high of 80% for both flatfish species; (3) selective trawls (mesh size 55-80mm) were assumed to be employed by only 50% of fleet; (4) landings were assumed to be underestimated by 10% owing to losses during the sieving on land; (5) natural daily mortality was taken to be at the lowest value from literature $M=0.002d^{-1}$ (= annual M=0,73). Presuming worst-case conditions, the mortality of 0-group Plaice caused by the Schleswig-Holstein shrimp fleet ranged between 3% and 11% (F= 0.03-0.11) in the years 1982-1989. For 0-group Sole the impact on the 0-group year-class was lower, with mortality of the year-class ranging between <1% and 8 % in the years 1982 to 1991. In this study only the mortality induced by the Schleswig-Holstein fishery was considered. When the effects of the entire *C. crangon* fleet and flatfish fisheries in the North Sea are taken into account the total mortality and thus the effects on year-class strength of 0-group Plaice and 0–group Sole will likely be significantly higher. To illustrate this, 0-group plaice mortality estimates were extrapolated to the total German fleet for 1982. This resulted in an increase in 0-group Plaice mortality from 6% (for the Schleswig-Holstein fleet) to 11 %. Considering that this study assumed worst-case scenarios, we may assume that the relative contribution of fishing mortality to total mortality will likely be smaller (e.g. natural mortality is usually higher). This study does not attempt to determine what effect this loss in year-class strength may have on the total population.

In the *C. crangon* fishery of Schelswig-Holstein, year-class strength in Plaice is affected the most. However, for other North Sea *C. crangon* fisheries, this may not be the case, depending on the composition and size of their by-catches and related spatial and temporal fishing patterns. Due to these differences, extrapolation (on the basis of shrimp directed effort) of results derived in the Schleswig-Holstein shrimp fishery to the entire North Sea fleet is not an option.

4.2.3 Effects of fishing mortality on population biomass for Plaice, Sole, Cod and Whiting

The ECODISC project of the EU went a step further than Berghahn and Purps (1998) and attempted to estimate what the impact of the losses in the four main discarded species (Plaice, Cod, Sole and Whiting) was on the population SSB and the landings in the respective fisheries. This was based on the extensive data sets derived in the by-catch sampling programme VAN MARLEN ET AL. 1998. A ten year average of effort for each fleet was used to obtain a C. crangon directed fishing effort with which discard data of no fish/10.000m^2 could be raised to fleet level for each quarter. Account was taken for fluctuations in abundance in discard species. The discard survival rates used were 0% for Whiting and Cod, 20% for Plaice and 50% for Sole. For the Dutch fleet, data obtained in the VAN MARLEN ET AL. 1998 by-catch sampling programmes of Denmark and Belgium was used. Biological models were used to determine the impact of discard mortality on the SSB (number of mature females). The results are indicated below [table 4.1].

Species	% loss to SSB's resulting from current levels of European *Crangon* related discarding (range shows 5% and 95% confidence limits of estimate)
Cod	0.5 – 1.8 %
Whiting	0.6 – 1.7 %
Plaice	6.2 – 16.2 %
Sole	0.4 – 2.2 %

Table 4.1 . The estimated losses to North Sea SSB's due to current levels (RESCUE data) of discarding in the European C. crangon fisheries (Source: ECODISC)

For Plaice, the total impact in terms of loss of SSB for the entire *C. crangon* fleet is 10.3% (upper confidence limit: 16.2% and lower confidence limit: 6.2%). The activities of the German fleet and the northern Dutch fleet were chiefly responsible for this. For Sole the loss in SSB was estimated at 1.1% (upper confidence level: 2.2% and lower confidence level: 0.4%). For Cod stocks, the loss in SSB was estimated at 1.0% (upper confidence level: 1.8%, and lower confidence level: 0.5%). Losses in SSB in Whiting stocks was estimated at 1.1% (upper confidence level: 1.7%, and lower confidence level: 0.6%).

To express the impact of discard mortality in economic terms, the total annual lost landings were calculated. These can be viewed below [table]. For Plaice this came to 12,006 (median value) tonnes which equated to 12.4% of the 2000 North Sea TAC set by ICES. For Sole this was 588 tonnes per year (median value) which is 3% of the 2000 North Sea TAC set by ICES. Whiting landings were reduced by 1,525 tonnes (median value) yearly which equals 5.1% of the 2000 TAC set by ICES. Cod landings were reduced by 1,890 (median value) tonnes yearly which is 2.3% of the TAC for 2000 set by ICES.

Species	Estimated annual lost landings due to discarding in the European *Crangon* fisheries (tonnes) (mid value estimate)	Estimated fish market value of annual lost landings (EURO)
Cod	1,890	2.7 million
Whiting	1,525	1.2 million
Plaice	12,066	17.9 million
Sole	588	3.9 million
Total		25.7 million

Table 4.2 . Estimated magnitude of lost landings arising from current levels (RESCUE Data) of discarding in the European C. crangon fisheries. (source ECODISC)

ICES sets TACs on the basis of estimated population biomass. Considering that discard mortality in *C. crangon* fisheries reduce the TAC considerably, it can be suggested that the *C. crangon* fishery is having a noticeable effect on population biomass and thereby contributing to the observed decline in Plaice, Sole and Cod stocks. Obviously the shrimp fishery alone cannot be held responsible for these dwindling stocks, as, in the absence of the Cod, Plaice and Sole fisheries, its fishing pressure would be too small to exert such detrimental.

4.3 Reflections and insights

4.3.1 Summarizing the effects of the C. crangon fishery on populations of non-target species

Only for the four most highly discarded species in *C. crangon* fisheries (Cod, Plaice, Whiting, and Sole) can we say anything about population effects. These are species which are of socio-economic significance and for which biological population parameters exist. The impacts were assessed in terms of loss in year-class strength (Plaice and Sole for German fleet), lost landings, and losses in spawning stock biomass. The latter is a biological parameter commonly used in fisheries to determine the state of a stock and is indicative of the fecundity of the population. Losses in SSB thus have an effect on total biomass and the reproductivity of populations. Likewise, losses in landings indicate that the C. crangon fishery has affected population biomass of the cacheable population via both the effects of losses in SSB and direct losses of recruits into the fishery (caused by the fishing mortality in juvenile fish). The impacts are expressed as percentages of total SSB and landings. However, only when such percentages are brought into relation with some form of pre-defined criteria (such as the precautionary level of SSB and TAC) do these really become meaningful. The lost landings were expressed as percentages of TACs. Assuming that TACs are set at biologically safe levels, this suggests that the *C. crangon* fishery cannot be held responsible for the dwindling of the Cod, Plaice and Sole stocks, although they are certainly making a contribution. This implies that the high absolute mortalities in juvenile fish (especially 0-group Plaice) in this fishery can have a significant effect on population parameters such as biomass and SSB, despite high natural juvenile mortality.

4.3.2 Management implication: fisheries intervention and management measures

Considering the poor state of many North Sea flat-fish species, reducing discard mortality of juvenile demersal fish species could most certainly contribute to stock recovery and biomass growth. Moreover reduction in discard mortality in Plaice, Sole, Cod and Whiting is suggested to be beneficial in terms of regained landings, which could deliver financial benefits to the respective fisheries. Considering this, firmer implementation of selective devices in *C. crangon* fisheries is warranted and improvement of trawl selectivity merits research efforts.

4.3.3 Improving impact assessment in *C. crangon* fisheries

Evaluation of a fishery in terms of population effects is not achievable without a set of management tools.

- Firstly, to conduct an impact assessment we need fishery data to determine fishing mortality on non-target species, and a set of biological parameters to determine the effect of this fishing mortality on stock characteristics. Obviously such biological knowledge is not available for all by-catch species. Moreover, by-catch figures are not consistently recorded or monitored, which causes inaccuracies when estimating total fishing mortality. Improvement in these areas is required.

- Secondly, in order to evaluate the effects on stocks, and to be able to base management decisions on them, we need to formulate suitable criteria against which these effects can be tested. These criteria must relate to specific stock parameters and must be measurable and quantifiable. Formulating such criteria involves setting management objectives and conducting biological research in order to translate management objectives into quantifiable criteria.

Chapter 5

INDIRECT EFFECTS ON POPULATIONS THROUGH SPECIES INTERACTIONS

The *C. crangon* fishery extracts large numbers of *C. crangon* annually and moreover it discards vast amounts of fish and invertebrates, both dead and alive, which may form a source of food for various kinds of predators. These energy extractions and supplements may have an indirect effect on the relevant predator, prey or competing species. Structural distortions to the energy flows in the food-web may result in an altered community structure and composition.

5.1 Indirect effect of *C. crangon* mortality on populations of interdependent species

C. crangon is an omnivore, although during its benthic life a carnivorous diet prevails. It is an opportunistic feeder, its dietary changes corresponding to changes in seasons and levels of development, the latter reflecting its capacity to handle and digest larger food particles as it grows (Lancaster, 1999). During their benthic life stage, small *C. crangon* feed on meio fauna, whereas large *C. crangon* feed on macro fauna, having a significant effect on populations of amphipods, worms, schizoids, snails, young bivalves and young fish. Food competitors are other crustaceans but above all bottom feeding fish. In those areas where high densities occur, such as The Wash and the Wadden Sea, the *C. crangon* is regarded as the most important carnivore. *C. crangon* itself is a major prey item for fish. Pre-recruits are heavily predated upon by juvenile fish. *C. crangon* make up a large part of the diet of larger commercial fish species such as Cod (*Gadus morhua*) and Plaice (*Pleuronectes platessa*), and of other estuarine fish such as Lesser Weever (*Trachninus vipera*), Pogge (*Agnus cataphractus*) and the Common Sea Snail (*Liparis liparis*).

Because it connects different trophic levels, and because of its high consumption and production rates the *C. crangon* takes a keystone position in the food-web, giving it an indispensable and highly significant role in the functioning of the marine ecosystem (Lancaster, 1999). This also suggests that large extractions of *C. crangon* may have an impact on both its predator and prey species, as well on those species which compete with *C. crangon* for food. Research into this area does not yet exist, so the magnitude and the relevance of this impact remains speculative. The *C. crangon* fishery extracts the larger specimens (> 45mm) of the *C. crangon* population and discards juveniles. The discard survival of juvenile shrimp is relatively high (77.5 - 84.5%, Revill, 2000), therefore our focus should be turned to the potential effects of extractions of commercial sized shrimps.

5.2 Indirect effect of discarding on populations of interdependent species

The discards resulting from the by-catch are thrown overboard manually or discarded via a subsurface outlet. These discards, both dead and alive, form a food subsidy for various opportunistic scavenging species such as birds, invertebrates and fish, and also marine mammals such as seals, at the same time depriving other (particularly bottom living) species of their food source. It has been suggested that, by increasing the amount of food available to scavengers, fishing may lead to an expansion in the size of some scavenger populations, which could, by disproportional growth of populations, result in a change in the community structure and composition. For the *C. crangon* fishery this will especially apply to sea bird populations, as these have been observed to feed extensively on the discards.

5.2.1 Effects on bird populations

Indications of population increases have, according to Ramsay et al. (2000), been strongest in a study of seabird populations in the North Sea conducted by Furness et al. (1988), which showed that the growth of seabird populations occurred concurrently with an increase in fishing effort. One may not however directly assume that an increase in food availability will result in population growth. This will depend on the ability of such potential scavengers to find the food items; the life history of the scavenging species, and; the counteracting negative effects exerted on these species through trawling (Ramsay et al. 2000).

Walter et al. (1997) studied the scavenging behaviour of seabirds on discards produced in the *C. crangon* fishery off the coast of Germany (Lower Saxony). This data was used to produce a crude estimation of the total numbers of birds that could be sustained by this food source. Earlier studies by the same authors (1994), and by Berghahn et al. (1992), have shown that up to 3000 birds may be found to follow a shrimp beam trawl in pursuit of food items. These birds feed on moribund and damaged fish that float on the sea's surface or that are unable to escape quickly enough. The bird species that followed the trawlers were shown to vary seasonally and spatially. Two species dominated throughout the year, namely the Herring Gull (*Larus argentatus*) (48% of total) and the Black Headed Gull (*L. ridibundus*) (45% of total). This composition, observed in the inshore areas (German Wadden Sea), is rather different when compared to fish beam trawling in the open North Sea where six to eight common scavenging bird species were recorded (Camphyusen et al. 1993, 1995; in Walter et al., 1997). Other species such as the Common Gull (*L. Canus*), the Lesser black-backed gull (*L. fuscus*), the Great Glack-Backed Gull (*L. marinus*) and the Common/Arctic Stern (*Sterna hirundo/paradisaea*), were also observed, but were less numerous. Feeding behaviour of the observed bird species varied per species, Herring Gulls proving most successful (accounting for 82% of total consumed items). Experiments showed that the birds are selective in what they prey upon. In total, the scavenging seabirds following the shrimp vessels consumed 41% of the offered mass of flatfish, 79% of round fish, and 23% of four invertebrate species. Extrapolation of these figures over the total amount of discards produced by the Lower Saxony fleet (118 vessels) Walter et al. (1997) estimated that this fishery could potentially sustain 60,000 scavenging birds annually. The catch of this fleet only represents one fifth of the total landings produced by Germany, the Netherlands and Denmark (1983-1992), so the effects on seabirds are assumed to be larger. Given the numbers of breeding birds in the inshore areas discards in the *C. crangon* fisheries are considered by Walter et al. (1997), proportionally, to be of a higher significance to seabird populations than fleets operating further offshore. This would be especially true in the breeding season, as was demonstrated for Herring and Lesser Black-Backed Gulls in The Netherlands (Spaans, 1971; Noordhuis and Spaans, 1992; in Walter et al., 1997) and during migration (Walter et al., 1997).
The study by Walter et al. may be used as an indication that discards are an important food source for particular seabirds and may potentially support seabird populations. However no evidence is provided to demonstrate that this may lead to population growth. If significant population growth of the main benefited bird species were to be observed, further research into the interaction between discard feeding and population growth may be warranted.

5.2.2 Effects on benthic and pelagic populations

Fonds and Groenewold (2000) conducted research into this issue for the Sole and Plaice beam trawl fishery in the North Sea. The Sole and Plaice beam trawl fishery can be assumed to have smaller levels of by-catch but make a bigger impact on the sea-bottom. The results from this study must be seen in this light. Their study observations point out that trawling, by ways of discarding and inflicting damage and mortality on benthos in the trawl tracks, results in an increased rate of recycling of macro-benthic fauna and fish through the food-web. Dead discarded fish that sink to the bottom are consumed mainly by invertebrate scavengers such as swimming crabs, hermit crabs, starfish, sea urchins, and whelks (Evans et al. 1996; Fonds et al. 1998; Ramsay et al. 1998; in Fonds et al. 2000). The larger round fish species may take some of the smaller discarded fish (Fonds et al. 1998; in Fonds and Groenwold, 2000). Although these food subsidies may help maintain the population of benefiting species, it was considered unlikely that it would support population growth. Possibly locally, an increase in population densities may occur for certain species (starfish and small fish species) as a result of increased trawling intensity (Philipart et al. 1998; in Fonds et al. 2000). However, in consistency with the conclusions of Fond et al. (2000) no increase in population density of scavenging species has been observed over the whole area of the North Sea (Buijs et al. 1994; in Fonds and Groenewoud, 2000).

Effects of food subsidies produced in beam trawl fisheries to benthic scavengers was also studied by Ramsay et al. (2000) using quite a different methodology. Their study focussed on the starfish *Asterias rubens,* which is an opportunistic scavenger, feeding off food subsidies created by trawling, and which occurs in vast densities throughout European waters in almost any habitat. Their study could not make a direct link between increased food ability and the abundance of populations, although at low effort- levels abundance did increase as effort increased which may indicate a positive relationship. At higher effort-levels however population growth ceased as effort increased. This was assumed to relate to other deleterious impacts of the fishery, such as depletion of natural prey items and fishing-induced starfish mortality. In their conclusion, Ramsay et al. state that although food subsidies may promote population growth, other factors may prove more important in influencing population size.

The study by Ramsay et al. (2000) illustrates that relationships between energy supplements and population growth are not straightforward and depend on several interacting factors and the life history of the species in question. In addition, the discussed study results may indicate that the effects of discarding on scavenging pelagic and benthic species are not significant or are not a prime motivation to reduce discarding.

5.3 Reflections and insights

5.3.1 Summarizing the indirect effects of C. crangon fishing on populations

The ways by which indirect population effects on scavenging, competitor, predator and prey species may be brought about in the *C. crangon* fishery are through the extractions of biomass from the system (catches of *C. crangon* >46mm) and energy displacement in the food web (through discarding).

The supposition that food subsidies (through discarding) are causing population growth in scavenging benthos and seabirds is not well supported in the literature. Such interrelationships are not straightforward and will depend on the interaction of several factors. Although feeding off discards may sustain populations, population growth of the main benefiting scavengers, seabirds, could not be demonstrated or observed. This also applies to benthic scavengers.

It is possible that by making bottom-living species (juvenile flatfish, C. crangon) available to avian predators, we are depriving other, especially bottom living species of their food source, potentially affecting these populations and the energy flow in the system. Moreover, extractions of large amounts of C. crangon (> 46mm) from the system could be affecting prey, predator and competitor species alike. Neither of these issues are addressed in the literature, however, as research on the effects on bird populations already points out, such extractions or displacements of energy may not necessarily imply major population changes, although of course this will depend very much on the species.

5.3.2 Management implication: fisheries intervention and management measures

The discussed indirect population effects are a poor mandate for intervention. Nevertheless, reducing by-catch and discard mortality will certainly contribute to limiting or preventing any such changes taking place in populations and assemblages. Subsurface discarding has been shown to reduce avian predation, and selective devices are shown to reduce by-catches. These are technical measures that should be encouraged in the fishery.

5.3.3 Improving assessment of indirect population effects of *C. crangon* fisheries.

No pressing research requirements result from this brief literature review. Nevertheless, future investigations into such areas will benefit from consistent and continuous efforts dedicated to delivering thorough spatial effort and catch data. Such data allows for accurate catch and by-catch estimates and determines which populations and assemblages may potentially be affected.

PART III

DIRECT AND INDIRECT EFFECTS OF
MECHANICAL DISTURBANCE OF THE SEA-BED AND ASSOCIATED SPECIES

Chapter 6

ASSESSING IMPACTS OF MECHANICAL DISTURBANCE ON BENTHIC HABITATS AND ASSEMBLAGES

In order to assess how shrimp beam trawling in the North Sea is affecting benthic habitats and assemblages account needs to be taken for spatial and temporal patchiness in both fishing effort as well as environmental conditions.

6.1 Impact assessment and spatial and temporal effort distribution patterns

An assessment of the indirect and direct impact of trawling on benthos and habitats requires a thorough understanding of the spatial and temporal distribution of fishing effort. Such data will indicate which areas, corresponding to typical environmental conditions and associate biota, are being swept and at what intensity.

As has been discussed in previous chapters, trawling for *C. crangon* takes place throughout the coastal waters and in the estuaries of Belgium, the Netherlands, Germany, Denmark and the UK, within the 20m iso-bath. Because of the keel-depth shrimp trawling in estuarine areas such as the Wadden Sea, the Voordelta, the Wash and the Oosterschelde is generally limited to the sublittoral zone, below the low water mark. Only occasionally does fishing take place on the tidal flats (eulittoral zone), this concerns vessels with a small keel depth which, at high tide, may advance into the lower eulittoral zone. Because of this, the area in which shrimp fishing may take place is limited in the estuarine areas, especially in the Wadden Sea, and may be concentrated in particular areas (Lavalije and Dankers, 1993). The introduction of more powerful vessels has allowed for fishing beyond the tidal channels into the coastal waters of the North Sea. In the Schleswig-Holstein area this was argued by Buhs and Reise (1997) to result in effort becoming more smoothed out with a decrease in fishing intensity in the tidal channels of the Wadden Sea, from an estimated twenty times a year twenty years ago to an estimated five times a year in 1997. This indicates that increases in effort may not necessarily lead to increases in intensity.

Systematic documentation of spatial fishing effort in logbooks is required by EC law. This is limited to effort documentation in ICES rectangles (a rectangle is 0.5 latitude by 1º longitude which is approx. 60x60 km). Using this data, ICES (ICES WGCRAN report 2005) produced a time series (2000-2003) of the seasonal spatial effort (hp days) patterns of the Danish, UK and German *C. crangon* fleet in the North Sea [see appendix 6] It is obvious from the ICES study that effort is concentrated in the coastal areas; the effort being highest in the ICES squares directly bordering the shore. In the column of ICES rectangles adjacent to these, thus referring to deeper, off-shore waters, effort decreases markedly in intensity. This pattern is less expressive in the spatial effort patterns of the first quarter (January-April), with effort distribution smoothed out more evenly. This can be explained by an overall decline in shrimp-directed effort over winter, which especially applies to the smaller vessels operating the inshore, and a migration of the *C. crangon* population into deeper waters. As has been remarked upon by the ICES working group on *C. crangon,* the last couple of years show a general trend of larger effort (by Danish fleet) north of Horns Reef and further offshore, in deeper waters. This South-North shift and this shift of effort into deeper waters is a trend that is evident in most North Sea *C. crangon* fleets and is explained by a shift of *C. crangon* stocks into deeper and cooler waters. (ICES WGCRAN report 2005). These observed trends are important to take into account when we want to know which areas are being trawled, when, and with what intensity.

Although effort distribution data over ICES rectangles may be useful to give a general impression of spatial and temporal patterns over larger areas, ICES rectangles provide a poor indication of the specificity of fishing grounds as ICES rectangles are of a very low resolution. This effort data does not allow scientists to determine whether the area from which a given research sample is taken has actually been trawled or not, making such data of limited use in studies on the effects of trawling on benthic fauna and habitats (Jennings et al. 2000). More consistent and comprehensive spatial effort data of the North Sea shrimp fleet, which would allow for a determination of effort intensities at micro-scale, is unfortunately absent.

Another complication arises due to the activity of multiple trawler fisheries operating simultaneously throughout the coastal zone in which shrimp trawling takes place. This will add to the difficulty of empirically distinguishing the long term effects of shrimp trawling and drawing causal links between changes in benthic habitats and communities and shrimp trawling activity. The study by Jennings (2000) attempted to discern spatial and temporal effort patterns (presented as hours of fishing per ICES square) in the North Sea for beam trawling, otter trawling and seine netting activities by the eight North-Sea bordering countries in the period 1990 to 1995. Spatial beam trawl effort patterns proved to be relatively stable over the studied period and were largely confined to the Southern and Eastern North Sea, with the highest levels of fishing effort being recorded inshore (12-mile zone) off the Dutch coast. Despite the stable spatial effort pattern, marked annual fluctuations in the intensity of fishing on the east coast of the North Sea, were observed. The results of this study are not however specific enough to employ into any impact assessment.

Drawing these threads together, we may assume that fishing effort is distributed spatially, leading to patchy effort distribution patterns on both a large and micro-scale. This implies that some areas will be more intensely fished than others. Moreover, spatial distribution of effort has not proven stable over time, but fluctuates according to environmental dynamics and technological developments. This will clearly have implications for the impact of the fisheries on benthic habitats and populations. A proper assessment of the possible effects of beam trawling in the North Sea will not be possible without taking into account macro as well as micro-distribution of trawl effort, through space as well as time.

6.2 Natural diversity and stratification of effects of trawling in the North Sea

Once spatial fishing patterns have been specified, we can couple this with ecological spatial data. Trawling will have different immediate and long-term effects on different benthic habitats, benthic species and communities, some proving more resistant to the various forms of disturbances inflicted by trawling than others. Taking this into consideration, stratification of effects by biotope is both useful and necessary to allow for a proper assessment of the impact of commercial shrimp trawling on the marine ecosystem.

A habitat is composed of various components and may be exposed to high or low levels of natural disturbance, resulting in unstable habitat conditions. Habitat conditions and their dynamics, determine to a large extent the species' assemblage and abundance typical to a particular area.

It is quite obvious that commercial shrimp trawling on the North Sea does not occur in an entirely homogenous area; not geo-morphologically, hydrologically, bio-chemically or biologically. Across the trawled area there are noticeable differences in depth, substrates, temperature, tidal influences and currents, salinity and primary production, leading to a scalar of marine environments with their own distinct biota.

The shallow estuarine areas, with their tidal channels and flats, have a distinct identity when compared to the deeper coastal areas of the North Sea, where disturbing forces such as currents, gales and tides have a smaller impact, and therefore have more stable environmental conditions (such as temperature and salinity). Deltas (where terrestrial rivers flow into the sea), with their riverine influences, also have a distinct identity in terms of environmental conditions and biota. They have a characteristic biochemical composition showing high variability according to river discharge and sediment deposition. The latter will also influence substrate types in the area.

Within the estuaries we also encounter diversity. The tidal channels branch off the deeper tidal inlets, fan out towards the mainland into a shallow tidal 'delta' and constitute distinct geomorphologic and hydrological structures in the Wadden Sea. They serve to transport the ebbing waters from the inter-tidal flats to the North Sea and the flooding waters back to the tidal flats (Buhs and Reise, 1997), and may be regarded as marine rivers with fast currents of 0.7-1.5m/sec, a length of 10-30km, a width of up to 2km and an average depth of 5-15m (Wadden Sea of Schleswig Holstein). The environmental conditions in these tidal channels may be assumed to be much more dynamic as natural but highly variable forces such as wind, air temperature and currents have a greater effect on these shallow, tidal zones. Consequently, sediment displacement and restratification is phenomenally high in these areas (pers. note Neudecker 2006). Tidal channels may be seen as a transition zone between the tidal flats and the North Sea. This is reflected by the typical species' assemblages encountered in the tidal channels; containing both distinct ecotone biota as well as characteristic species of the two adjacent benthic communities of the tidal flats and the North Sea (Buhs and Reise, 1997). Also along the vertical lines of a channel, nuances in geomorphologic and hydrological conditions can be observed, giving way to a range of micro-habitats with their own typical benthic species' assemblages and abundance. The study by Buhs and Reise (1997) demonstrates that tidal channels in the Wadden Sea are not entirely equivalent in terms of epifaunal species richness and abundance, a marked difference being detected between channels situated in the northern part of the Wadden Sea and those situated in the southern part of the Wadden Sea, indicating diverse environmental conditions.

The above implies that when assessing the kind and the scale of effects of shrimp trawling the diversity of micro and macro habitats, and associate species' assemblages occurring throughout the commercially trawled area will have to be taken into account.. Moreover, these effects will have to be understood as taking place against a background of natural disturbance and change. Only when such patchiness and variability has been considered, mapped out, and attributed with spatial effort data can we make an attempt to assess the full scale, immediate and long term impacts of commercial trawling on the marine ecosystem and find sound management advice.

6.3 Reflections and insights

6.3.1 Summarizing impact assessment of mechanical disturbance on benthic habitats and assemblages.

Both effort patterns and environmental conditions display spatial patchiness and variability through time. Gaining insight into both is vital to conducting a proper impact assessment, in which the short-term, but especially the long-term effects, of trawling at different levels of intensity may be determined and scaled, and in which spatial nuances in sensitivity to trawling, deriving from the spatial heterogeneity in benthic habitats and assemblages and the way these are adapted to disturbance, are expressed.

Spatial effort patterns of the *C. crangon* fleet remain at a descriptive level. Trawling occurs throughout the coastal waters (within the 20m isobath) and the tidal channels and inlets of the estuaries, throughout the year. These hydrological entities are all distinct in terms of environmental conditions and dynamics and result in a tapestry of benthic habitats and assemblages. We may expect to encounter typical assemblages in the coastal waters, the tidal inlets and channels, and along a vertical gradient in the tidal channels. The spatial effort data are, however, too non specific to locate fishing effort with precision and determine at what intensity any such areas are being disturbed.

Attempting to conduct impact assessment in the absence of such information would make such an assessment fundamentally flawed.

6.3.2 Management implications: fisheries intervention and management measures

This chapter highlights the fact that management measures taken to reduce impacts of trawling on the marine environment must account for spatial diversity in benthic habitats and assemblages encountered in the trawled areas. The challenge will be to tune fishing effort on a local scale to the natural propensity of a community to endure disturbance. Because the natural propensity varies across communities and habitats, and because communities and habitats can be spatially defined, a spatial dimension has to be brought into fisheries management.

6.3.3 Improving assessment of the effects of trawling on benthic communities and habitats

To conduct a proper impact assessment that can consequently be employed in management, fisheries must deliver accurate spatial effort data which tells us exactly where, at which time, for how long and on what date trawling has taken place. This must be complemented with a determination of the typical assemblages and habitats occurring in these areas so that we can stratify and scale impacts and focus our research efforts.

Chapter 7

TEMPORAL AND PROLONGED HABITAT DISTURBANCE

Direct physical contact of the trawl with the substratum can lead to compaction and re-suspension of sediments, to the resorting and displacement of particles, and to the destruction of biogenic and biological substrata. The magnitude and duration of this impact is determined by the speed of the towing, physical dimension and weight of the gear, the type of substratum and strength of currents or tides in the areas in which fishing occurs (Jennings et al., 2000) and, in the case of biological and biogenic substrata destruction on the potential of the biogenic substrata to be rebuilt. Effects may persist for several hours in shallow tidal zones or up to decades in deeper areas subject to less natural disturbance (Fontyne, 2000). These impacts matter because they imply temporal or prolonged alteration of habitat conditions, structure and complexity, which may, when occurring on a large scale, have a significant impact on benthic populations and assemblages.

7.1 Physical pressure exerted by the gear and gear-bottom interaction

The beam of a shrimp beam trawl hovers about 50cm above the ground. The bottom line is supported by rollers, making it practically impossible to drag the bottom-line through instead of over the bottom (Lavalije and Dankers, 1993). Contact with the bottom is made by the trawl shoes and the rubber rollers which are connected to the bottom-line. Both the beam and the shoes are made of iron (Berghahn and Vorberg, 1998). The bottom line is fitted with 35-40 rollers. Rollers are made of hard rubber, the shafts and fittings of iron.

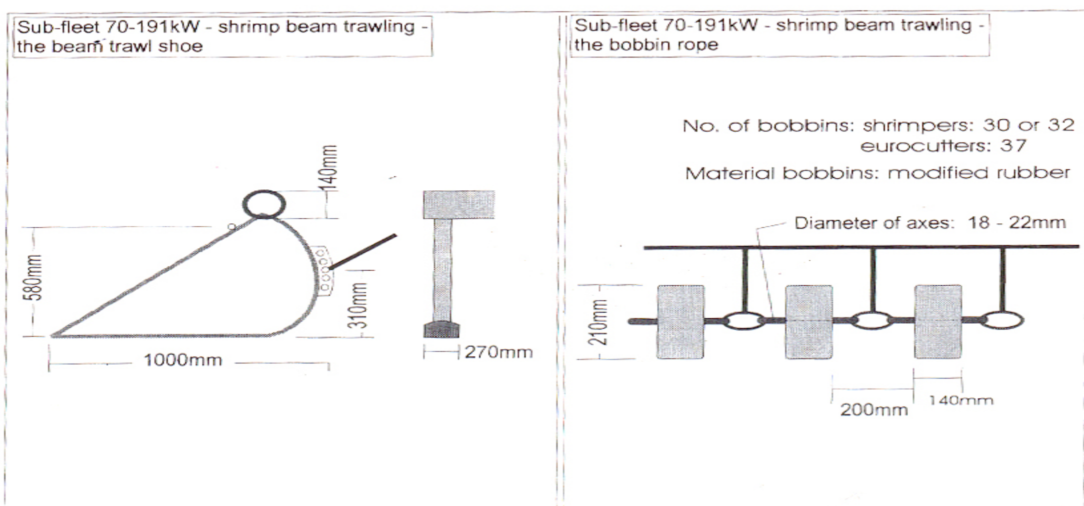


Fig. 7.1. Trawl shoe and bottom-line with bobbins (source: Lindeboom et al. 1998)

The pressure that these elements exert on the sea bed is strongly dependant on the weight of the beam trawl and the trawl speed. As the speed increases, the lift of the gear will increase and the resultant pressure force decreases (Fontyne, 2000 and Berghan and Vorberg , 1998). The speed at which the gear is towed (ca. 3 miles/hour) assures bottom contact and is much lower than the trawl speed in Plaice and Sole fisheries. At higher towing speed and with lighter gears the trawl will start to hover, which is not desirable. Using a 9m shrimp-beam trawl, Berghahn and Vorberg (1998) found that the beam and shoes together weighed 550 kg. The rubber rollers, including shaft and fittings weighed 6.5kg each. The force exerted by these components on the contact surface is 0,23 kg/cm^2 for the trawl shoes and about 0.33 kg/cm^2 for the rollers on hard sandy bottoms. The force of the rollers will vary depending on the substrate, which determines the contact surface of these cylindrical rollers. Soft substrates (silt) will provide greater contact and thus smaller force than hard substrates (sand). These forces must be corrected for buoyancy and the vertical force exerted when trawling. The latter is a function of the angle between the warp and the seabed (generally constant) and the tractive force of the vessel (165 kg per beam for a 200hp vessel, assuming trawling with half the max. tractive potential). Correcting for buoyancy and vertical force the pressure exerted by the shoes as well as for the rollers is calculated to be 0,13kg/cm^2 on hard sandy bottoms. This is merely a tenth of the pressure exerted by a human foot (1,5kg/cm^2) and only half of the pressure exerted by a typical beam trawl used in the flatfish fishery (Vorberg, 2000 using findings of Lindeboom and de Groot, 1998).

The bottom-line is longer than the beam. This creates a camber which serves to offset unevenness in the sea bottom and to overcome obstacles. This camber also increases catch efficiency of *C. crangon* (Berghahn and Vorberg, 1998). The size of the camber will vary according to the substrate and fisherman's experience. This camber causes the outer-most rollers to be dragged, instead of rolled, across the seabed, thereby leading to a higher level of disturbance (Berghahn and Vorberg, 1998).

The net is also said to make bottom contact (pers. note Dankers, 2006), sweeping the bottom at intervals. No further mention of this is made in the literature.

Trawl-bottom interaction during trawling over different substrates was recorded by Berghahn and Vorberg (1998) using an underwater camera. The contact time with the bottom was recorded for the rollers using different *warp length*s for hard and soft sands, shells and Sabellaria reef. On average the rollers had only 50% bottom contact during the entire trawl time. Images showed that rollers are never in permanent contact with the bottom. On sandy bottoms with ripples, a typical substrate structure for the Wadden Sea, the rollers regularly bounced off the bottom. This behaviour was even more pronounced on a shell covered bottom or on Sabellaria reef, which represent even harder substrates. This 'jumping' behaviour of the rollers results in shorter bottom contact, limiting the impact on the sea bottom. The warp length can be manipulated by fishers. Typically they pay out more warp when the bottom is known to be free of net destroying structures. When fishers are aware of the danger of snagging the warp is shortened (Berghahn and Vorberg, 1998). Due to their larger weights the shoes have more constant bottom contact as was demonstrated by the experiments conducted by Berghahn and Vorberg (1998). However, with their overall width of 80 cm they will potentially affect only a relatively small part of the sea bottom. The depth of penetration into the sediment is considered light due to their low exerted pressure. This penetration depth can be expected to vary depending sediment type. This assumption is derived from a study conducted by Bergman and Hup (1992, in Berghahn and Vorberg, 1998) on trawling in Sole fisheries, in which a correlation between penetration depth and sediment type is demonstrated. On hard sediments the shoes of a beam trawl used in Sole fisheries (weighing 5-15t) penetrate only the top 2cm, whilst in softer sands penetration of the shoes into the sediment up to 10-12 cm was observed, potentially causing much greater disturbance.

The way and extent to which the trawl (shoes, rollers and net) exerts pressure on the sea bottom is thus a function of trawl characteristics such as; weight, warp length and haul speed, as well as substrate characteristics such as; sediment type and structure. The trawl is shown to have higher bottom contact in soft, smooth substrates, also having a higher penetration depth opposed to harder sandy substrates and substrates with more structure on which the trawl shoes show jumping behaviour thereby limiting bottom contact. As opposed to the rollers the shoes have more continuous bottom contact, this being observed on all sampled substrates.

7.2 Mechanical disturbance of substrata and habitat destruction

As described in the previous paragraph, a shrimp beam trawl is relatively light gear, exerting relatively low pressure on the sea bottom. Nevertheless, by the passage of a beam trawl the topography and structure of the seabed may be altered by displacing sediment (incl. restratification and suspension); destructing biogenic and biological substrata, ultimately smoothing and flattening the seabed. By causing re-suspension of sediment and toxic particles settled on the sea bottom into the water-column, turbidity and chemical composition of the water-column will be affected. The extent of mechanical disturbance depends on trawl-bottom interaction, as has been discussed in the previous paragraph, whilst the persistence of this disturbance will depend on the level of natural disturbance such as currents, wind and tidal forces as well as the sediment type, which will influence the sensitivity to disrupting potential of these forces. For biogenic and biological substrata persistence of the disturbance will depend more on the intrinsic recovery potential or the rebuilding capacities of populations. The substrata are subdivided in sedimentary substrata, biological and biogenic substrata. These three are all distinct in their exposure and sensitivity to the trawl, the way in which they perform a habitat function.

7.2.1 Mechanical disturbance of sedimentary habitat structure

Anon (1988, in Fontyne 2000) demonstrated that areas with soft muddy bottom or with low tidal currents are likely to be more severely effected by bottom trawling than areas with a firm substratum (compacted sand) and those subject to periodic strong tidal currents or wave turbulence caused by gales in shallow coastal areas. This relationship was also demonstrated in the work of Berghahn and Vorberg (1998), who did trawling experiments in the Schleswig-Holstein area of the Wadden Sea. The sublittoral zone in the Schleswig-Holstein national park (a part of the German Wadden Sea) is for 95% composed of sandy substrate, only occasionally being interrupted by other types of sediments (rocks, stone, clay, peat and silt) or biogenic benthic habitat structures such as mussel banks, Sabellaria reefs and *Lanice conchilega* carpets. Their study was therefore centred on areas with predominantly sandy substrate. After trawling tracks of the beam trawl shoes could be distinguished on the sandy bottoms and in the area of the Lanice carpets. Experiments conducted by Berghan and Vorberg (1998) in the eulittoral zone on mixed flats of a more silty nature showed that both the shoes as well as the rollers left parallel grooves of 2cm deep, which were still evident 12 hours after trawling. This differential effect on the sea bottom as compared to experiments conducted on the hard substrates of the tidal channels is attributed by Berghahn and Vorberg to the soft sediment which permitted penetration of the shoes and the rollers, which was induced by both a lower trawling speed and finer sediment type.

According to Lavalije and Dankers (1993) it is unlikely that shrimp trawling will change the structure of sand or silt bottoms. This may not be true for clay and peat banks which have a typically rough relief due to eroding effects of the currents. Nevertheless this may not be relevant as shrimp trawlers refrain from these areas. However, occasionally and locally trawling on such grounds will occur when economically valuable species such as lobsters are targeted. This trawling activity may destroy the naturally occurring relief and structure of these substrates.

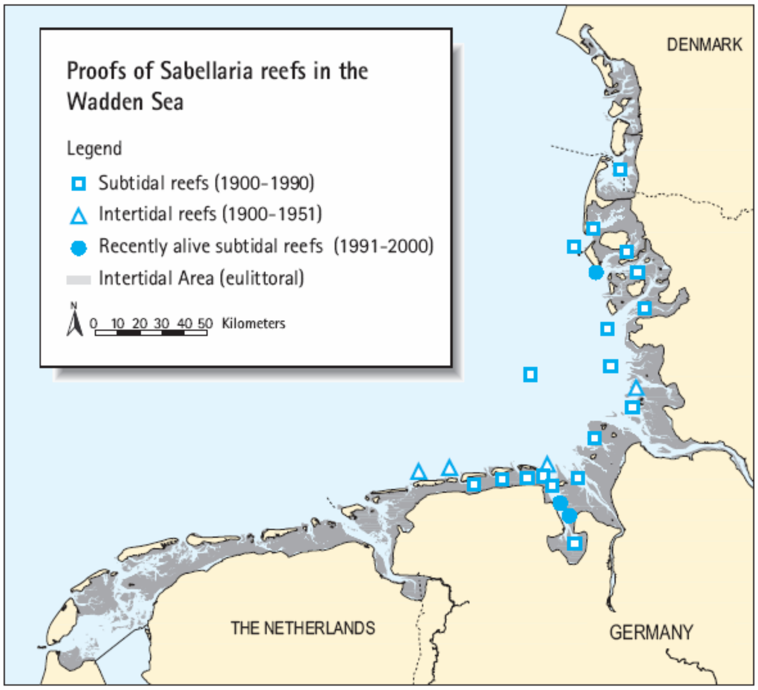
Relationships between the extent and persistence of disturbance, and sediment type were demonstrated in the study of Fontyne (2000), who assessed the physical impact of flatfish beam trawls on seabed sediments. His study results indicate that the length of time that the beam trawl marks remain visible depends on the upper sediment layer. On a seabed consisting of mainly coarse sand, the tracks remained visible for up to 52 hours whereas on sediments with mainly finer particles, the tracks had completely faded after 37 hours. Re-suspension was observed to make the bottom harder and less rough, these effects being most pronounced in areas with lighter sands as lighter sediment fractions prove more susceptible to being re-suspended. This effect was not long lasting as the conditions were restored to the original situation within 15 hours. However, the problem of turbidity is argued by Lavaleije and Dankers (1993) to play no significant role as the fishing grounds in this fishery are generally not muddy (silt-rich).

7.2.2 Mechanical disturbance of biogenic habitat structures

Sabellaria reefs

Sabellaria reefs are hard biogenic structures, composed of numerous long hard tubes produced from sand grains by the *Sabellaria spinulosa* worm. The species is found in hard substrata. In the North Sea the occurrence of *Sabellaria spinulosa* is sporadic and under particular conditions may develop enormous colonies, resulting in the formation of extensive reefs. In shallower waters these reefs generally occur for a limited amount of time but in deeper waters they tend to take on a permanent status (Lavalije and Dankers, 1993). These reefs have a habitat function and are argued to belong to the estuarine biota of the Wadden Sea.

Sabellaria spinulosa colonies have become increasingly rare in the Wadden Sea (Lavalije and Dankers 1993, and Vorberg 2000). No sightings of Sabellaria colonies in the Dutch Wadden Sea have been reported in the historical literature. Opposed to this, German literature (Richter 1927) mentions large atolls of Sabellaria-tubes in the German Wadden Sea 10km off the coast of Busum. Whereas 20 Sabellaria reefs have been recorded to have existed in the past, now only 3 remain (Vorberg 2000). Also in the Minsener Balje a 120m riff has been observed. According to Lavaleije and Dankers (1993) most of these riffs have disappeared from the Wadden Sea and are now only encountered in few areas. Also along the coast of England the worm has suffered major decline. Only below the tidal zone in the Wash riffs have been signalled (Lavaleije and Dankers, 1993).



The decline of Sabellaria reefs is often hypothesized to be the result of mechanical disturbance inflicted by shrimp trawl fisheries, which have operated in corresponding areas throughout the last century (Riesen and Reise 1982; Buhs and Reise 1997). Riesen and Reise (1982) argue that the shrimp and trawler fisheries deliberately destroyed these obstacles to facilitate shrimp trawling and prevent damage to the nets. Vorberg (2000) criticises this claim by Riesen and Reise. According to Vorberg the tractive force of the vessels used in the mid-20th century (30-65hp as compared to 200hp today) was insufficient to release gear after entanglement or to damage the robust reef construction, thereby putting serious question marks behind the supposition of Riesen and Reise (1982). Buhs and Reise (1997) cite Tiews (1953) who claimed that trawling along the slopes of the channels especially in the vicinity of Lanice carpets and Sabellaria reefs proved most rewarding in terms of crangon catches. This, under repetitive trawling, is suggested by Buhs and Reise (1997) to have resulted in the destruction of Sabellaria reefs.

Very little studies have however been carried out to verify this hypothesis. Vorberg (2000) made such an attempt in his study which experimentally assesses the short-term impacts of beam trawls on Sabellaria reefs. Compressive strength measurements and gear-bottom interactions were observed in the laboratory and in the Wadden Sea using a 9m shrimp trawl fitted with 10 rollers. Furthermore a 3m beam trawl was used in trawl experiments over a *Saballaria alveolata* reef in France. The beam and the shoes of the 9-m trawl weighed 550 kg on land. For each roller this was 6,5kg. Thus, as in Berghahn and Vorbergs study (1998) exerting a force of 0.13 kg/cm^2 for both the shoe as the rollers at a towing speed of 2-4 knots. Compressive strength measurements suggest that Sabellaria reefs are highly stable structures. This is also supported by observations made by persons walking over the reef surface at low tide, leaving no visible damage. The study revealed that rollers had no problem running over the reef which forms a relatively hard bottom. The rollers regularly jumped off the reef surface and had bottom contact for 39% of the overall trawling time. This is consistent with earlier studies carried out by Vorberg (1997). Taking this, and the relatively low force exerted by a roller, into consideration Vorberg (2000) concludes that the rollers used in the crangon fishery cannot cause damage to the reef. This was confirmed during the towing trials in which no damage to the reef structure (30-40 cm) was observed. The trawl shoes did however make clear impressions. All traces of trawling disappeared after four to five days of trawling. The *Sabellaria alveolata* worm was not harmed by trawling practices, therefore recovery is relatively quick and depends on the rebuilding capacities of the worm, which is a matter of days (Gruet 1971, in Vorberg 2000). Vorberg remarks on the possibility of reef damage occurring due to entanglement with the ground rope on steep reef edges. This is, according to Vorberg (2000), also a reason why shrimp fishers tend to avoid reef contact as this causes damage to the gear. The fact that recent reefs reside in intensively trawled areas (Vorberg 2000) supports his argument. The study done by Vorberg (2000) assessed the short-term impacts, following only one disturbance. As Vorberg himself points out, impairment of the reef may occur in the circumstance of high trawling intensity, despite the lightness of the gear.

What becomes clear when analysing the literature and the study conducted by Vorberg that trawling occupying on Sabellaria reefs has not been empirically proven, this claim remains highly contested. Secondly, the study of Vorberg (2000) indicates that the impact of trawling over Sabellaria reefs is limited to the trawl shoes, this damage being restored within a matter of days. If it can be confirmed that trawling occurs on these reefs it would be worthwhile to asses the impact of endured commercial trawling. Despite all this ambiguity, it is seems reasonable to assume that re-colonization of vast numbers of *Sabellaria spinulosa* and the rehabilitation of Sabellaria reefs is not facilitated by the trawling activities of the crangon fishery.

Lanice carpets

In the sublittoral zone in the Schleswig-Holstein national park (a part of the German Wadden Sea) *Lanice conchilega* carpets occur. After trawling, tracks of the beam trawl shoes could be distinguished in the area of the Lanice carpets (Berghahn and Vorberg, 1998). The ends of the *Lanice conchilega* tubes protruding with 5cm above the sediment had been flattened by the shoe. Opposed to this, no damage was observed for the trawl rollers. The worms themselves are not harmed as they have the capacity to retreat quickly into the depths of their tubes which reach 30-40cm into the sediment. This indicates that the regenerative capacity of this biogenic substrate is not affected. The work of Berghahn and Vorberg does not determine the long-term impacts of trawling on these worms and these habitat forming structures.

7.2.3 Mechanical disturbance of biological habitat structures

Mussel banks

Mussel banks occur primarily in the tidal zone where they may take on a permanent form (Lavelije and Dankers, 1993) and constitute a unique habitat with a typical flora and fauna. Natural factors such as rough weather conditions and predation, but also the mussel fishery can pose a threat to mussel banks, residing on the tidal flats. Also below the sublittoral line mussel banks may occur. Due to high predation pressure, these have a more temporary form. The shrimp fishery could potentially have an effect on these mussel banks but this effect will be minimal considering the large impact of natural predation and the effects of the mussel fishery. Moreover, shrimp fishers are argued by Lavaleije and Dankers to avoid these mussel banks when their presence is known as they damage the nets

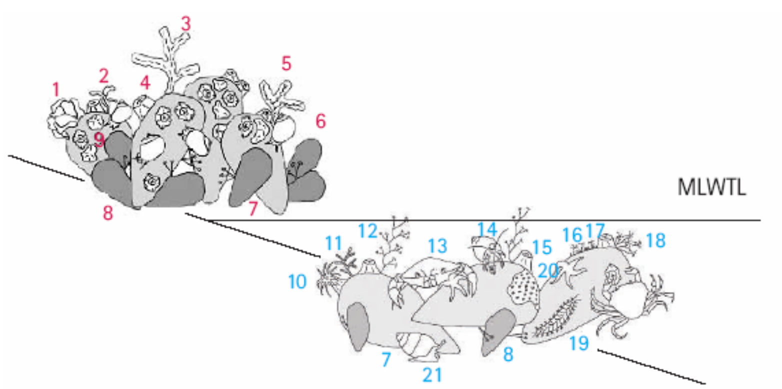


Fig. 7.2. Subtidal (below) and intertidal (above) mussel beds show different Ecological patterns in relation to biogenic structure, species interactions and the community of associated organisms. Typical species associated with inter-tidal and subtidal mussel beds are shown. MLWTL = Mean Low Water Tide Level.

Oysterbanks

The flat oyster *Ostrea eulis* is an 'endemic' species to Dutch waters and resides on hard substrata, which are generally scarce in these waters. In vast numbers they may form oyster banks. According to Lavaleije and Dankers (1993), due to the activities of the oyster and mussel fishery, entire oyster banks have disappeared or else have severely declined since the 17th century. Recovery of these oyster banks is slow as oyster banks take tens of years to develop. Even though the shrimp fishery is not held responsible for this decline, it is argued by Lavaleije and Dankers that it may be one of the factors that prevent resettlement of this species and rehabilitation of these oyster banks.

White weed beds

S*ertularia cupressina* is a colony forming hydroid polyp commonly known as white weed (plant-like appearance), occurs on hard substrates (sandy bottoms with shells) and is generally considered as belonging to the oyster bed biocoenosis. The optimal growth takes place at a salinity of 25-30% at a depth of 4-8 meters and may grow 25 cm a year; it can become tens of centimetres high and 2-3 years old. Extensive beds were encountered in the sublittoral zone in the German Wadden Sea up until the end of the 1960's. White weed beds once occurring in Dutch waters were found in the mouth of the South Sea (Zuiderzee) and in the Wadden Sea (the 'Blauwe Slenk' and 'De Meep') (Lavalije and Dankers, 1993). These beds coincided with the locations of the oyster beds (Hagmeier and Kandler, 1927, in Berghahn and Vorberg, 1998). Since the early 1970 stocks have dwindled, and white weed beds have disappeared, although the species still occurs in the Wadden Sea especially in the gullies. The cause of this decline is remains uncertain. Some scientists ascribe the decline to the white-weed fishery which took off at the end of the 19th century and continued, with irregular patterns of intensity, up until 1970s (Berghahn and Vorberg,1998). This decline may also be associated with the disappearance of the oyster beds at the end of the 1920's and the decline in Sabellaria reefs with which an important secondary substrate for *S. cupressina* went lost. Despite the fact that shrimp trawling has occurred in the areas in which white weed was encountered, Berghahn and Vorberg (1998) argue that the shrimp fishery is unlikely to have effected these beds as shrimp trawling takes place with the current, moreover exerting only very little pressure. *S. cupressina* is known to be a very flexible structure which is pressed flat against the sea bottom in contact with the trawl; moreover it endures a high compressive strength, therefore enduring relatively high pressures.

See grass fields

Only in very few areas in the Dutch coastal waters does sea grass still occur (Lavaleije and Dankers 1993). In the Oosterschelde Sea Grass is relatively most common. All Sea Grass fields found in the Dutch waters reside in the tidal zone, on the tidal flats. Sublittoral Sea Grass fields are no longer found in Dutch waters (Polderman and Den Hartog, 1975, in Lavaleije and Dankers, 1993). The depth to which the sublittoral grass fields may develop is strongly related to light intensity and is therefore limited to a maximum depth range of 1,75m for the Wadden Sea (De Jonge and De Jonge, 1992, in Lavalije and Dankers, 1993). Only in areas with very clear waters will Sea Grass occur to higher depths, of up to 5m (Nienhuis 1985, in Lavaleije and Dankers, 1993). The drastic decline of Sea Grass fields in West Europe since 1932 is, according to Dankers and Lavaleije (1993) not related to the activities of the former Sea Grass fishery, but ascribed to a set of environmental and other anthropogenic factors. The still existing and seemingly declining Sea Grass fields, are argued to be very sensitive to mechanical disturbance (Philippart et al. 1992, in Lavaleije and Dankers, 1998). Mechanical disturbance, being exerted by for instance the shrimp fishery operating in the sublittoral zone, will inhibit and thwart the resettlement of the species. Because this species in the Wadden Sea, only grows in shallow waters of up to 1,75m, the potential impact of the shrimp trawlers would depend on the depth range in which the trawlers operate.

Meyer et al. (1998) dedicated a study towards the short-term effects of shrimp trawling on seagrass beds (Turtle grass, *Thalassia testudinu*) in Tampa Bay, Florida). Sampling was done using a double beam trawl with a beam length of 3.38m and net fixed to a stainless steal frame with a slotted roller along the entire lower portion of the frame. The roller trawl was purposefully designed to reduce seagrass fragment collection, thus, if this typical design significantly influences the effects of the beam trawl on seagrass the results of this study may not be directly applicable to the North Sea Crangon fishery. The beam trawl weighed ~75kg. No significant impact on shoot density, structure or biomass of turtle grass was detected with increased trawling intensity (up to 18 trawls a month). This study does not however asses the effects of repetitive trawling over a longer period of time. According to Kenworthy and Haunert (1991, in Meyer et al 1998) the photosynthesis potential of sea grass can be affected through possible local increase in water turbidity. In contrast to this, limited trawling in areas with substantial epiphytic growth and numerous senescent turtle grass leaves, light availability may be enhanced by removing old plant parts and epiphytic growth from the plants (Woodburn et al, 1957, in Meyer et al., 1998). Meyer et al. also point to associated faunal community by collecting and redistributing macro algae and turtle grass litter, ultimately affecting the habitat complexity in different areas in different ways. This in turn may take an effect on species abundance and composition (Gore et al., 1981; Kulczycki et al., 1981; Leber, 1985, in Meyer et al,. 1998).

7.4 Habitat destruction and effects on populations of associate species

The ways in which trawling affects habitats has been discussed in the previous paragraphs. It was discussed how trawling may; smooth sedimentary bed forms and reduce bottom roughness; destruct, biogenic substrata or remove taxa which produce structure. Through these effects habitat complexity and structure will be reduced. The spatial scale, frequency and intensity at which disturbance occurs but also the rate at which substrata may recover, will determine whether the properties of a benthic habitat may be fundamentally and irreversibly changed. Temporal and prolonged but especially chronic changes of habitat conditions matter, because they may have and effect on associated species. Just how big this effect on populations will be depends of course on the habitat function that the substrate performs and the way that populations are dependent on the benthic habitat in their survival and life cycle, and how they respond to (temporal or prolonged) changes to their habitat.

Disturbance of biological substrates, typical to the trawled areas in the North Sea (sandy substrates) was shown to be mild and of a temporary nature. The high levels of natural disturbance correct for the changes brought about through trawling. Although no further research has been conducted to determine the effect of this disturbance on populations it is imaginable that the species which are encountered in these environments are adapted to high levels of disturbance to the habitat conditions implying that trawling induced disturbance to the habitat will be relatively low and the effect on populations equally so.

In contrast to disturbance of sandy substrates, large scale and prolonged disturbance to biogenic and biological substrata is argued to have a significant impact on populations as such benthic structures perform unique habitat functions and form a more stable and permanent substrate. Species such as *Sabellaria spinulosa*, Bivalves, White Weeds, *Lanice conchilega* and seagrasses, when in vast numbers, perform important habitat functions by providing hard structures to which other species may attach or alternatively providing refuge and shelter. White Weed beds are home to a characteristic fauna but also function as spawning area for Garfish and Herring. Similarly sublittoral Sea Grass fields are home to a unique and very rich community of species. Species such as the Fifteen Spine Stickleback *Spinachia spinachia* and the sea snails *Rissoa membranacea* and *Lacuna vincta* are typical species for this biotope and have entirely disappeared from Dutch waters (Lavalije and Dankers, 1993). Also their rich flora of Red Weeds makes Sea Grass Fields unique. Mussel banks occur primarily in the tidal zone where they may take on a permanent form (Lavaleije and Dankers, 1993) and constitute a unique ecosystem with a typical flora and fauna. Removal of, or disturbance to such structures, will fundamentally affect the species which rely on these structures. No evidence can be delivered that the *C. crangon* fishery has caused chronic disturbance to any of these structures. It remains rather disputable whether trawling has actually occured over these structures. Nevertheless, the argument that trawling may prevent re-colonization and recovery of such structures by constant disturbance of these fragile life forms, seems to be well supported. However, this has not been researched.

7.5 Reflections and insights

7.5.1 Summarising trawl-bottom interaction and the effects of temporal and prolonged habitat disturbance

The beam trawl employed in *C. crangon* fisheries has been demonstrated to have the potential to disturb sedimentary as well as biogenic an biological substrates. This matters as substrates have a habitat function and may be vital in supporting benthic populations and assemblages.

The way substrates are disturbed depends primarily on substrate type and structure, and the weight and characteristics of the gear. The elements of the gear that may make contact with the substrate are the beam trawl shoes, the rollers and the net. The latter is not mentioned in literature and has therefore not been dealt with. Bottom contact may be shortened to more than half the trawl time on harder irregular surfaces due to the jumping behaviour of the gear. This behaviour is much more expressed for the lighter rollers than for the heavy trawl shoes. As opposed to the rollers which are dragged over the sea-bottom, the shoe is generally dragged through the upper layer of the substrata thereby causing much greater disturbance. The penetration depth and extent of this effect depends on the sediment type and structure of the substrata. On softer substrata this effect is much greater than on hard substrata. The typical behaviour of the gear elements characterises the way in which they disturb. Whilst the rollers seem especially to cause compaction and crushing, the shoes especially cause the re-suspension and stirring up of sediments. In summary the impact on the sea bottom is much greater for the trawl shoe than for the trawl rollers. The direct impact increases in softer substrata with finer sediment types.

The persistence of the disturbance depends on both the severity of this disturbance, the level of natural disturbance occurring in the area and the sediment type. In those areas subject to high levels of natural disturbance (caused by strong tidal currents and wave turbulence caused by gales in shallow coastal waters) trawl tracks may disappear within hours, even more so in fine sediments. In those areas which are subject to low levels of disturbance the trawl tracks will remain visible longer. This especially applies to the shoe tracks.

Considering that trawling takes place predominantly in the sublittoral zone of the tidal channels and in the shallow coastal waters where harder substrata (sandy sediments) prevail with irregular surfaces, the direct mechanical disturbance will be limited. Moreover, these are also areas with strong tidal influences and wave turbulence implying that the disturbance to the substrata caused by the trawl will be short term and relatively insignificant compared to the force and magnitude of natural disturbance. Species occurring in such areas will most probably be adapted to such dynamics suggesting that temporal disturbance of the substrata through commercial trawling will unlikely affect associate species and assemblages. This makes trawling on such substrata less concerning.

The biological and biogenic substrata that have been considered in this chapter form relatively stable and permanent structures and perform important habitat functions by supporting their own unique biocoenosis. This makes them especially important from an ecological perspective and implies that prolonged and chronic disturbance to such substrates is detrimental to the species abundance and richness in an area. Trawling over biogenic structures such as Lanice carpets and Sabellaria reefs has been demonstrated to be damaging. This damage is limited to the trawl shoe. Different to sandy substrates, the persistence of the disturbance depends on the rebuilding capacities of the worms, which remain unharmed. This is a matter of days for *Sabellaria spinulosa* implying that at low trawling intensities and scale effects on associate species will be limited. The impact of repetitive trawling at high intensities has however not been researched. Furthermore it remains unclear whether trawling actually takes place on these reefs and carpets. Hard biological substrata such as mussel and oyster banks are not visibly affected by the trawl. Moreover *C. crangon* trawling generally does not take place on these substrates. Similarly flexible biological substrata such as White Weed bed and Sea Grass fields also seem not to be disturbed by the trawl. Despite multiple evidence suggesting that commercial trawling is not responsible for causing chronic damage to these habitat structures, trawling may be preventing re- colonization and the rehabilitation of fragile structure forming populations by repetitive disturbance to the substrata on which such structures are fixed. This hypothesis has not been verified but nevertheless seems to be well accepted.

Thus with the knowledge we have now, evidence of irreversible and chronic impacts of shrimp trawling on habitat structures and their associate assemblages does not seem to be very strong as: (1)Trawling seems to be taking place primarily on the sandy substrata, moreover, avoiding hard structures which potentially damage or block the nets.(2) The gear is relatively light causing relatively little disturbance of the sea bottom (especially on sandy bottoms) and minor effects on habitat forming taxa. (3) Species inhabiting the highly dynamic environments of the shallow tidal zone endure a high level of disturbance.

The strongest case against trawling in terms of chronic habitat disturbance is still hypothetical, yet plausible, and concerns the effect that repetitive disturbance has on the recovery of habitat structures.

7.5.2 Management implication: fisheries intervention and management measures

Management measures are warranted when trawling is demonstrated to take place on substrata that prove to deliver an important habitat function (or a potential habitat function), moreover, which do not sustain the levels of trawling thereby resulting in prolonged alteration of the habitat conditions. If this should be the case, then such substrata should be preferably avoided and 'spatial planning' brought into fisheries management.

Improvements to the gear may prove effective in limiting the disturbing potential of the trawl. This should focus on resolving the dragging effect of the outer rollers, the net and on the trawl shoes.

7.5.3 Achieving a better understanding of the disturbing impacts of trawling on substrata

The most pressing issue on the research agenda, in terms of mechanical disturbance and habitat destruction, concerns biogenic and biological structures. And must deal with key questions such as: what structure forming taxa and substrates are encountered in the trawled areas? Where would we expect to find extensive habitat structures, but are absent? What intensities of trawling do these structure forming taxa sustain? These questions once again demand sound spatial effort data combined with spatial data on substrates and species distribution. As for our most urgent hypothesis concerning how disturbance inhibits recovery of such structures may only be answered by closing particular areas to trawling for longer period of time (for instance a tidal channel or else a suitable depth band in which such structures are supposed to occur).

Chapter 8

DIRECT TRAWLING MORTALITY AND EFFECTS ON BENTHIC POPULATIONS

The beam trawl is a bottom-fishing gear with small mesh-sizes. In targeting shrimp, it may have a direct effect upon those species living or feeding in this benthic environment, despite its slow haul speed (~ 3 miles an hour), relatively light gear and the absence of tickler chains. Benthic species may suffer direct mortality through the crushing effects of the trawl or by being caught as by-catch. They may suffer injuries by the passage of the trawl or through the catch handling on board, leaving them vulnerable to predation and infections. Furthermore, trawling may uncover benthos burrowed in the substratum thereby exposing them to predators. Finally, although not necessarily leading to mortality, the disturbances, when accumulated and occurring at a high frequency, may place an excess energy demand on benthic species, potentially leading to distorted growth, development and reproduction (Wilbers 1971, in Lavalije and Dankers 1993). Trawling induced mortality may, when occurring at a sufficiently high scale and intensity, amount to population effects ultimately affecting species richness and abundance. By-catch and discard mortality has been discussed in previous chapters so this will not be discussed again extensively.

8.1 Ways to die and differential effects of trawling on benthic species

The way that trawling affects benthic species varies between species as well as within populations and is determined by the extent to which a specimen is exposed and sensitive to the impacts of the trawl and the potential to recover from and therefore endure a certain level of disturbance. The capacity to resist disturbance depends on the reproduction, growth and re-colonization rate of a population or species. This may be expected to be high in the opportunistic species inhabiting highly dynamic environments with high levels of natural disturbance. Consequently these species or benthic communities will endure a higher intensity of trawling.

In assessing trawling induced mortality, it is useful to distinguish between endo-benthic and epi-benthic species as well as between sessile and vagile species, as is done in most scientific studies. This is useful because it determines the vulnerability of a species to the trawl and the kind of physical disturbance it may be subjected to. Moreover, the occurrence and abundance of epibenthic and endobenthic, vagile and sessile species in a given area will vary remarkably per area depending on the habitat conditions and kind and intensity of natural disturbance. This potentially enables a stratification of effects per habitat and brings in a spatial dimension, facilitating management advice.

Especially epibenthic sessile fauna such as sponges, hydroid polyps, anemones, moss fauna, oysters and mussels will be susceptible to the effects of bottom trawling (Lavalije and Dankers, 1993). Mobile epibenthic fauna such as crabs and hermit crabs have a smaller chance of damage, but may become trapped in the nets with their legs and potentially lose them (Lavaleije and Dankers, 1993). Infauna will be less susceptible to the damaging effects of the trawl as long as it stays buried. The suspension of sediments caused by the passage of the trawl will, at some stage, be deposited, thereby potentially burying benthic fauna. Benthic fauna in the coastal waters are, according to Lavalije and Dankers (1993), most likely reasonably adjusted to this, as such processes occur naturally in such dynamic systems. Immobile benthic species may be affected to a higher degree as these do not have the potential to free themselves when being buried. Buried fauna may be exposed tough, this effect is temporary as most species have the capacity to rebury, but may increase predation. This increased predation is argued by Lavaleije and Dankers (1993) to be further induced by the supposed attraction of predatory fish to a trawled area.

8.2 Trawling-induced mortality and effects on populations of endobenthic fauna

Although the relatively light gear hardly penetrates the bottom, effects on endobenthic organisms through the squashing, severing, digging out, stirring and drifting cannot be entirely ruled out. Berghahn and Vorberg (1998) carried out before/after experiments (1990 and 1991) to assess the extent to which the bottom is disturbed and the way in which this affects endobenthic organisms (infauna). This study was conducted in the eulittoral zone on the sandy mixed flats (of a more silty nature) and observed changes following a single disturbance, thus not accounting for the long-term effects of repetitive disturbance. Both the trawl shoes and the rollers left impressions in the substratum, indicating a disturbance. Although these experiments showed no difference in endo-benthic species richness, the abundance, both aggregated over all species as well as at species level, showed a decline (18 to 29%) after trawling had taken place. This decline in abundance is possibly due to the stirring of the top sediment layer (Berghahn and Vorberg, 1998). This causes exposure during which organisms may be predated upon or be displaced by the currents. The unequivocal results achieved by Berghahn and Vorberg (1998) are attributed to the soft substrate which permitted penetration of the shoes and the rollers. When conducting this experiment at higher trawling speeds and in the sublittoral zone of the tidal channels where typically harder, sandy substrates prevail, and which is typically the zone in which shrimp trawlers operate, it is assumed that the impact would be considerably less. Recovery assessment was conducted a week after disturbance. Certain samples revealed an increase in abundance, whilst others did not. No statistically sound conclusions could be drawn from this unfortunately. The effects take place against a background of natural disturbance and dynamics. Large-scale sediment restratification produced by tidal currents or heavy gales have a far higher potential impact (Berghahn and Vorberg, 1998). Considering the impacts of naturally occurring disturbance and the recovery potential of endobenthic fauna, it is to be expected that the impact of the shrimp fishery on endobenthic fauna is only minor. The study of Berghahn and Vorberg (1998) does not account for the long term effects of chronic trawling at high intensities. At intensities that exceed the threshold of natural disturbance, different results may be expected to be obtained.

The study by Dolah et al. (1991) goes a step further than that by Berghahn and Vorberg. Their study was dedicated to evaluating the effects of commercial shrimp trawling in intensely trawled, soft-bottom areas on abundance, diversity and species composition of benthic infaunal assemblages after five months of commercial trawling activities. South Carolina shimp fishers use otter trawls, in many cases equipped with tickler chains. This gear is much heavier and has a higher impact on the sea-bottom than the otter trawls used in the North Sea shrimp fishery. Despite this, no pronounced adverse effect on the abundance, diversity or species composition of benthic infaunal community could be observed. These findings according to Dolah et al. are supported by the observation of Graham (1955) and Gibbs et al. (1980), that is, otter trawling on sandy/muddy sediments causes little, if any, degradation on infaunal communities. The study was carried out over a period of only five months, thus impacts due to repetitive trawling over a longer period of time were not assessed. The control area used in the study was only closed to trawling during the study year and therefore cannot be used as a long-term reference area. Nevertheless, these study results are consistent to those of Berghan and Vorberg and support their presumption of the impacts of continued trawling over longer periods of time. This may indicate that effects on endobenthic species are not of a prime concern. Nevertheless, uncertainty cannot be excluded entirely.

The endobenthic species *Sabellaria spinulosa* has been discussed in the context of mechanical habitat destruction in the previous chapter. That chapter discussed the impact of trawling on the biogenic structures created by this worm. Only the shoes were observed to cause damage to these structures. The worms themselves were left unharmed, resulting in the relatively rapid recovery of these habitat structures. Similar results apply to the worm *Lanice conchilega*. Although trawl shoes were observed to destroy the biogenic structures, no harm was done to the worms in both cases as they have the capacity to retreat quickly into the depths of their tubes which reach 30-40cm (for *Lanice conchilega*) into the sediment. These studies only observed the short-term effects of a single disturbance. Chronic trawling may cause stress, thereby having a detrimental effect on populations. Moreover, Lavaleije and Dankers (1993) mention that, due to trawling, re-colonization of vast numbers of the *Sabellaria spinulosa* species may be inhibited.

8.3 Trawling-induced mortality and population effects epibenthic species

Similar to endobenthic fauna, epibenthic fauna may be squashed, severed or swept away by the trawl. In addition, larger epibenthic species may not be selected by the net and consequently end up as by-catch in the trawl. Berghahn and Vorberg (1998) however argue that all typical epibenthic by-catch species are robust enough to survive capture and catch handling, or else have a high regenerative capacity (Brittlestar and Sea Urchin). This indicates that the effect upon such populations could possibly be negligible, as displacement and injury (through catch handling and discarding) are the only effective impacts.

Berghahn and Vorberg (1998) conducted experiments in areas with sandy substrates and assessed the short-term impacts of trawling on the epibenthic fauna. Underwater transactions in Hornum Tief (Schleswig Holstein) showed that this firm, sandy bottom was highly covered in bivalve shells and *Lanice conchilega*, both serving as excellent substrate or refuges for the associated epibenthic species, such as shore crabs and rock-dwelling crabs. As was mentioned previously, the contact time of the rollers on this substrate was relatively short. This, and the low pressure exerted by the rollers, led Berghahn and Vorberg (1998) to suppose that mechanical destruction by the rollers to the epibenthic fauna is negligible. In consistence with this claim, no damage could be observed by the rollers during their experiments. Evidence of damage to sessile epifauna such as sea anemones, white weed and mussels was weak, as was the damage to less mobile epibenthos such as starfish, sea urchin and common whelk. The direct effects of trawling on vagile epifauna were argued to be limited (Berghahn and Vorberg, 1998) as these had the possibility to escape or else, when caught, had a high survivability.

Seagrasses, which have been mentioned earlier in chapter 7 were not observed to suffer from the impacts of trawling. However this result was obtained in a study using quite different gear and did not research the effects of repetitive trawling. Lavalije and Dankers (1993) argue that the *C. crangon* fishery could have an impact by frustrating the processes of resettlement of the species.

8.4 Reflections and insights

8.4.1 Summarizing the effects of trawling mortality on populations of benthic species

The way in which trawling affects benthos varies considerably amongst species and is determined by the extent to which a species is exposed to the trawl, the sensitivity to the damaging potential of the trawl and the capacity to recover from the impact of the trawl. This recovery is a function of growth, reproduction and re-colonization rates of species and populations. Generally we distinguish between epibenthic and endobenthic, and sessile and vagile flora and fauna. Exposure and sensitivity to a shrimp beam trawl are distinct for these groups. Generally however, it is likely that most of the typical benthic species encountered in the trawled areas (the shallow coastal waters, the tidal channels and the inlets) are well adapted to high levels of disturbance, implying that such species may endure high rates of disturbance.

Endobenthic fauna are not highly exposed to the trawl but may be squashed, severed or dug out. In softer substrates, in which penetration of the trawl shoes and rollers are higher, endobenthic fauna may be dug out, thereby becoming exposed to predation. This was observed to directly influence infaunal abundance. The recovery of this impact was not, however, thoroughly researched, nor was the impact of repetitive trawling at high intensities researched. Comparable research on trawling impacts on epifaunal communities conducted in the flatfish fishery on soft bottoms could not observe changes to the epifaunal community after five months of commercial trawling. Added to the fact that trawling on *C. crangon* primarily occurs on sandy substrates, impacts on endobenthic fauna may not be a concern in terms of population effects. Nevertheless, suggestions have been made that beam trawling inhibits resettlement or re-colonization of vast infaunal populations (such as the *Sabellaria spinulosa* worm). This has been mentioned in the previous chapter and has not been researched.

Exposure to the trawl is higher in epibenthic species, particularly in sessile benthos, which do not have the capacity to avoid the trawl. Epibenthic species may be squashed, severed or swept away, and futhermore the larger epibenthos may be trapped in the net and end up in the by-catch. Very little research dedicated to assessing the direct impact of trawling on epibenthos has ben conducted and is basically limited to the work of Berghahn and Vorberg (1998). This study, which was conducted on sandy substrates in the German Wadden Sea, delivers little proof that epibenthos are affected by the trawl. This was explained by the relatively small pressure exerted by the trawl and the limited bottom contact by the gear on these substrates. No damaging impact was detected on benthos by the rollers. The damaging impact of the shoes on sessile epibenthos (mussels, anemones, white weed) and near-sessile epibenthos (starfish, urchin and common whelk) could hardly be observed. The direct effect on vagile epifauna was argued to be limited as these had the opportunity to escape and, in the circumstance of being caught (larger epibenthos), were assumed to have a high survivability. A study of the impacts of trawling on seagrasses delivered no proof of significant effects. Nevertheless, similar to infauna trawling disturbance may thwart the resettlement of vast epibenthic populations. No research has been conducted to test this hypothesis. Research efforts on the direct effects of trawling on epibenthic species are of too small a scope to make any firm statements. Moreover, no research has been conducted in which the impacts of endured trawling at high intensities on different benthic species at a population level are assessed.

8.4.2 Management implications; fisheries intervention and management measures

At this stage no preliminary management preliminary advice can be given. It is clear however that trawling intensity and scale are two effort factors that influence the impact on different populations, suggesting that adjustments to these may potentially bring trawling disturbance to acceptable levels. Despite the lack of understanding of the population effects of endured trawling, it has become clear from the few studies observed in this chapter that improvements to the trawl, especially the shoes, could reduce the disturbing characteristics of the trawl.

8.4.3 Improving assessment of effects on populations

Research efforts need to focus on long-term population effects of repetitive trawling at commercial levels on benthic populations encountered on sandy substrates, in those areas where fishing for *C. crangon* is concentrated. This especially applies to epibenthos. Moreover, for both epibenthos as well as endobenthos, effects on the resettlement success of populations under repetitive disturbance need to be assessed. The output could be a map of assemblages indicating their sensitivity to trawling. All these issues again emphasize the need for precise spatial effort data and spatial data on distribution of benthic flora and fauna (also along the vertical lines of the channels).

Chapter 9

CHRONIC CHANGES IN BENTHIC COMMUNITIES

Whilst the immediate effects of trawling on benthos may be obvious and reasonably straightforward, we are especially concerned about the long term impacts of prolonged commercial trawling on different benthic populations and communities encountered in the trawled zones.

The extent to which the species abundance and assemblages in a given area are affected by trawling is dependent upon the duration, extent and frequency of the physical disturbance, and the intrinsic capacity of the populations to withstand and recover from the disturbance (Underwood 1989, in Lindegarth et al., 2000). Trawling may induce the decline or disappearance of certain species whilst promoting the abundance of others, ultimately altering the species assemblage and community structure. The effect on the biota will be induced through various complex interspecies interactions and interdependencies. Depending on the position of a species in the community, this causal effect may be small or large. In this way the benthic community may move from highly complex and heterogeneous to homogenous, with low species diversity. It seems obvious that chronic changes to habitats will have the most fundamental, far reaching and irreversible impacts on benthic communities.

A problem that is encountered when looking at macro changes over longer time sets is that it becomes increasingly difficult to discern the effects of shrimp trawling alone, as trawling disturbance is not the only factor driving ecological change. To obtain the necessary evidence that changes have taken place at a community level as a result of *C. crangon* trawling, we need to undertake a comparative analysis of a trawled and un-trawled state. This has not been done so far for this fishery. Our assessment is currently limited to a number of studies which compare benthic surveys that have been carried out through time in the German Wadden Sea.

9.1 Comparative analysis of benthic surveys and changes in benthic communities

Surveys of epibenthic fauna have been conducted by various scientists in the German Wadden Sea throughout the last twelve decades and reveal long-term changes as well as short-term effects: 1869-1891 (Mobius, 1893); 1923-1926 (Hagmeier and Kandler, 1927) 1932 and 1938-1940 (Hagmeier, 1941); 1980 (risen and Reise, 1982); 1985-1988 (Reise and Schubert, 1987)(Reise and Bartsch, 1990); 1992 (Buhs and Reise, 1997).

In comparison such surveys enable the detection of long term changes and trends in epifaunal species abundance and richness of the area. Observed changes may be attributed to both environmental factors and anthropogenic activity occurring on a consistent or random basis in the same area over a certain time period.

Riesen and Riese (1982) carried out a comparative study using the research findings of two surveys completed in the same area from 1923 to1926 by Hagmeier and Kandler (1927) and in 1980 by Riesen and Reise (1982). This analysis focused on the macro benthos in the sub-tidal area of the Wadden Sea near Sylt. Comparative analysis showed a trend towards a massive long-term increase of mussel banks and associated species, particularly of polychaetes and barnacles. In contrast to this, species richness in molluscs and the abundance of some amphipods associated with seagrass and Sabellaria reefs decreased. Large epibenthic predators and scavengers seemed to hold their position. Oyster beds and Sabellaria reefs have entirely disappeared from the area. Moreover a large sea grass bed was observed to have disappeared.

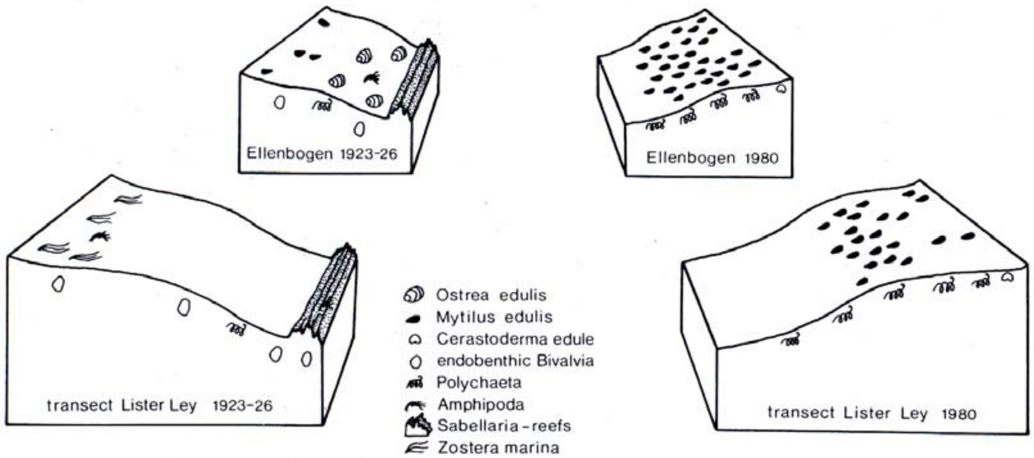


Fig. 9.1 benthic assemblages in Lister Ley, a comparison between 1923-1926 and 1980 (Near island of Sylt) two different locations (source: Riesen and Reise 1982)

Lavalije and Dankers (1993) reflect on the studies conducted by other authors. Their review of the work of Riesen and Reise (1982) points out that of the 28 species which were shown to have declined, only two of these species belong to the inter-tidal area, whilst the remainder belong to the benthic community in the sub tidal area. This, according to Lavalije and Dankers (1993), indicates that sublittoral fauna is much more vulnerable to disturbance than the opportunistic species typical to the inter-tidal zone. Many of the species that have declined (generally epi-benthic fauna) have been replaced by the more opportunistic Bristle worm (Laveleije and Dankers, 1993). According to Lavaleije and Dankers (1993), Reise and Schubert (1987) noticed similar changes in their study in the Wadden Sea near Fohr. Prior to 1960 no historical data of species assemblages exist for Dutch waters. Nevertheless, similar shifts in the benthic fauna have been recognized in Dutch waters (Dekker, 1989; Wolff 1992 in Lavalije and Dankers, 1993).

Buhs and Reise (1997) conducted such a survey in the years 1988 and 1992, but also analysed the surveys carried out by other scientists. They observed a severe decline in epifaunal species richness (25%) and species abundance (~ 50%) over the last 100 years. Oyster beds and Sabellaria reefs were described as characteristic benthic features of the tidal channels by Hagmeier and Kandler in 1927 (Buhs and Reise, 1997). Buhs and Reise, on the other hand, observed how sessile and slow-moving animals have declined while fast-moving decapod crustaceans and sessile mussels have persisted and dominate the tidal channels. This suggests a historical change has taken place in the area.

The cause of all these changes remains speculative. The regularly occurring cold winters, though shown to have lasting effects on benthic fauna in the North Sea, could not in this case be held accountable for the changes observed in the study by Riesen and Reise. Besides the occurrence of an epidemic seagrass disease during 1933 and 1934, which resulted in the loss of the seagrass bed, alternative environmental explanations could not be ruled out as no reliable long-term data of such physical factors exist for the area. Riesen and Reise (1982) argue that the observed changes are caused, promoted or have been given a permanent status by anthropogenic activity in and around the area. At least in part, these changes are viewed by Riesen and Reise (1982) to be the effect of the accumulated pressure exerted by the various fisheries operating in the area. Dredging for mussels and oysters and shrimp trawling are the three mentioned fisheries which operate in the area and are assumed to have triggered these changes. Other anthropogenic factors, such as the building of dams, are also mentioned as possible drivers of this change.

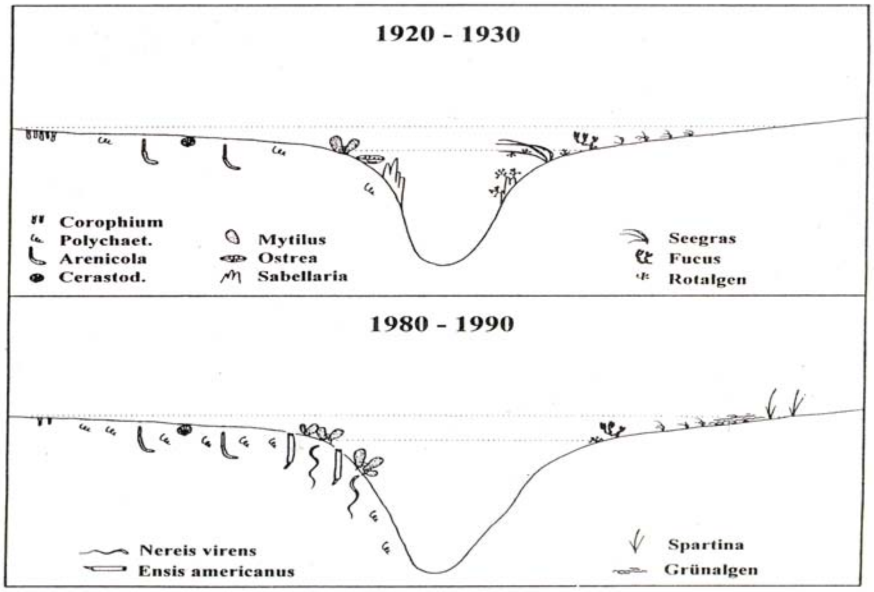


Fig. 9.2 Schematic view of long-term changes in macro-benthos in Sylt-Romo Wadden Sea. The above dotted line is the eulittoral line and the bottom dotted line is the sub-littoral line. The zone in-between is the eulittoral/inter-tidal zone. Left the macrofauna is given and on the right benthic flora/vegetation is given source Reise and Lacksewitz, 1998)

Despite this uncertainty, Buhs and Reise (1997) argue that the typical differential long-term response that was observed (sessile and slow-moving animals have declined, whilst fast-moving decapod crustaceans have persisted) is strong evidence against bottom-disrupting fisheries, suggesting that mechanical disturbances such as dredging for mussels, oysters, seagrasses and hydroids and trawling for shrimp have had an effect on benthic communities. Trawling for crangon in the tidal channels of Schleswig-Holstein Wadden Sea has taken place over the past fourteen decades, at fairly high intensities. According to Tiews (1953, in Buhs and Reise 1997), this also included the trawling in the vicinity of beds of polychaete *Lanice conchilega* and on reefs of *Sabellaria spinulosa*. It is the repetitive trawling over such sessile epibenthic fauna that, according to Buhs and Reise (1997), causes the crangon fishery to have an effect on benthos. Depending on the tolerance and recovery rate of benthic species, this may still be higher than the threshold of natural disturbance tolerated in these especially sessile epifauna.

The difficulty in determining the cause of these shifts in benthic species assemblages is that there are no suitable reference areas which have remained un-trawled. Moreover, because of the accumulate effects of the multiple fisheries, it is difficult to discern the effect of the shrimp beam trawl alone. Therefore a large uncertainty remains when assessing the long-term impacts of shrimp trawling on benthic habitats and communities. As Buhs and Reise (1997) rightly point out, before any of the above mentioned speculations can be confirmed, research needs to be dedicated to understanding the long-term impact of continued shrimp trawling at various intensities. This implies undertaking long-term assessments using control plots and trawled plots.

Although comparative studies of historical benthic surveys have pointed out some obvious changes that may indicate that shrimp beam trawling may have had an impact on benthic communities, no long-term impact studies have been conducted for the commercial shrimp trawl fishery in the North Sea to verify any such suspicions.

9.2 Reflections and insights

9.2.1 Summarizing the effects of *C. crangon* trawling on benthic communities

Changes taking place at a population level can have an effect at a community level. Community level effects are a function of both the direct effects of trawling on single species and the indirect effects of trawling on species through habitats change and interspecies relationships. Such changes can only be observed over longer periods of time during which trawling has taken place. To isolate the effects of the *C. crangon* fishery on benthic communities from the effects of other drivers of change, a comparative analysis is required of a trawled and an un-trawled area in which all other conditions are similar. Such studies have not been conducted for the *C. crangon* fishery, the Wadden Sea, the Wash, the Scheldt estuary, nor for the deeper coastal waters. Strong changes in benthic assemblages have been illuminated in the tidal channels of the Wadden Sea (Schleswig-Holstein area) through comparative analysis of benthic surveys conducted in the area throughout the past twelve decades. A significant decline in epifaunal richness and abundance was observed. This decline especially concerns epibenthic fauna occurring in the tidal channels and especially slow-moving or sessile epibenthos. Although the typical changes that have taken place seem to be related to bottom-disrupting fisheries, they may not be directly ascribed to the *C. crangon* fishery as this has not been the only fishery operating in this area throughout the last century.

9.2.2 Management implication: fisheries intervention and management measures

No preliminary management advice can really be given on the basis of the above. At the most, it might be an argument to discourage trawling areas of tidal channels in which there are sessile epifauna populations, if it should be that commercial shrimp trawling is responsible for causing or else sustaining the observed changes.

9.3.3 Achieving better assessment of community level effects of *C. crangon* fishing

To assess the long-term impacts of trawling on a community level, a comparative analysis must be completed, comparing a trawled area with an un-trawled area. This un-trawled area serves as a reference area and must be chosen appropriately as all other conditions must be more or less similar to the trawled area. A comparative analysis must be undertaken for both the Wadden Sea as well as for the deeper coastal waters as these are both distinct hydrological entities in which trawling for *C. crangon* takes place. In the Wadden Sea, one option is to close a tidal channel for an extensive period of time. Closure allows the area to ‘recover’ to an un-trawled state. In this way comparative research should answer some of our most fundamental research questions, namely how the *C. crangon* fishery is affecting the marine ecosystem. One thing that must be realised when reading the results of such an analysis is that these results will not show at which intensities trawling starts to have an effect. As is imaginable, most benthic species occurring in these highly dynamic environments will sustain a certain level of disturbance. Moreover, it is imaginable that benthic communities will endure different levels of disturbance in different stadiums, with higher levels of disturbance being endured by a community in a ‘mature’ state than by a community which is in a disturbed state (with fragile populations and specimens) in which trawling especially impacts by frustrating recovery processes. Just what the threshold levels of disturbance are cannot be directly deduced from comparative research of trawled and non-trawled areas. This is to our disadvantage if we wish to give specific management advice and bring fishing intensity to a sustainable level so as to strike a balance between fisheries and the environment.

CONCLUSIONS AND RECOMMENDATIONS

EFFECTS OF C.CRANGON FISHING ON THE MARINE ECOSYSTEM

The key question that this paper attempts to answer is how fishing for C. *crangon* in the North Sea is affecting the marine ecosystem. This was approached by looking at the direct effects on individual populations and habitats and the knock-on (flow) effects of these effects on populations through species interrelationships and species-habitat dependencies, bringing it to a higher level of complexity. Finally, the focus of the lens was widened in order to observe community effects. The quality and utility of this inventory is a reflection of the availability and accessibility of data and literature specific to this fishery and data quality, completeness and consistency. For the C. *crangon* fishery, in most respects, this is poor. The most important findings will be reviewed below.

Direct effects on C. *crangon* populations

Although several fundamental biological parameters required making a proper assessment of the fishery in relation to C. *crangon*, stocks remain undefined for this species, and landings and LpUE data give no indication that overexploitation of the C. *crangon* stocks is currently taking place. Continuous decline in local C. *crangon* abundance, observed in LpUE and DYFS data for the more shallower southern waters, was argued to have natural causes and is contrasted by an increase in C*. crangon* abundance in the deeper and more northern waters. There is ambiguity in the evidence of changes taking place in population size-structure and uncertainty as to the persistence of this trend.

Direct effects on non-target fish and invertebrate populations

In targeting C. *crangon,* close bottom contact of the gear and small mesh sizes are required, thereby affecting non-target species living or feeding in this benthic environment. Our assessment of the kind and scale of these effects is thwarted by our inadequate understanding of spatial and temporal fishing effort distribution.

By-catches and discard mortality of especially juvenile fish (0-group and 1-group) species are high in this fishery. The effect of juvenile fishing mortality on populations was only estimated for a limited number of commercial fish species, for which population parameters exist (Whiting, Cod, Plaice and Sole). Due to high natural mortality rates in these age classes, we would expect population effects to be minor. Nevertheless, for Plaice (the most significant by-catch species), this was certainly not the case, with an estimated 10.3% loss in SSB calculated, as opposed to percentages around 1,1% for the other species. Using losses in landings and relating these losses to the TACs of these stocks, we can conclude that the C. *crangon* fishery cannot be held responsible for the dwindling stocks in the North Sea, although they are certainly contributing. Quantification of by-catches in non-commercial fish and invertebrate species and the effects of this on populations remain under-researched. Nevertheless, by-catch of invertebrates (bivalves and crustaceans) is argued not to be of concern as these do not suffer high discard mortalities.

In addition to discard mortality, trawling may inflict mortality on benthic species through severing, digging out, and squashing. This, and the effect of this on populations at commercial trawling intensities, has not been researched very extensively. Assuming, however, that trawling occurs predominantly on sandy substrates on which bottom contact of the trawl is limited and where reasonably robust or flexible species occur that are generally well adapted to high levels of (natural) disturbance, directly inflicted mortality will be limited, whilst the populations recovery rate will be high . The capacity to resist disturbance may be lower in fragile specimens in their earliest life stages. This is used to argue that even light disturbance can be detrimental to populations of especially sessile epibenthic species that are in an instable or recovering state by preventing re-colonization or rehabilitation.

Flow effects on populations through trophic species interrelationships

By extracting biomass (C. *crangon*) from the system and through discarding practices populations of predator, prey, competitor and scavenging species may be affected. This has not been researched for C. *crangon* extractions, despite it holding a keystone position in the food web. Such effects have been studied for avian scavengers which feed off discard material. Although discards were argued to sustain populations this could not be demonstrated to lead to population growth as population growth is complicated function depending on a multitude of factors. Effects of discarding on benthic competitor species which may be deprived of their food source (by discarding and avian predation) have not been addressed in the literature but as research on scavenging bird population already points out this deprivation may not necessarily result in changes in population abundance.

Direct effects on habitats and flow effects on associate species

Disturbance of the substratum matters when this affects the habitat function it performs and consequently the benthic populations and assemblages it supports. Trawling on sandy substrates in the coastal waters, tidal inlets and channels, where the C*. crangon* fishing predominantly takes place, does not seem to be the problem as (1) mechanical disturbance of this substrate is relatively light, (2) it is even more so when compared to the disturbance caused by natural forces, (3) due to the high levels of natural disturbance this mechanical disturbance is short-lived and (4) species inhabiting such areas are well adapted to disturbance of the habitat conditions. This suggests that trawling-induced disturbance has a negligible effect. This may not be so for prolonged and large-scale disturbance of substrates which form more stable and permanent structures. Such substrates perform a pronounced habitat function and support unique assemblages. Disturbance of these relatively stable habitats will reflect strongly on the species diversity and abundance. Nevertheless, the considered substrates that fall into this category (mussel beds, oyster beds, white weed beds, seagrass fields, Sabellaria reefs, Lanice carpets) were not observed to be highly sensitive to the trawl. At the most, the trawl foot caused disturbance (to Sabellaria reefs and Lanice carpets), but such disturbance was not very persistent as the regenerative capacity of these biogenic structures is high. Nevertheless, repetitive trawling at high intensity and scale may fundamentally damage these structures. No research efforts have been dedicated to this. The relevance of this for Sabellaria reefs is questionable as it is unclear whether trawling is actually taking place on these gear-damaging structures.

Despite the evidence that shrimp trawling is not having an observable effect on the considered habitats, what the discussion concerning trawling and habitat disturbance seems to boil down to is the supposition that trawling disturbance of the seabed prevents re-colonization and the rehabilitation of fragile, structure-forming populations by repetitive disturbance to the substrata on which such structures are fixed. This hypothesis has not been verified but nevertheless seems to be well accepted.

Effects on benthic communities

Thus far the population effects of pressures exerted by the C. *crangon* fishery on species and habitats, and the mechanisms through which these pressures are exerted, have been considered individually. However pressures on species are exerted simultaneously and it is the sum of these pressures that may prove to be significant. How the sum of pressures amount to population effects, and how population effects amount to shifts in species assemblages and abundance can only be observed after longer time periods throughout which trawling has taken place. Repetitive and thorough benthic surveys, from which such changes become evident, have been completed for the German Wadden Sea area. Although changes to benthic assemblages are observed to have taken place over the past twelve decades, and although some of these changes constitute strong evidence against bottom-disrupting fisheries, the effects of the C. *crangon* fishery cannot be isolated from the effects of other bottom-disrupting fisheries or alternative natural, as well as anthropogenic, drivers of change. This leaves us pretty much in the dark when it comes to determining the long-term effects of commercial shrimp trawling at a community level. In addition, these studies do not illuminate if and how the C. *crangon* fishery is responsible for giving these changes a permanent status by preventing recovery of populations and assemblages.

MANAGEMENT IMPLICATIONS: WHEN EFFECTS WARRANT INTERVENTION

Quite obviously our understanding of the way the C. *crangon* fishery interacts with its natural environment is incomplete. Although we are not short of well-grounded presumptions and intuitions, we are very far from being able to express the effects of commercial trawling in the North Sea in absolute figures (for example: what number of 0-group Plaice die annually in the C. *crangon* fishery?). Furthermore, in obtaining quantitative figures, we are often not in possession of the required tools to determine if and how this reflects on populations in both absolute and relative terms (for example: what does 900 million dead 0-goup Plaice mean for a population in terms of abundance, reproductivity size-structure etc?). Moreover, how do we interpret these results and how do we translate these population effects into a meaningful language, which can be employed in management and upon which a value judgement can be based? (for example: what does a 10,4% loss in SSB for Plaice mean for the population and to us?). This requires detailed knowledge on population dynamics as well as setting specific and quantifiable management objectives. This is not a one-off event, but entails an entire process which requires the close involvement of both public stakeholders and scientists. A common language needs to be developed leading to a common vision concerning the functions the marine system must support. Simply put, this is posing ourselves the question what effects and what changes to the marine environment we are willing to accept, realising that any level of fishing will inevitably bring about some form of change. This must be translated into management goals and principles, and supplemented with clear definitions of a 'desired state'. This may then be converted into quantifiable objectives through appropriate biological and ecological research. Only when such steps have been taken are we in the position to build an instructive research agenda which describes where research efforts need to made so as to realise a more comprehensive impact assessment and, are we able to determine on the basis of this assessment, whether and in which areas intervention is called for?

RECOMMENDATIONS

The study that has been conducted has given some worthwhile insights as to the question:" where to now?". This involves a recommendation of how we should invest our efforts so as to enhance our understanding of the interaction between this fishery and the marine environment. At this stage, and on the basis of this inventory, only some preliminary suggestions can be given concerning intervention in this fishery. These suggestions concern how we could mitigate the pressures this fishery exerts on the marine ecosystem.

Improving impact assessment of North Sea C. crangon fishery

Our chief goal to achieve an instructive and comprehensive impact assessment which gives the necessary insights as to where intervention is suitable and what measures may prove effective. Several priorities are mentioned.

Fisheries data and statistics

Understanding the fishery is the key to beginning to understand the interactions between fishery and marine environment. Sound fisheries data is therefore a prerequisite.

I We cannot conduct a proper assessment without understanding how fishing effort is distributed in space and time. Therefore:

- Logbook data needs to include the date, time and duration of each and every haul and the geographical location of shooting and hauling the trawl. Facilities to locate vessels, are already on board every >15 m vessel, in the form of a satellite system (vms or blackbox), however, this data is not available to the public: possibilities need to be explored

II Fisheries data needs be complete, accessible, continuous and consistent. This relates to procedures of data recording, collection, storage and translation. Therefore:

- Logbooks need to be kept accurately and consistently over all C. *crangon* vessels, big and small. This requires thorough and uniform implementation, and cooperation of fishers in all countries.
- Logbook and other fishing data need to be compiled and stored in a collective and accessible database (tagged: North Sea C. *crangon* fishery, everything there is to know, for all), in a uniform language, and not concealed and fragmented over different institutions and administrations.

Research agenda

Understanding the environment the fishery operates in, is the second step towards understanding interactions between the fishery and the marine environment. Combining such data with fisheries data will allow for further specification of the research agenda.

I To assess the effects of trawling on benthic populations and assemblages and to tune fishing effort to the natural capacity of assemblages to endure disturbance, we need:

- To map out which sediment-types, benthic flora and fauna and benthic habitat structures are encountered in the trawled areas.
- A preliminary stratification of areas can be made according to their sensitivity to trawling (by employing knowledge of gear-bottom interaction, levels of natural disturbance, species assemblages), so that research efforts can be specified and fishing effort can be spatially tuned.
- Research needs to be done to assess the effects of repetitive trawling at different levels of intensity on the sensitive benthic biotopes.
- To close a suitable area to trawling for a longer period of time in order to determine whether C. *crangon* fishing is preventing the recovery of habitats and assemblages and to assess the full

impact of C. *crangon* fishing on benthic habitats and assemblages. This could be a channel or a part of a channel (to a certain depth range for instance)

II Reducing by-catches and assessing the population effects of by-catching cannot be achieved without more continuous and thorough by-catch monitoring, spatially as well as seasonally. Such knowledge can also be employed in management. Therefore;

- We need to map out where and during which seasons we encounter typical by-catch fish species (commercial as well as non-commercial), in what densities, accounting for migration patterns and intra-species variation in spatial distribution of age-groups. Such a map should be stratified according to typical hydrological conditions that determine fish distribution (depth-range, north-south, estuarine-coastal). This allows for a visualization of by-catch composition in both space and time. This can be used (in combination with spatial and seasonal effort data) to approximate the magnitude of by-catches per species, but also to tune spatial effort and the use of selective devices seasonally;
- Using species specific data on discard mortality rates, rough indications of by-catch quantities and the size-structure of by-catch, we can make a preliminary classification indicating which species are of relative significance and on which our management and research efforts should focus.

Preliminary management advice

A few suggestions can be made concerning how we might reduce pressures exerted on the marine ecosystem in a feasible way:

I All forms of pressure exerted by the fishery will be mitigated by reinstalling effort and landings limitations, in addition to placing a ceiling on licenses (as in the Netherlands). This will benefit both the sector and the environment.

II Reducing fishing mortality in by-catch species is a matter of preventing especially juvenile fish and round-fish from being caught and, only secondly, of reducing discards mortality inflicted through the various catch, handling and discarding processes. Therefore:

- Selective devices, which have been shown to be effective in reducing certain by-catches in particular periods of the year, need to be used by all fishers trawling in these areas and seasons. This requires better implementation and the enforcement and cooperation of fishers;
- Improvements of the trawl should focus on the selectivity of the trawl for juvenile (<10cm) by-catch of flatfish and round-fish. Improvements to the trawl that enhance the escape opportunities of juveniles before entering the cod end, seem most promising;
- Reducing discard mortality is only relevant for juvenile flatfish. This could be achieved by; reducing trawl time and catch volume; limiting exposure (time) to air and high temperatures in summer, for instance by using continuous flow mechanisms, and; reducing avian predation through subsurface discarding.

II Sea-bottom disturbance can be reduced by making trawl adjustments and bringing spatial planning into fisheries.

- Trawling on soft-substrates or substrates with fragile populations (structure forming benthos) should be avoided. This concerns the eulittoral zone and the shallower parts of the sublittoral zone.
- Adjustments to the trawl, in order to avoid bottom-disturbance, should focus on improvements of the trawl foot and outer rollers, as these inflicts the most damage.

GLOSSARY

12-mile zone The Territorial Sea. Stretch of sea between the Baseline and the 12 nautical-mile limit (as measured from the Baseline). Established under the United Nations Law of the Sea Convention. Fishing in the territorial waters of a nation occurs under specified conditions(on the basis of historical fishing rights).

3-mile zone Stretch of sea between the Baseline and 3 nautical-mile limit (as measured from the baseline). Under the "freedom-of-the-seas" doctrine a nations rights and jurisdiction was limited to a 3-mile stretch of sea surrounding the coastline. This was extended to 12-nautical miles under the United Nations Law of the Sea which came into force in 1994.

6-mile limit Fishery limit, 6 nautical miles from the baseline. Relevant in defining national fishing rights.

Baseline The Baseline for measuring the breadth of the Territorial Sea (12-mile zone) is the low-water line along the coast. In the Wadden Sea this line runs just in front of the Frisian Islands.

BHD EU Bird and Habitat Directive

Biocoenosis A group of interacting organisms that live in a particular habitat and form an ecological community.

Biota The combined flora and fauna of a region.

Biotope An area that is uniform in environmental conditions and in its distribution of animal and plant life.

Bivalves A class of phylum Mollusca (Molluscs), also known as Lamellibranchia. Contains all the common bivalves like mussels, cockles, clams etc. The animal is protected by two shell valves which are joined dorsally by a ligament and closed vertically by one or two adductor muscles.

By-catch By-catch includes all non-target species and unwanted target species in the catch.

Carapace Shield of exoskeleton covering part of the body (several segments) of some Arthropoda e.g. shrimps and crabs.

Catch efficiency The ratio between caught animals and those actually present.

CFP Common Fisheries Policy

Clupeidae The family of the herrings, shads, sardines, and menhadens.

Crustacea A subphylum of the phylum Arthropoda. A phylum of segmented animals of which the body is entirely covered with chitinous exoskeleton. To the crustacea belong crabs, shrimps, hermit crabs and lobsters.

Demersal Found near the sea bottom (as opposed to pelagic).

DFS Demersal Fish survey

Discards The fraction of the by-catch that is disposed of over board. It may include target species (*commercial discards*) and/or non-target species (*non-target catch*).

Ecotype The smallest taxonomic subdivision of an ecospecies, consisting of populations adapted to a particular set of environmental conditions. The populations are infertile with other ecotypes of the same ecospecies

Endo-benthic Living in the subtrate of a bod of water.

Epi-benthic Living on the substrate of a body of water.

Epifauna Aquatic animals that live on the substrate of a body of water.

EU European Union

Eulittoral zone (Inter-tidal zone) Zone between the low water mark and the high water mark which is periodically exposed during low tide.

Fishing effort A measure of the activity of fishing boats. Fishing effort is strictly defined in terms of "total standard hours fishing per year" but is often described less rigorously in terms of number of vessels, fishing time, or fishing power for instance.

Fishing intensity Fishing effort per unit area.

Fishing mortality Total direct mortality in the population of a species, generated by a trawl fishery over a certain time period, expressed.

Gadoid Of or pertaining to the family of Gadidae fish which includes the cod, haddock, and hake.

Hp Horse power : a unit to that indiactes capacty of a vessesl (1hp = 0.7355 kW)

ICES statistical-rectangle (ICES square) A rectangular grid of approximately 30x30km used by ICES in their study area.

ICES International Council for Exploration of the Sea (founded 1902 in Copenhagen). All nations bordering the North Atlantic are members.

Incidental catch Incidental catch is the by-catch fraction that is retained and landed.

Infauna (endofauna) Aquatic animals that live in the substrate of a body of water, especially in a soft sea bottom.

Inshore (**fisheries)** Refers to the coastal waters extending up to 12-miles (19,3 km) which generally covers all Members' States territorial waters.

LOA (length overall) The total length from the foremost to the aft most points of the vessel's hull.

Macrofauna Bottom living organisms retained on a 1mm meshed sieve.

Off-shore fishery Fisheries operating outside of the 12-mile zone.

Otter trawl A large conical net supplied with two otter boards which keep the mouth at the net open horizontally.

Pelagic Of or in the main water-mass of sea or lake.

Recruits The in-streaming juveniles of the species under consideration, the offspring, the new year-classes(fish).

Sessile Permanently attached or fixed; not free-moving (may relate to benthic fauna).

Spawning stock biomass The total weight of the fish in a stock that are old enough to spawn; the biomass of all fish beyond the age or size class in which 50% of the individuals are mature. May be used instead of measuring egg production (abbreviated as SSB).

Subliteral zone (subtidal zone) Zone below the low water mark.

Target species The species or range of species which the fishery targets.

Tickler chain A chain rigged in front o the ground rope of a beam trawl to disturb flatfish from the bottom and to increase the fishing efficiency.

Vagile Characterized by vagility/mobility; able to move about or disperse in a given environment (may relate to benthic fauna).

Vertebrates Animals possessing a backbone.

Warp Long flexible steel rope connecting the fishing gear to the vessel.

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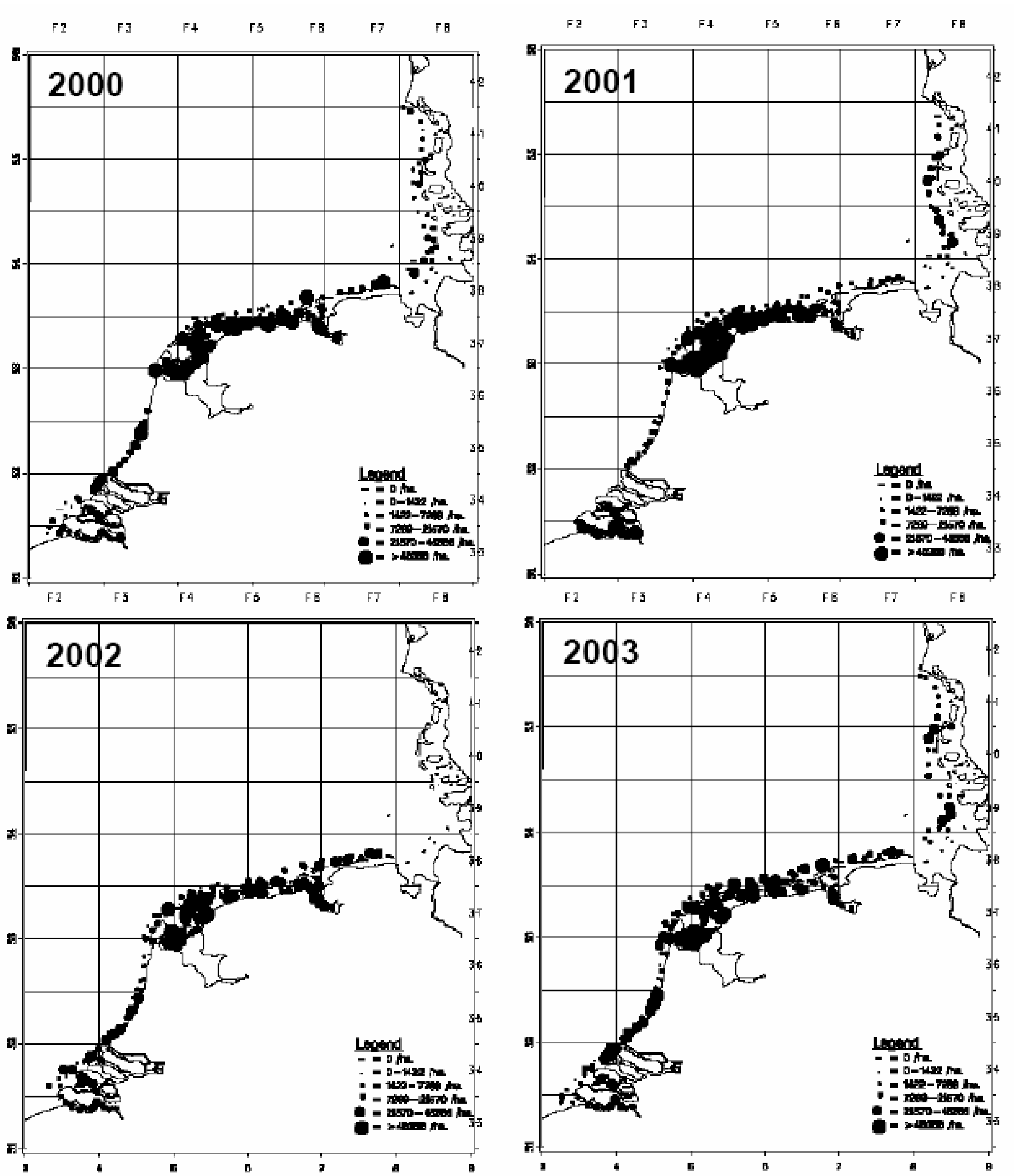
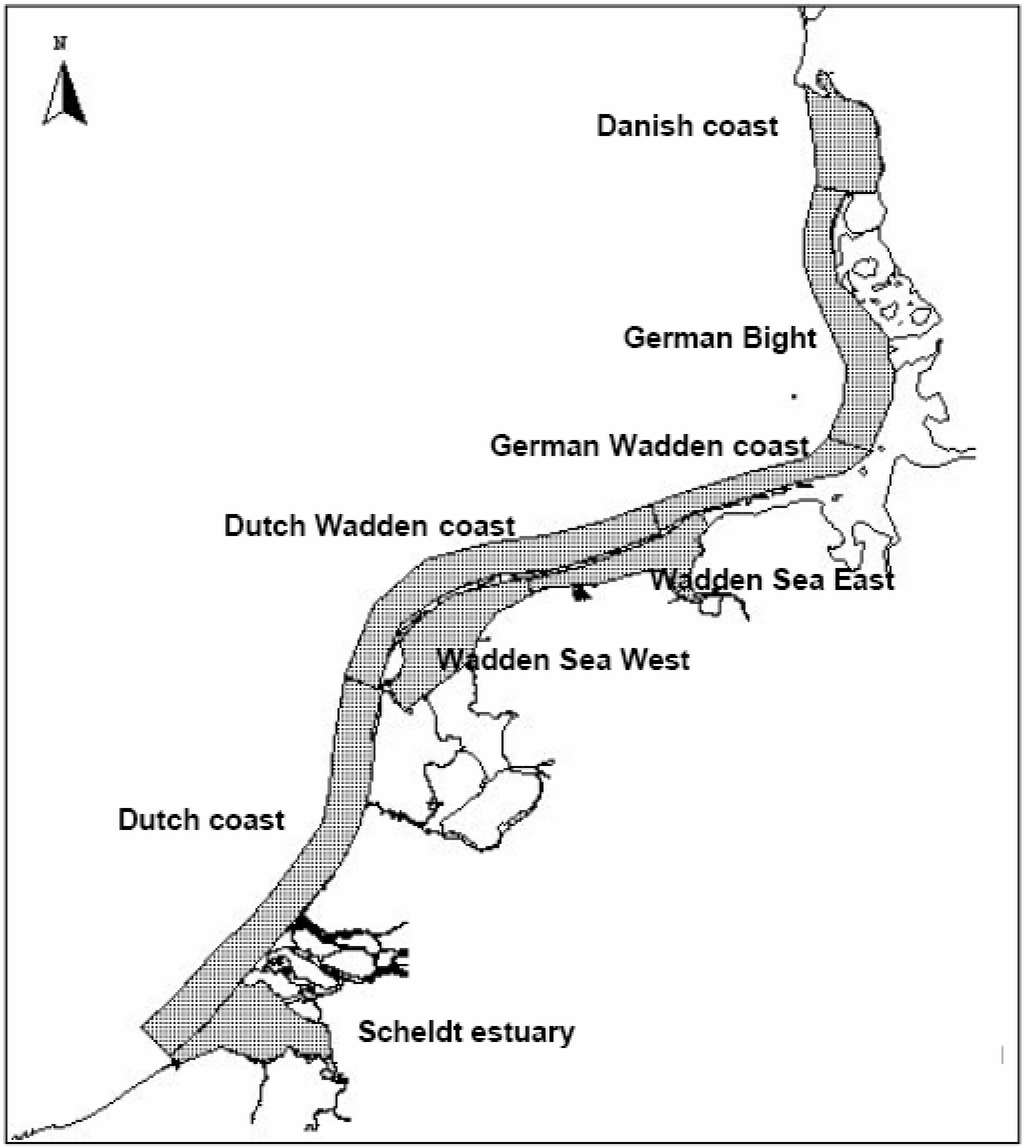
APPENDICES

APPENDIX 1



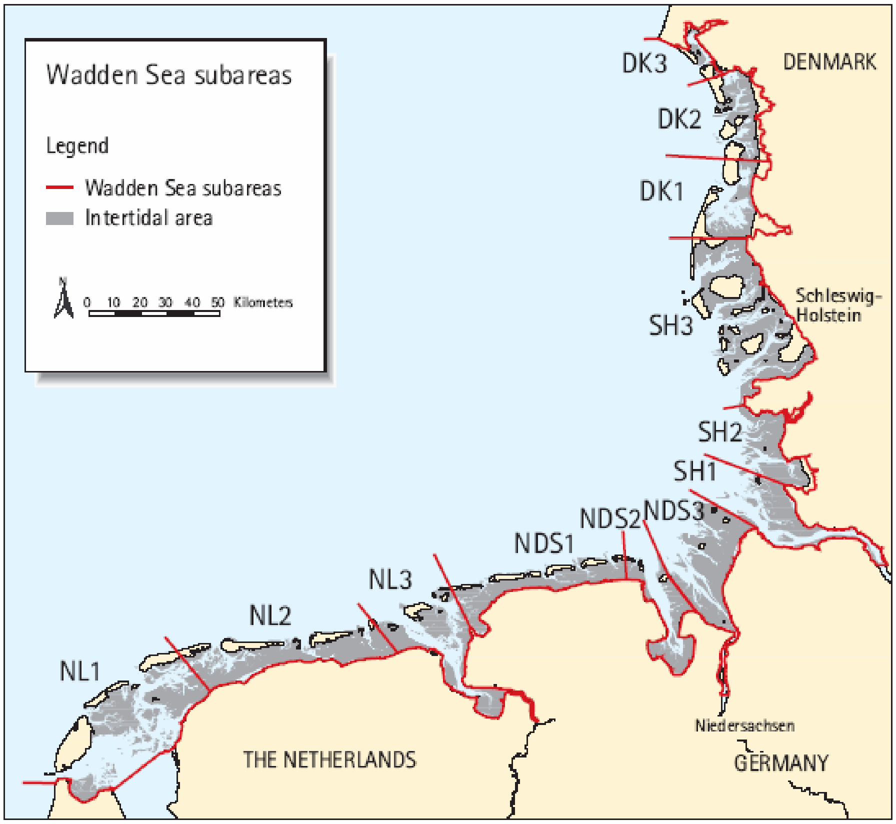
Distribution of C. crangon (all sizes) in the years 2000–2003. (Source: WGCRAN rapport 2005)

APPENDIX 2



Map showing the eight different sub-areas (Source: WGCRAN rapport 2005)

APPENDIX 3



QSR Subarea Description

NL1	Western Dutch Wadden Sea. The area receives fresh water directly from Lake IJsselmeer by the sluices of Den Oever and Kornwerderzand at an average rate of $16.3 \cdot 10^9$ m^3/y. The water mass which originates from the river Rhine passes Lake IJsselmeer in about 50 days. The coastal North Sea water entering the Wadden Sea at the Marsdiep constitutes about 15% Rhine water.
NL2	Eastern Dutch Wadden Sea. The area receives a minor freshwater source from Lake Lauwers and an industrial waste line. The area is considered to be dominated by coastal North Sea water.
NL3	Ems-Dollard estuary. The freshwater sources to the area are the river Ems (90%) and Westerwoldsche Aa (10%) at a total average rate of about $3.4 \cdot 10^9$ m^3/y. Industrial and harbour activities border the estuary at Emden, Delfzijl and Eemshaven.
NDS1	Niedersachsen Wadden Sea. The area is slightly influenced by local fresh water sources. Only small harbours are present. The area is considered to be dominated by coastal North Sea water.
NDS2	Jade Basin. The harbour of Wilhelmshaven is the main activity in the area. Virtually no fresh water enters the area. The area is considered to be dominated by coastal North Sea water, which becomes enriched by sediment efflux of components during high tide.
NDS3	Weser estuary. The river Weser is the main freshwater source at an average rate of $11.3 \cdot 10^9$ m^3/y. The river borders are densely populated. Harbour activities are present at the cities of Bremen and Bremerhaven.
SH1	Elbe estuary. The river Elbe is the main freshwater input into the area at an average rate of $24.5 \cdot 10^9$ m^3/y, which is about 43% of the total freshwater input in the international Wadden Sea. The river is bordered by large cities (*e.g.* Hamburg), harbours and industrial activities.
SH2	Eider estuary. The river Eider constitutes a relatively small freshwater source of about $0.9 \cdot 10^9$ m^3/y on average. The population density is moderate. Some small recreational and fisheries harbours are present.
SH3	Halligen. Virtually no freshwater input and a low population density. The area is considered to be dominated by coastal North Sea water.
DK1	Sylt-Rømø basin. The area is physically bordered by the dams connecting Sylt and Rømø to the mainland. The area is considered to be dominated by coastal North Sea water. The freshwater input from southern Jutland was about $0.8 \cdot 10^9$ m^3/y in 1990, which was about $1.3 \cdot 10^9$ m^3/y to DK1 + DK2 in the same year.
DK2	Ribe and Konge Å estuary (Knudedyb), Rejsby and Brøns Å (Juvredyb). The rivers Ribe, Konge, Rejsby and Brøns Å are small rivers, thus constituting a small freshwater input. The input to DK1 + DK2 is about $1.2 \cdot 10^9$ m^3/y on average. The area is considered to be dominated by coastal North Sea water.
DK3	Varde and Sneum Å estuary (Grådyb). The last natural estuary of the Wadden Sea. The city of Esbjerg is the main center of population and harbour and industrial activity. The area is considered to be dominated by coastal North Sea water.

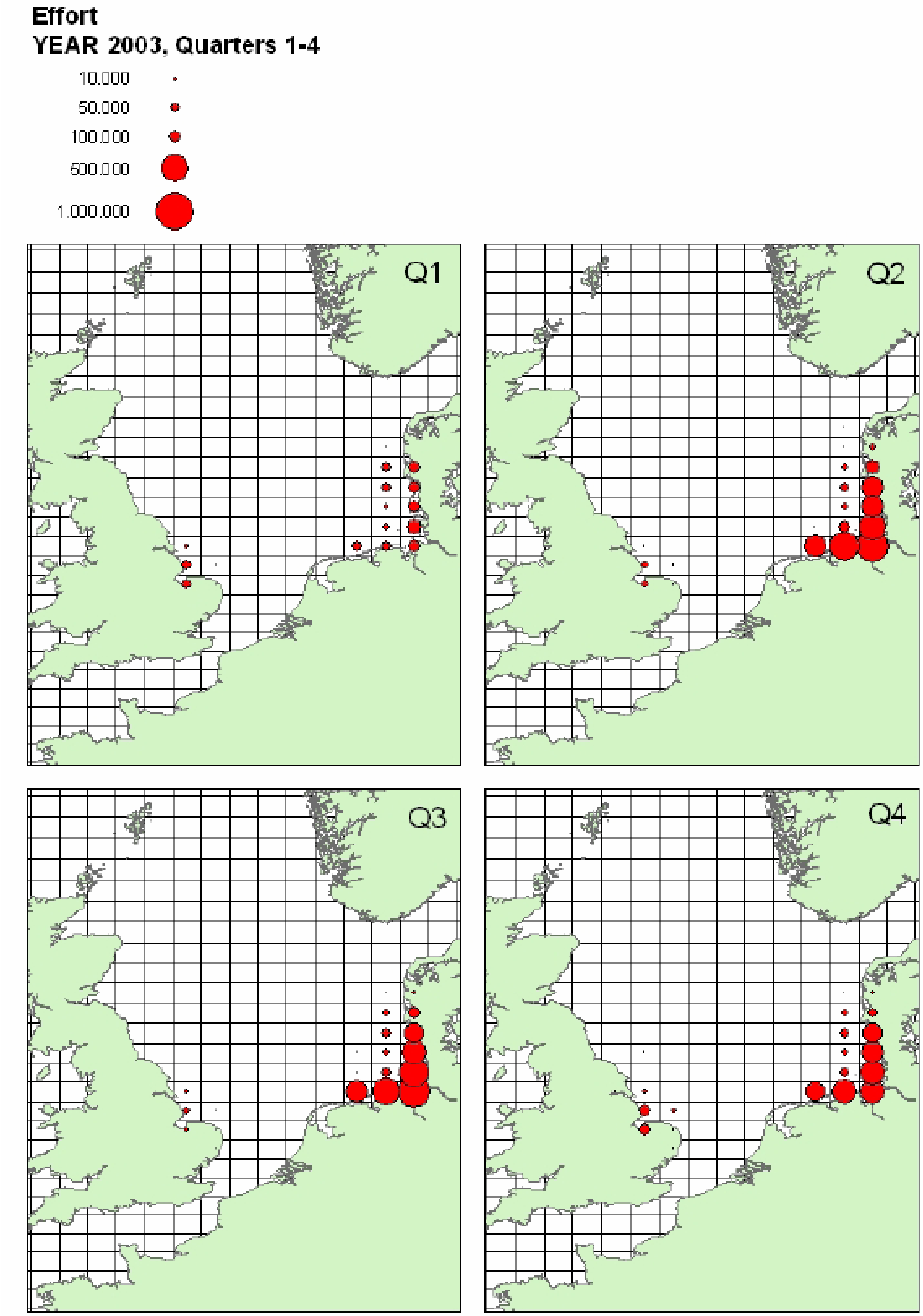
APPENDIX 4

Wadden Sea with islands and countries and regions. Grey is inter-tidal zone. (source: www.waddensea-secretariat.org)

APPENDIX 5

Ices-squares (source: www.noordzeeatlas.nl)

APPENDIX 6



Seasonal spatial effort distribution (hp-days) in 2003 of Danish and German fleet (ICES WGCRAN rapport 2005)

APPENDIX 7

Germany - Overview – numbers of fish caught/10 000m^2

Numbers in annual catches for fleet: high/Intermediate/low

Species	Q1 - 1997	Q2 -1996	Q3 - 1996	Q4 - 1996	Tot. no caught annually raised to fleet level (Crangon x 10^6 Fish species x 10^3)
C. crangon (commercial)	1.795	1.995	5.071	5.286	**27.278**
C. crangon (undersized)	11,578 87% of tot. Crangon catches	7.144 78% of tot. Crangon catches	29.126 85% of tot. Crangon catches	20.084 79% of tot. Crangon catches	**128.415** 82% of tot. annual crangon catch
Bib and Poor Cod					0
Cod	16,00 1-group 0,83 2+	0,19 0-group 0,02 1-group	53,44 0-group 0,06 1-group	21,09 0-group 0,55 1-group	**17.322** 16.546 0-group 727 1-group 32 2+
Whiting	1,38 1-group 0,15 2+	2,13 0-group 5,69 1-group	22.76 0-group 7,12 1-group 0,05 2+	0,73 0-group 0,22 1-group	**9.808** 6.296 0-group 3.434 1-group 78 2+
Gurnards		0,32	0,39		**184**
Brill	0,09			0,18	**33**
Turbot		O,16	0,23		**100**
Flounder	10,41	6,56	1,12	10,98	**4,296**
Plaice	225,89 1-group	564,6 0-group 20,2 1-group	1.188,08 0-group 1.54 1-group	1607,39 0-group 0,77 1-group	**724.734** 709.824 0-goup 14.892 1-group
Dab	41,12 1-group 6,22 2+	23,97 1-group 0,27 2+	144,44 0-group 12,57 1-group	222,81 0-group	**83.148** 71.427 0-group 11.406 1-group 315 2+
Solenette	6,79 1-group 0,19 2+	0,07 0-group 0,46 1-group 0,33 2+	28,9 0-group 0,29 1-group	6,34 0-group	**8.691** 8,128 0-group 464 1-group 100 2+

APPENDIX 8

Denmark - Overview – numbers of fish caught/10 000m^2 Numbers in annual catches for fleet: high/Intermediate/low

Species	Q1 - 1997	Q2 -1996	Q3 - 1996	Q4 - 1996	Tot. no caught annually raised to fleet level (Crangon x 10^6 Fish species x 10^3)
C. crangon (commercial)	2776	1,994	4,101	3,860	**1,408**
C. crangon (undersized)	6,684 71 % of tot. Crangon catches	4,751 70% of tot. Crangon catches	6,047 60% of tot. Crangon catches	6,176 62% of tot. Crangon catches	**3,396** 71% of tot. annual Crangon catches
Bib and Poor Cod					**0**
Cod	1.86 1-group	0,02 1-group	11,76 0-group	9,02 0-group	**3,037** 2780 0-group 257 1-group
Whiting	1.23 1-group	1,21 0-group	3,99 0-group 2,71 1-group	0,14 0-group	**1,118** 683 0-group 435 1-group
Gurnards		0,01	0,1		**17**
Brill			0,67		**103**
Turbot		0,10	0,62		**104**
Flounder		0,63			**55**
Plaice	88,07 1-group	15,53 1-group	151,72 1-group	44,07 1-group	**33,706** 1-group
Dab	408,57 1-group	94,52 0-group	15,24 0-group	203,52 0-group	**52,440** 36.753 0-group 15.440 1-group
Solenette	0,81 1-group	0,05 0-group	0,25 0-group	0,30 1-group	**111** 46 0-group 65 1-group

APPENDIX 9

Belgium - Overview – numbers of fish caught/10 000m^2

Numbers in annual catches for fleet: high/Intermediate/low

Species	Q1 1997	Q2 1996	Q3 1996	Q4 1996	Tot. no caught annually raised to fleet level (Crangon x10^6 Fish species x 10^3)
C. crangon (landed)	630	1,553	6,061	3,042	477
C. crangon (discarded)	1274 67% of tot. Crangon catch	2,158 58 % of tot. Crangon catch	2,338 28 % of tot. Crangon catch	1,453 32% of tot. Crangon catch	1.038 69% of total annual Crangon caches
Bib & Poor Cod	0,21	11,72	32,78	9,67	5.091
Cod	3,18 1-group 5,95 2+	0,02 2+	0,12 1-group 0,02 2+	2,83 1-group 0,65 2+	551 372 1-group 178 2+
Whiting	0,15 0-group 0,19 1-group 0,02 2+	1,84 0-group 22,53 1-group 2,07 2+	54,98 0-group 1,09 1-group 0,17 2+	22,42 0-group 4,77 1-group 0,38 2+	10.239 8.132 0-group 1.929 1-group 177 2+
Gurnards		0,53		0,01	33
brill					0
turbot	0,02				1
Flounder	4,42	0,56	1,04	0,47	268
Plaice	9,8 1-group 0.96 2+	1,88 1-group 0,70 2+	6,78 0-group 2,91 1-group 0,10 2+	8,27 0-group 0,53 1-group 0,07 2+	2,271 1,551 0-group 645 1-group 76 2+
Dab	6,66 1-group 6,77 2+	15,31 1-group 21,23 2+	3,33 0-group 6,06 1-group 0,14 2+	12,82 0-group 2,67 1-group 1,02 2+	5.061 1,656 0-group 1,920 1-group 1,484 2+
Solenette	2,79 1-group 0,01 2+	0,01 0-group 3,48 1-group 1,14 2+	4,98 0-group 3,24 1-group 0,51 2+	3,73 0-group 0,10 1-group 0,03 2+	1.619 895 0-group 600 1-group 122 2+

APPENDIX 10

UK - Overview – numbers of fish caught/10 000m^2 Numbers in annual catches for fleet: high/Intermediate/low

Species	Q1 – 1996	Q2 -1996	Q3 - 1996	Q4 - 1996	Tot. no caught annually raised to fleet level (Crangon x 10^6 Fish species x 10^3)
C. crangon (commercial)	720	720 (no sampling data for 2nd quarter: figures assumed to be similar to Q1)	4.693	5.842	**1.306**
C. crangon (undersized)	473 40% of tot. Crangon catch	473 40% of tot. Crangon catch	5.411 54% of tot. Crangon catch	5.989 51% of tot. Crangon catch	**1.367** 49% of tot. annual Crangon catch
Bib and Poor Cod					**0**
Cod	9.44 1-group	0	8,82 0-group 2,5 1-group	17,90 0-group 4,63 1-group 0,02 2+	**4.552** 3.341 0-group 1.209 1-group 2 2+
Whiting	28,47 1-group 0,12 2+	5,18 1-group 0,04 2+	19,56 0-group 14,88 1-group 0,25 2+	51,20 0-group 8,25 1-group 0,47 2+	**12.874** 9.073 0-group 3.705 1-group 95 2+
Gurnards					**0**
Brill					**0**
Turbot					**0**
Flounder	0,15 2+	0,15	0.03 0-group 3,28 1-group 2,23 2+	0,08 0-group 2,39 1-group 1,37 2+	**1.040** 14 0-group 629 1-group 397 2+
Plaice	21,37 1-group 0,04 2+	24,26 1-group	18,23 0-group 12,84 1-group 0,29 2+	29,36 0-group 7,18 1-group 0,03 2+	**9.920** 5.799 0-group 4.092 1-group 30 2+
Dab	20,35 1-group 2.86 2+	38,61 1-group 3,79 2+	1,00 0-group 16,89 1-group 0,31 2+	4,60 0-group 1,61 1-group 0,56 2+	**5.465** 751 0-group 4.317 1-group 397 2+
Solenette	0,04 1-group	0.04 1-group	0,43 0-group 4,13 1-group 0,43 2+	5,72 0-group 0,34 1-group 0,02 2+	**1.386** 864 0-group 420 1-group 102 2+